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The Works of Jules Dupuit

François Vatin, Jean-Pascal Simonin, Luc Marco

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The Works of Jules Dupuit

Collection
“Classical texts in Economics
and Management”

1. Jules DUPUIT.
2. Henri FAYOL (forthcoming in 2016).
3. Frederick Winslow TAYLOR (forthcoming in 2017).

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François VATIN and Jean-Pascal SIMONIN (editors)
With the collaboration of Chris HINTON (translator)

**THE WORKS
OF JULES DUPUIT**
*Engineer and Economist
of the French
XIXth Century*

With a grant from the CEPN's University of Paris 13,
Sorbonne Paris Cité and a support of the GEAPE
(University of Angers)

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Foreword to this edition

*In Memory of Bernard Grall (1962-1997)
who renewed the reading of engineers' economic thought.*

IN its French version, this book was published in 2002 by the Angers University Press. Strange as it may seem, this is the first volume dedicated to Jules Dupuit in French literature. We find, in the catalog of the “Bibliothèque Nationale de France”, only two other references with “Jules Dupuit” in the title: the re-edition of a set of Dupuit’s texts by Mario Bernardi in 1933 in Turin, Italy, and a twenty-nine paged booklet containing the speeches of René Roy, François Divisia and Daniel Boutet. These speeches were given during a memorial session at the “École nationale des Ponts-et-chaussées” in January 1945 in honor of Jules Dupuit to celebrate the centenary of his famous 1844 “Mémoire”¹. The Anglo-Saxon literature is not much richer, with two books: the collection of texts gathered by Mark Blaug in 1992 and devoted to three “precursors” of “neoclassical” economics: Heinrich von Thünen, Augustin Cournot and Jules Dupuit, and in 1999, the book of Robert Ekelund and Robert Hébert on Jules Dupuit and the engineers².

This literature is very small but, if we look at it more closely, we see that it is actually concerned with a single text: the 1844 “Mémoire” on the utility of public works, considered since the late nineteenth century, as one of the founding documents of the “neoclassical” tradition³,

¹Jules Dupuit. *De l'utilité et de sa mesure*. Textes choisis et publiés par Mario de Bernardi, Turin, La Riforma sociale et Paris, Marcel Giard, 1933. René Roy, Daniel Boutet, François Divisia, *Jules Dupuit et son œuvre économique*. [Séance commémorative en l'honneur de Jules Dupuit... à l'occasion du centenaire de son premier mémoire « De la Mesure de l'utilité des travaux publics »], Paris, École nationale des Ponts et Chaussées, 1945.

²*Johann von Thünen, 1783-1850, Augustin Cournot, 1801-1877, Jules Dupuit, 1804-1866*, selected texts edited by Mark Blaug, Aldershot (Great-Britain), E. Elgar, 1992. Robert B. Ekelund, Jr., and Robert F. Hébert. *Secret Origins of Modern Microeconomics: Dupuit and the Engineers*, Chicago, University of Chicago Press, 1999.

³The edition of De Bernardi combines this memoir and a few other texts with the same central theme.

but also as the basis of pricing theories. A systematic analysis of all the articles on Dupuit throughout the twentieth century would lead to the same result. In contrast, this book is the first to have tried to capture this author in all dimensions of his work. It is the product of a meeting between the two directors of the book, who have approached Dupuit each in an original way. Jean-Pascal Simonin discovered Dupuit's texts, up until now, totally neglected, concerned with food shortages and about demography, making Dupuit a somewhat paradoxical precursor of the theory of demographic transition. François Vatin, associated with Bernard Grall, read his economic theory in the light of industrial mechanics tradition⁴, but also of the political economy of Jean-Baptiste Say and Pellegrino Rossi, these two crossed origins of inspiration.

Taken out of the single question of the genesis of the “neoclassical” theory of value-utility, the work of Jules Dupuit was becoming more profound. In order to take measure of this, it was necessary to place it in its time, instead of pulling it into the future and take it into consideration in its entirety, rather than to confine one's self to one text and its annexes. This is what we aim to do in this volume by asking a number of colleagues who were not specialists of Dupuit, but specialists of the questions dealt by Dupuit. We invited them to analyze Dupuit's thoughts in their respective fields, in the light of texts contemporary of Dupuit's works. Through this approach, we believe we have thus opened a number of new perspectives for the interpretation of Dupuit's thought, including understanding of the text, indeed fundamental, published in 1844. From the figure of Dupuit, it is also the entire history of the French economic thought of the nineteenth century, long neglected, which takes on a new dimension. We know that Joseph Schumpeter, in particular, considered with condescendence this French nineteenth century economic thought, while contrasting it with these who he considered as three “geniuses”, Dupuit, Cournot and Walras, whom we should therefore totally isolate from their context⁵. However this is not

⁴This rereading of Dupuit's work was inspired by previous work of François Vatin showing the economic foundation of industrial mechanics, *Le travail, économie and physique (1780-1830)*, Paris, PUF, 1993. This book aims to show that the mechanical concept of “labor” and that of “yield”, from what which it infers, are inherently economics.

⁵Joseph Schumpeter, *Histoire de l'analyse économique* (1954), French traduction, Paris, Gallimard, 1983, tome 3, p. 130.

historian approach, and, at the opposite we must to fully set down such writers, here Dupuit, in the thought of their time and their environment.

Since this book came out, Yves Breton and Gérard Klotz published in two-volumes a critical edition of the *Oeuvres économiques complètes* of Jules Dupuit⁶. These two volumes provide considerable material to francophone readers, bringing together a large number of scattered publications and also unpublished texts. This is an extremely valuable work. The expression of complete economic works is nevertheless problematic. It has been used to show that not all of the Dupuit's texts were published in these volumes, as everything that the publishers, considered fell within his engineering work was left out. In order to compensate for this, they asked Konstantinos Chatzis to write a long and valuable study on this topic⁷. The problem with this editorial decision is not so much the fact that Dupuit's work was not published in its entirety, rather the way the conceptualization of what falls within the realms of economy thought was proposed.

Let us explain. These two rich volumes do not create a single "Dupuit economist" as opposed to other dimensions of his work, especially his engineering thought, but "two Dupuit", which do not seem to communicate to each other: that of the first volume and that of the second. The first Dupuit economist is the best known: this is the "precursor of the neoclassical school" who alone had interested historians of economic thought up until our 2002 book. The second, on the other hand appears as a French liberal economist, who does not employ mathematics in his reasoning. He seems to be an ordinary representative of the French economic school so criticized by Schumpeter! The paradox actually comes from that the texts of the "first Dupuit" considered by publishers are still those of an engineer. Thus considered, they should not be separated from his other engineering works, or from those of all his colleagues in the body of Ponts-et-Chaussées⁸.

⁶Jules Dupuit, *Oeuvres économiques complètes*, established and presented by Yves Breton and Gérard Klotz, Paris, Économica, 2009.

⁷Konstantinos Chatzis, « Jules Dupuit, ingénieur des Ponts-et-Chaussées », in Jules Dupuit, *Oeuvres économiques complètes, op. cit.*, tome 1, p. 615-692.

⁸This reintegration of Dupuit among engineers of the "Ponts-et-Chaussées" also food the thought of Robert Ekelund (1999), as well as the previous one of François Etner (*Histoire du calcul économique en France*, Paris, Economica, 1987). But, in the absence of a general thought on the relationship between industrial mechanics and political econo-

This is where the work of Bernard Grall, that Francois Vatin he published in 2004, after the author's death in 1997, proves particularly valuable for a correct interpretation of Dupuit. Considering the whole corpus of “Mémoires” of the “Ponts-et-Chaussées” engineers, and not just a few texts taken out of their context, he showed the consistency of questioning based on industrial mechanics. That is to say the theory of the mechanical yield, which is simply an economy of the machine⁹. The misunderstanding comes from the concept of engineer-economist by which Dupuit is often defined. This expression is suitable for subsequent authors, certainly heirs of Dupuit, Clément Colson Marcel Boiteux, through François Divisia and Maurice Allais. Trained by the polytechnician mind, these engineers have specialized in economics, where they have imported engineering thinking patterns. For Dupuit, as for all “Ponts-et-Chaussées” engineers of his time who carried out calculations that we believe rightfully “economic”, this expression is meaningless because the economic principle was constitutive of their engineering approach. They were economists, because as engineer, in Claude Burdin terms in 1815, the mechanics had to be “connected” to political economy¹⁰.

Still to be understood, the second part of Dupuit's works would have disappointed Joseph Schumpeter if he had had the curiosity to read it, where Dupuit appears as an ordinary liberal economist, a supporter of free trade without hindrance and maintaining the established order. Yet a closer look shows that this view on many subjects, from the right of ownership to the question of food, are more rich and complex than one might first think and that we find in his reasoning the analytical rigor, which sometimes drives him to the intransigence of these engineering works. But in this respect, Dupuit differs less than we might think from many French eco-

my, the authors are induced to isolate in the engineering thought what would fall in own economic theory. We thus find, on a larger corpus, the same questionable caesura that governed the composition of the corpus of Dupuit's “economic” works.

⁹Bernard Grall, *Economie des forces et production d'utilité. La pensée gestionnaire des ingénieurs des ponts (1831-1891)*. Edition corrected et annotated by François Vatin, Presses universitaires de Rennes, Rennes, 2004.

¹⁰C. Burdin, « Considérations générales sur les machines en mouvement », *Journal des mines*, n° 221, 1815, p. 320-346.

nomists of his time, who are now mostly forgotten, who, without mathematics, reasoned and debated vigorously¹¹.

Finally, the interesting thing about a complete and contextualized reading of Dupuit is that it motivates the reader to delve into the richness and quality of the discussions that agitated the French economists in the nineteenth century. Dupuit's "analytical" reputation, in Schumpeter's terms, made him a "Trojan horse" for studies of French nineteenth century economic thought. However, much remains to be done. The list of publications at the end of this text, dedicated to Dupuit since the publication of the first edition of this book, indeed show a high recurrence in the treated themes. The question of the relationship between Dupuit and Walras remains at the heart of the questioning. It is however enriched by more philosophical concerns about utilitarianism; the problem of pricing, particularly in transport companies, certainly topical nowadays, is also always extensively discussed; the other dimensions of Dupuit's work remain little studied. However, if we compare the way this author is treated to the one still practised in early 1990, we will notice a much greater openness towards both about Dupuit's work and that of his contemporaries. We hope that this book will be able to contribute to this intellectual renewal. At a time when economic theory is the subject of intense debate concerned with his ability to guide collective choices, the detailed reading of a writer such as Jules Dupuit remains instructive.

Book reviews of the first edition of this book

¹¹See particularly on this point the doctoral dissertation of Claire Silvant, *L'école libérale française et l'intervention publique dans la deuxième moitié du XIXe siècle*, université de Paris Ouest, 2010, and the book *Jean Edmond Briaune (1798-1885). Cultivateur, agronome, économiste*, directed by Jean-Pascal Simonin, Presses Universitaires d'Angers, Angers, 2006.

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1. Jules Dupuit: Overshadowed by his own reputation

POLITICAL economy in 19th-century France has commonly been represented, for example in Joseph Schumpeter's *History of Economic Analysis*, by the image of a chasm separating a small number of "geniuses" such as Cournot, Dupuit and Walras from the mediocre mass of ten-a-penny liberal ideologues: "Counting peak performances only, we might feel inclined to put French economics at the head of all countries. But (...) the peak achievements almost entirely failed to percolate..." (Schumpeter, 1954/1994, p.840). Schumpeter goes on to contrast "those brilliant French engineers in the public service", by which he means Dupuit, as well as Colson and Cheysson, with the "others", whom he describes with some condescension: "But even the others, whose flights cannot be described as high, had one great merit. Their philosophies were deplorable, their theory was weak; but when they wrote on practical questions they (...) knew what they were writing about" (idem, p.841). Even this limited recognition—of their competence in applied economics—has been denied them by an entire school of thought which accords primacy to the French engineer-economists. Thus Ekelund and Hébert (1999b, p.39), pondering why the engineers produced more economic theory than "the orthodox economists", echo Cacquot's assertion, quoted by Divisia (1950, X), that "engineers *do* economics while others talk about it". This clearly overlooks the fact that many members of the "Société d'Economie Politique" were industrialists, bankers, shopkeepers or merchants, farmers or landowners, lawyers and actors on the local or national political stage,¹ who were "doing economics" every bit as much as the engineers and in a way that arguably gave them a broader knowledge or understanding of economics in action—a view that concurs with Schumpeter's judgment.

¹ Of course, the ranks of the S.E.P. also included many trained or practising engineers whose contributions to economic theory were unremarkable. One thinks of A. Chéret, M. Chevalier, R. de Fontenay, O. de Labry, E. Lamé-Fleury, Léon, Ch. Le Lièvre, L. Marchal, L. Molinos, L. Simonin, and others. Jevons, however, in praising French economic thought, cites not only the names of Cournot and Dupuit, but also Bastiat, Joseph Garnier and Courcelle-Seneuil, as well as J.-B. Say.

This portrayal of 19th-century French thought, or something very like it, was long accepted by most commentators. According to the consensus view, 19th-century French economists were lamentably weak on theory: the three great names, Cournot, Dupuit and Walras—widely accepted as the founders of modern, mathematicised, economic thought—were from a different planet. Being ahead of their time, they had no influence on their contemporaries and therefore do not belong, despite the overlap in dates, to the same epistemological stratum. Thus, in the work co-edited by Yves Breton and Michel Lutfalla (1991) on 19th-century French economic thought, there is no chapter dedicated to Cournot, Dupuit or Walras;² not because the authors in any way fail to recognise their value, but rather, paradoxically, because their undisputed scientific merit places them outside the scope of an analysis for which the salient characteristic is, implicitly, mediocrity.³

In this analysis, 19th-century French economic thought—beyond these "precursor" geniuses, these prophets in their own land—is of no more than academic interest. It is merely a symptomatic illustration of an ordinary liberal doctrine, intrinsically tautological and therefore of no analytical value. It is a product of its time, a time when capitalist economics was at its apogee and not open to doubt. By contrast, a different frame of reference applies to our three national heroes: one that looks not backwards to historical erudition but forwards, to a supposedly timeless economic science.⁴ Walras is considered, rightly, as the French foun-

² Another work on French political economy has since been published (Pierre Dockès et al., 2000) in which a respectable amount of space is devoted to Cournot, Dupuit and Walras. This is presented, however, as a set of conference papers, encompassing a range of contributions without seeking to impose any overall coherence.

³ Tellingly, the economists in the work in question are classified according to an exclusively doctrinal criterion, as more or less "liberal", confirming Schumpeter's judgment about what he saw as the analytical vacuity of 19th-century French economic thought. Another figure remarkable by his absence is Pellegrino Rossi. Underestimated by Schumpeter, who described his work as "diluted Ricardianism plus a little Say" (Schumpeter, pp.510-511n), Rossi does not, on closer analysis, fit in with the received wisdom on 19th-century French political economy, and has thus been omitted from the intellectual landscape, despite the fact that he was a formative influence on many French economists of the second half of the 19th century. Indeed, several of the contributions in this volume point to Rossi's profound influence on Dupuit.

⁴ This, of course, is the main essence of the economic epistemology advocated by Schumpeter, based on a distinction between scientific and therefore intemporal "economic analysis" and ideological, and therefore contingent, "economic doctrine". His

der of the "neoclassical" school, with Cournot and Dupuit as the school's "precursors".⁵ This is not the place for an epistemological critique of the notion of "precursor", a thorny issue in the history of science. The assumption is made here that all authors are "of their time" and the role of the historian is precisely to understand *how* they are of their time. The modern economic theorist will probably draw inspiration from Augustin Cournot or Jules Dupuit rather than from Joseph Garnier or Michel Chevalier, and this kind of intemporal reading of their work is perfectly legitimate, so long as it is not confused with a historical reading, which differs radically in that it requires an understanding of how and in what way Cournot, Dupuit, Garnier and Chevalier are part of the same political, epistemological and intellectual "epoch".

What needs to be understood here is that in sorting the wheat of great works, rich in analytical value, from the chaff of doctrinal vulgate one throws out most of the intellectual output of an entire epoch; worse still, one induces a truncated reading of the "great works" themselves and reinforces misconceptions about the conditions of their reception. Making Cournot and Dupuit the "precursors" of Walras, for example, is to ignore the fact that Walras had a poor opinion of Dupuit (and made no secret of it)⁶ and that although, by contrast, he tried to get into Cour-

whole oeuvre is aimed at freeing the rich ore of the former from the lode rock of the latter. This "internalist" approach to history needs to identify a breakthrough point, which for Schumpeter is the Walrasian theory of general equilibrium. In order to sort the wheat from the chaff, however, Schumpeter—as Mark Blaug (1961/1981, p.5) has pointed out with some irony—was led to do the exact opposite of his stated aim by compiling a vast and comprehensive intellectual history. Paradoxically, it is from this undertaking that the true value of his book ultimately derives.

⁵ Blaug (2001, pp.159-160) has reassessed the role of the French precursors, largely on the basis of Ekelund and Hébert (1999b), and also the role of the German precursors, while ignoring British precursors such as Whewell, Longfield or Thompson.

⁶ Walras evidently had little liking for Dupuit, with whom he had rubbed shoulders at the Société d'Economie Politique. He refused to accept that Dupuit had played any part in the development of the theory of demand and monopoly pricing, considering, quite unjustifiably, that he had lifted the central elements of his 1844 article from Cournot's "Research into the Mathematical Principles of the Theory of Wealth" (*Recherches...*, 1838/1980). The only merit he found in Dupuit was that he had identified the principle of discriminant tariffs and had advocated a deductivist conception of political economy. He was openly opposed to Dupuit on the issue of taxation. More generally, Dupuit's ultra-liberalism and, above all, his radical utilitarianism were at loggerheads with Walras' doctrinal convictions. On these various points, see the contributions of Sagot-Duvaurox, Grall and Vatin herein.

not's good graces, the latter obstructed him, politely but firmly, in all his attempts to embroil Cournot in the intellectual tussle for the recognition of the new school.⁷ As a result, Cournot was not appropriated by the neoclassical school until after his death.⁸ Nor indeed was Dupuit, at least in France,⁹ until after the death of Walras, and then only thanks to the "engineer-economist" movement centred on François Divisia.¹⁰

Such considerations may seem like unnecessary erudition, a tale of men too embroiled in academic bickering to grasp what seems, with hindsight, so striking to us: the way in which their thoughts converge at the deepest level. On closer analysis, however, it appears that the way in which their own efforts to position themselves in the theoretical "field" has been disregarded is co-extensive with the narrow way in which their works have been singled out for comment. The commentary has generally been restricted, for Cournot, to a few chapters from the *Recherches* of 1838 and, for Dupuit, to his 1844 article on the utility of public works (*De l'utilité des travaux publics*). Thus, from the sizeable bibliography left behind by both authors, economists have ultimately retained no more than a few dozen pages—those which concord with a finalised version of history leading in the direction traced out by Schumpeter for the evolution of economic analysis: a mathematical theory of economic "equilibrium", of which Walras, in his time, offered a particularly elaborate illustration.

Once again, such a version is legitimate for the economic theorist who subscribes to Schumpeter's epistemological model. This representation underpins the approach of Ekelund and Hébert (1999b) when they reinterpret all of Dupuit's economic writings, and not merely his articles

⁷ On the relationship between Walras and Cournot, see François Vatin (1998, pp.169-180; 2000, pp.305-321).

⁸ French readers did not have access to a reprint of Cournot's *Recherches* until 1938 (to mark the centenary). Likewise, five years earlier, Mario de Bernardi had brought out a new edition of Dupuit's work of 1844 and a number of associated documents, inspiring H. Guitton's (1937) article hailing Dupuit's contribution but restricting it to the sole domain of utility theory.

⁹ W.S. Jevons, unlike Walras, recognised Dupuit's contribution to the development of neoclassical thought. This led to a disagreement between the two authors, recorded in their correspondence (Jaffé, 1965, letters 377 and 379).

¹⁰ These appropriations overlooked the fact that the interested parties, like most of the precursors of the "neoclassical" revolution, saw themselves as following in the footsteps of "classical" British and French thinkers.

on utility, as "neoclassical" works. For the historian, however, it is unacceptable, as it makes a virtue out of ignorance—a cardinal sin for the discipline. Thus it is that Cournot and Dupuit, so famous for their genius as precursors, are for that very reason profoundly misrepresented. As early as 1908, Edgar Depitre arrived at the same conclusion for Cournot: "And yet, it would be fair to say that even today Cournot is, if not totally misunderstood, then at least generally poorly, or very inadequately, understood and appreciated. (...). Cournot is hailed as one of the founders of the mathematical method—true enough, although this truth is sometimes expressed in an alarmingly simplistic way—but he seems to have been no more than that. Believe me, this is quite wrong and insufficient. The first to blame for this fresh injustice would appear to be the mathematical economists themselves, who wanted to see Cournot as one of their precursors, and nothing else, and who have almost systematically left out of the picture a large part of his very important and highly personal work in economics, which is nonetheless closely related to his wider philosophical and critical writings." (Depitre, 1908).

Almost a century later, that assessment still largely holds true for Cournot. It also applies to Dupuit. As we said earlier, Dupuit is known mainly for his article of 1844. The article is rightly famous. It is brimming with ideas; not for nothing does it figure among the small number of literary monuments in the social sciences that inspire a seemingly inexhaustible flow of explanations and re-readings.¹¹ But insufficient attention has been paid to the highly marked position that this text occupies in Dupuit's work as a whole.

Dupuit's intellectual history can be seen as made up of two separate but partly overlapping lives. His first life was that of a brilliant engineer, active in the field, who came to prominence through his important work on the theory of friction, the design of road maintenance systems, the construction of bridge vaults and water supply systems, etc. Like all the engineers of the day, he was already an "economist" by virtue of his training in industrial mechanics—the economy of machinery.¹² Unlike most of his colleagues, however, Dupuit went on, in the course of a "second life", to become an economist in the full sense of the word, at least as understood in France in the second half of the 19th century and

¹¹ It is in the nature of truly "open" texts to spawn a prolific quantity of exegesis. One need only think of Marcel Mauss's "*The Gift*".

¹² On this point, see François Vatin, 1993, and Bernard Grall, 2003.

as exemplified by the rich scope and breadth of the *Journal des économistes*. This second life commenced in the 1850s when, after moving to Paris and becoming Inspector General and Member of the Conseil Supérieur du Corps des Ponts in 1855, his burden of technical and institutional duties was substantially reduced. He now had time to debate the issues of the day with his colleagues at the *Journal des économistes*: international trade, private property, demography, modes of taxation, the subsistence question, the teaching of economics, financial and monetary problems, business cycles, the agricultural situation, and other concerns.¹³

It was against this background that, in 1861, Dupuit published his only book on economics, *La liberté commerciale*. Close analysis of this work suggests that we need to take a fresh look at Dupuit the economist. It is far more than a simple plea in favour of free trade; it comes across, first and foremost, as a perfect little manual of "classical" economics. There are few specific references to earlier authors, but Dupuit is clearly steeped in the economic thought of the eighteenth and early nineteenth centuries.¹⁴ Our reading of this text leads us to diverge from Ekelund (2000) and Ekelund and Hébert (1999b) who are nonetheless, as far as we are aware, the only authors truly to address all of Dupuit's economic writings. Their work, though rich and frequently thought-provoking, is explicitly based on a method of "rational reconstruction" which assumes that Dupuit approached all the subjects he dealt with as a "neoclassical" economist *avant la lettre*.¹⁵ But as the various studies in this book illustrate, without attempting the ever-unattainable "historical reconstruction", Dupuit can only ever be an economist of his time.

¹³ The fact that these issues were frequently brought up by Dupuit himself illustrates his growing importance within the Société d'Economie Politique.

¹⁴ He subscribes totally to Ricardo's theories of costs and land rents; for Dupuit these form part of the irreducible core of political economy, along with Smith's concept of the division of labour based on absolute advantage, Malthus' principle of population, the quantitative theory, the neutrality of money and Say's law of markets.

¹⁵ Ekelund and Hébert insist, for example, that *La liberté commerciale* and certain statements by Dupuit herald elements of Marshall's theory of partial equilibrium. Market adjustment mechanisms would appear, however, to have been fairly well understood at the time (S.E.P., 1864b), even before the advent of supply and demand graphs.

The first part of Dupuit's œuvre is largely unfamiliar to economists, as they consider it falls outside their remit.¹⁶ Curiously, the second part is equally unfamiliar, as Dupuit comes across as an "ordinary" liberal, with more than a touch of Bastiat,¹⁷ and makes no use of the "mathematical instrument".¹⁸ In fact, Dupuit is only really known for one particular moment in his career, located at the very turning-point between his two intellectual lives, as an engineer and as an economist. This is no accident: most of the richness and analytical value of the 1844 text, for the modern reader, probably stems from its pivotal nature. But extracting it twice over from its context, or rather from its dual context (Dupuit's work both upstream and downstream of that moment) prevents us from asking to what extent the article is another engineering publication, which cannot be understood without reference to debates raging within the Corps des Ponts, and to what extent it belongs to the current of 19th-century French liberal thought—in which Dupuit was already immersed (mainly through Say and Rossi)—and thereby to the worldview that he himself would later expand upon in his contributions to the *Journal des économistes* and in *La liberté commerciale*.

It is therefore the "other Dupuit" (or rather "other Dupuits") that this book sets out to reveal, without attempting to be exhaustive, and without denying the unique value of the 1844 text. Our stance here is that of the historian, for whom a clearer understanding of the other dimensions of Dupuit's oeuvre—even if modern economists see them as less relevant to their concerns or of lesser analytical value—can only help us to gain a deeper insight into the article of 1844. But such a stance

¹⁶ For example, the compilation of Dupuit's economic works currently planned by the Centre Auguste and Léon Walras at the University of Lyon II does not propose to include his engineering works.

¹⁷ The affinity with Bastiat cannot be explained solely by the similarity of some their "laissez-faire" positions (which they arrived at from different conceptions of liberalism). Bastiat is, after all, one of the authors most frequently cited, along with Rossi, in *La liberté commerciale*, and some of Dupuit's declarations on methodology refer explicitly or implicitly to Bastiat, as the contributions in this book demonstrate. Dupuit was nonetheless opposed to Bastiat and his disciples on many issues, such as intellectual property or the causes of poverty.

¹⁸ With the notable exception of his study of life expectancy (Dupuit, 1865a), in which he sets out the formula for calculating the mean length of life and analyses graphs based on mortality tables. But in this case we have left the field of economics as such for that of demographic statistics—where, unlike in economics, formalisation was already widespread.

demands that we do not assume that all of Dupuit's work converges on his "masterpiece", and only has meaning relative to that one article.

Much work probably remains to be done on Dupuit the engineer, let alone Dupuit the scientist.¹⁹ That aspect of Dupuit's work is clearly not the main focus of this book, although it is touched on in three of the contributions. In Part One, Georges Reverdy retraces Dupuit's career as an engineer with a detailed look at all of his works in Angers, without doubt the French town which has preserved the largest number of constructions built under his supervision, and in the *département* of Maine-et-Loire as a whole, for which Dupuit served as Chief Engineer from 1844 to 1850. This article is illustrated by a number of plates, drawn largely from the municipal archives of Angers.

Part Two focuses on the transition from Dupuit's thinking as an engineer to his theory of utility. Konstantinos Chatzis and Olivier Courard place Dupuit's ideas on the distribution and pricing of water in the context of the mid-nineteenth century debate over city water supplies. Two previously published articles by Bernard Grall, one of them co-authored with François Vatin, have been revised especially for this compilation. They demonstrate the dual origin of Dupuit's 1844 article: on one side, a techno-economic discussion internal to the Corps des Ponts and the tradition of industrial mechanics which provides its theoretical underpinning; on the other, a fully-fledged economic dissertation on the theory of value, drawing on Rossi's interpretation of the debate between Say and Ricardo.

Whereas the three previous contributions gravitate around the article of 1844, discussing its origins or the conditions of its application to water management, those that follow concern the Dupuit of the *Journal des économistes* and *La liberté commerciale*. Part Three is devoted to Dupuit's moral and social thinking. Firstly, François Vatin examines Dupuit's "economic morality", underlining the difference between his resolutely utilitarian conception of liberalism and that of most of his colleagues at the Société d'Economie Politique. He then brings out the characteristics of this original economic doctrine by analysing Dupuit's positions on property rights and the management of food shortages. Two further contributions pick up on these last two points. In the first, Dominique Sagot-Duvaurox takes a fresh look at Dupuit's position on intellectual

¹⁹ Dupuit's talents as an experimental physicist have been documented by David Tabor (1961).

property and copyright—or the contrasting notion of *droit d'auteur*—establishing an appealing parallel with the controversy over Jobard's "monautopoly", an argument long since forgotten but which offers some interesting analogies with current debates on the same subject. In the second, Jean Pascal Simonin unpackages Dupuit's analysis of the subsistence problem by resituating it within the context of the long debate on that issue, which preoccupied economists from the early eighteenth century to the beginning of the twentieth.

Certain traits of Dupuit's economic analysis already stand out in these contributions, notably the great rigour of his reasoning compared with that of his French contemporaries. The last part of the book presents two further applications. Jean Pascal Simonin starts by examining the original theory of international specialisation put forward by Dupuit in *La liberté commerciale* and brings out its weaknesses with the aid of a formalisation based on Dupuit's own assumptions.²⁰ Finally, Philippe Compaire and Jean Pascal Simonin compare three analyses that sought to account for the apparent correlation between birth rates and life expectancy (or "mean length of life"): those of Dupuit, Legoyt and Jacques Bertillon.

These last contributions serve to underline the characteristics of Dupuit's analysis in two fundamentally different instances. In the first, Dupuit's approach is essentially deductive: he seeks to identify the determining factors behind international specialisation and the gain obtained by a disadvantaged nation from its participation in international trade. In the second, he reasons inductively from the observation of a link between birth rates and the mean length of life to confirm Malthus' "principle of population". In both cases, for all his rigour, Dupuit arrives at erroneous conclusions, and for exactly the same reason: a dogmatic attachment to the assumptions instilled in him by his "classical" training, assumptions which were unsuited to his enquiry; specifically, in the first case, his determination to combine Smith's notion of absolute advantage with Ricardo's ideas on agricultural and industrial costs, and in the second, his excessive reliance on the postulate of a stationary population. The dogmatic rigour of Dupuit's theories on subsistence, population and free trade—fields to which, in the long view, he contributed relatively few genuinely original ideas—therefore stands in marked contrast to the

²⁰ It is not the purpose of this study to account for the whole of *La liberté commerciale*. For an overview of Dupuit's ideas on international trade, see J.-P. Simonin (2001).

subtlety of his analyses of utility and property rights, although these are clearly the work of the same author, wielding the same analytical and doctrinal tools.

What emerges from all of these contributions is an unacknowledged master of French economic thought. Doubtless none of Dupuit's other texts can equal his article of 1844 for sheer ingeniousness and theoretical potential, but many of them still strike a chord with the modern reader. Looking beyond Dupuit himself, the analysis of hitherto overlooked dimensions of his work and the reconstruction of their intellectual and political context call for us to re-assess "mainstream" 19th-century French economic thought as less trivial than a reading of Schumpeter might suggest. This in turn throws Dupuit's masterpiece, the famous article of 1844, into a new light. If some of Dupuit's writings can still, even today, give us pause for thought, it is not due to his individual "genius" alone, but also to that of the two "collective intellectuals" to which he belonged: the Corps des Ponts and the Société d'Economie Politique, both marked by a strong shared culture as well as the richness of their internal debates. The former has been studied in depth²¹ and its influence on Dupuit has been widely commented upon.²² By contrast, much still remains to be discovered about the later and the existing studies on the subject have, as we noted earlier, ignored Dupuit.²³ By taking "Dupuit" as its starting point, by considering the whole of his œuvre without exclusion, and by repositioning it within its intellectual context, this book invites the reader to rethink a whole chapter in the history of French political economy.

²¹ On the Corps des Ponts, see Antoine Picon, 1992 and Bernard Grall, 2003.

²² On Dupuit's place within the Corps des Ponts tradition, see the works of Robert Ekelund and Robert Hébert, notably their recent overview (1999b), and also those of François Etner (1987) and Bernard Grall.

²³ On the history of political economy in France in the 19th century, see, in addition to the works cited above, the special issue of *Économies et Sociétés* (1986, PE series, vol.6) on "*Les problèmes de l'institutionnalisation de l'économie politique en France au XIX^e siècle*".

2. Jules Dupuit, 1804-1866, Chief Engineer of Maine-et-Loire, 1844-1850²⁴

Georges Reverdy
Ingénieur général honoraire des ponts et chaussées

THREE engineers, each remarkable in his own right, successively took the helm at the civil engineering department—the *Service ordinaire des ponts et chaussées*—of Maine-et-Loire under the Restoration and the July Monarchy.

The first and best known of the three, who served from 1814 to 1833, was Derrien, who as a young man had built the Mont-Cenis trans-alpine crossing, as well as strategic roads in Maine-et-Loire and throughout Western France;

Then, from 1833 to 1844, came Prus, who started with an extraordinary career in the French colonies—Guyane, Martinique and Algiers—and left the service to build the railway between Tours and Nantes;

And finally, from 1844 to 1850, came Dupuit, whose period in office was the shortest but nonetheless sufficient for him to leave a lasting mark, and whose reputation preceded him in Angers, thanks to the paper he had recently published on the "Measurement of the Utility of Public Works".²⁵

Dupuit's international reputation—which he cultivated up until his final days—was founded, without doubt, on his work in the field of political economy. His professional activities had led him logically down this path, as he himself wrote: "The functions of the civil engineer touch too frequently upon aspects of political economy for that science to remain foreign to our studies. Usage has made it a moral science: time, I feel convinced, will make it an exact science; a science which, by borrowing the reasoning processes of analysis and geometry, will lend its proofs the precision that they currently lack".

But the reason why Dupuit is so relevant to today's debate is the masterful way in which he approached and handled every aspect of the

²⁴Editor's note: This is the text of a conference paper delivered to the *Société des Etudes Angevines* in 1996, with additional notes from the author and editors.

²⁵*La mesure de l'utilité des travaux publics.*

engineer's art that he encountered in the course of his career, always putting forward new and often enduring ideas. Leaving political economy to one side for the moment, these contributions can be grouped under four headings:

- Highways: road design, layout and maintenance;
- Masonry bridges, to which he brought the last innovations prior to Séjourné;
- *roulage*, as was it then known, or what we now call transport technology and management;
- and finally hydraulics: from river navigation to flood drainage, aquifers, water supply and sewers.

It may seem surprising to see no mention of the railways here; they were, after all, the most significant public works of the age. But this was the period when the routing of the first trunk lines was still being discussed at national or regional level, and studied by private companies or ministry experts. Though Dupuit was not involved in the quarrels over planned routes—which had already been raging in Angers and Maine-et-Loire for twelve years by the time he arrived—it was, as we will see, the advent of rail in Angers that gave him the opportunity to reshape the town and its road system. And more generally, as has already been written of him: "He left an indelible stamp on everything he dealt with, and all of these works are, as it were, signed by the master's hand".

1. THE PROVINCIAL ENGINEER SUMMONED TO PARIS

Jules Dupuit was born in 1804 at Fossano in Piedmont, where his father served as a treasury official. In 1822 he entered the elite engineering-oriented *École Polytechnique*, followed by the *École des Ponts et Chaussées*, a graduate training school for state civil engineers. After two assignments in the French departments of Loire-Inférieure and Seine, he was posted in 1827 to the civil engineering department of the Le Mans district of Sarthe, where his responsibilities naturally included the road system and projects to make the Sarthe river more easily navigable. In 1833-34, he conducted his first experiments on the causes of wear and deterioration in metalled roads, and in 1837 he published his first paper,

"Rolling Friction and the Traction of Carriages",²⁶ in which he contested hitherto accepted formulae. After failing to obtain a new posting closer to Paris, which he sought for family reasons, he asked in 1837 for permission to set up a special research and engineering service for Sarthe river navigation, but again without success. In 1838 he published another note, on the "Movement of Wagons over the Curved Sections of Railways",²⁷ in which he corrected the calculations of the recently deceased Navier.

His work on the roads must have been remarkable, however, as he was summoned to Paris in 1839 by the Director General Legrand to pursue his experiments on the traction of carriages for the benefit of a commission responsible for drafting new legislation on traffic policy, and to supervise the resurfacing of the Avenue des Champs-Élysées, notorious for its apparently irredeemable state of disrepair. "The metalled surface was covered with a thick layer of jet-black mud, from which, at alarmingly frequent intervals, the points of large stones poked forth". Before long, by applying the methods he had used in the Sarthe, Dupuit had made a road surface as fine as any in France.

Legrand even asked Dupuit to draft a circular for implementation throughout France. This was to become the well-known directive of 25 April 1839 on the procedures for the maintenance of metalled roads,

²⁶ This 160-page work (*Le tirage des voitures et le frottement de roulement*) was subtitled "considerations on the various types of road, on traffic policy and on the construction of highways". Already evident are subjects which were long to remain at the heart of his research and reflection—namely the upkeep of roads and the conditions of road usage—as well as his working method, which consisted of carrying out practical experiments, interpreting them rationally, and extracting as much information from them as possible. And yet he had conducted his tests with the barest of resources: a few men harnessed to the shafts of a carriage, and dial scales to measure the effort expended. His study was so original, however, that the chief editor of the *Annales des ponts et chaussées* saw fit to publish a detailed analysis of it. For metalled roads, he concluded that traction was independent of speed, that the friction at the wheelband was the same going uphill or down, that the said friction was independent of the gradient or of the width of the band and inversely proportional to the square root of the wheel's diameter, etc. He pursued these experiments with more ample resources in Marne and published his findings in another paper in 1842. In addition to what he learned from them with respect to road maintenance, these experiments totally vindicated his ideas on the free circulation of road traffic, which was enacted into law in 1851, sweeping away earlier regulations that limited loads in proportion to the number of horses in harness and the width of the wheelbands.

²⁷*Note sur le mouvement des wagons sur les parties en courbe des chemins de fer.*

probably one of most enduring texts of its kind, as it remained in force until the roads were tarmacked in the early part of the twentieth century. In it, Dupuit underlined the crucial role played by parish road gangs in removing mud and dust as they form, and in laying down only as much material as was lost in curing. The 15-page circular closes with the words: "These principles are so simple, so self-evident, that in any other instance it would be sufficient to recite them. The explanations that I have given, the meticulous details that I have entered into, are justified only by the importance of the question of improving our roads, and the results that this improvement should bring to the public".

2. CHIEF ENGINEER OF THE MARNE

On 1st March 1840 Dupuit was appointed Chief Engineer of the Marne, no doubt because that département had a reputation for especially dreadful roads. Thirty years later, one of the engineers who worked under his orders recalled Dupuit's arrival: "I shall never forget our first meeting, when Monsieur Dupuit summoned us all to Châlons. We wondered by what secret means, by what wave of the wand, he could succeed where we had slaved away to no effect...". Dupuit was quick to realise that the implementation of his method and the training of the road gangs were only a part of the road maintenance story, and that it nonetheless remained necessary to put back into the roads every year a quantity of material proportional to their usage: a quantity which could be determined accurately in advance. He also carried out new experiments with the dynamometer on rolling friction and the traction of carriages, and in 1842 published his *Considérations sur les frais d'entretien des routes*,²⁸ even managing to convince his superiors of the need to double spending on road maintenance in Marne. Showing no hesitation in travelling far and wide to find sources of flint to replace the frost-prone limestone grit, he transformed the state of the roads in the Champagne region. Soon their parlous condition was no more than a bad memory.

Ever a stickler for detail, he then invented a small instrument for rapidly calculating all surface areas on plans, especially for cutting and banking work. This was simply a wheel ten centimetres in diameter, held

²⁸*Considérations on the Cost of Maintaining Roads.*

by a fork, with a vertical needle and a pinion that drove a cogwheel which acted as a counter.²⁹

Dupuit's main discovery at this period, however, lies in his reflections on the utility of public works, and how best to assess it. He published his famous paper in the *Annales des ponts et chaussées* in 1844; it earned him a gold medal and was translated into several languages.

3. CHIEF ENGINEER OF MAINE-ET-LOIRE

On 16 August 1844, having proved his mettle in the Marne, Dupuit was appointed head of the “*Service ordinaire*” in Maine-et-Loire, at the same time, as it happened, that the young engineer Mahyer, who was to become his faithful right-hand man in all of his major projects, was placed in charge of the Angers district. Over the previous ten years, significant improvements had been made to the road system in Angers, most notably the almost simultaneous construction of the Basse-Chaine suspension bridge and the Haute-Chaine Bridge, both completed in 1838-39. For the first, the town of Angers was the concession holder and the toll fees went into the municipal coffers, while the second was conceded to the builders, Joseph Chaley and Théodore Bordillon.³⁰

In Maine-et-Loire, Dupuit naturally had to continue the studies and construction work already initiated by his predecessor, Prus. Thanks to the July Monarchy's mania for road works, there was no shortage of

²⁹ Dupuit's calculation wheel was designed to relieve planners from the onerous task of calculating surface areas for cutting and banking from cross-sections of the roads or railways they were working on. To do so, they used sets of numerical tables, issued for the most part in 1836 or 1837. In 1839 Dupuit presented his invention to Director General Legrand: a toothed wheel, which one simply rolled along equidistant parallel straight lines drawn on tracing paper. The design was submitted to the Conseil Général des Ponts et Chaussées, which recognised that it could be genuinely useful, but Dupuit—too busy with other things—took the project no further until two years later, when he had 80 models made by a craftsman in Chalons-sur-Marne on the strength of a credit line granted by the Minister of Public Works. Not until 1844 was this ancestor of the opisometer, or map-measurer, presented in the *Annales des ponts et chaussées*.

³⁰ The building of the second bridge had been dogged by controversy: the initial plan was for a wooden structure on masonry piers, whereas the Conseil Général des Ponts et Chaussées had expressed a preference for a single-lane suspension bridge. Then, at the end of 1836, the successful tenderers came up with a totally different variant, with cast-iron arches using the Polonceau system. This solution was finally adopted, despite its higher cost, but was built with three arches instead of the five originally planned.

such projects throughout the department. The transition was often seamless, as with the elevation of the Quai de Limoges in Saumur (Route 147) which had been flooded over in 1843, or the improvement of the Nantes-Laval crossroads in Angers on the site of the former Porte Saint-Nicolas. In other cases, the initial projects had to be modified due to opposition voiced at enquiries: in Doué, for example, after plans to enlarge Route 160 within the town were turned down, several new routing projects were in turn rejected until work was finally carried out in 1847. For the planned road through La Membrolle, the Divisional Inspector, on a tour of inspection, requested that the pavements be omitted and the width reduced from 12 meters down to 10. Nonetheless, in July 1845 Dupuit managed to get the initial project ratified by the Minister.

On occasions he also stepped in to modify and improve some of his predecessor's projects that had already been approved. In the case of the road through Durtal, he openly said as much: he overruled the plans for a new bridge on the Argance, improved the curve of the bend on the approach to the bridge over the Loir so that carriages would have more room to turn, and further reduced the gradient on the road surface—for which, as in the Marne, he made use of more economical siliceous materials. The cost of the project was almost halved.

But the most important project that Dupuit succeeded in modifying and improving, with the support of the Divisional Inspector, was the straightening of Route 160 through Cholet. The project, for the most part perfectly valid, had been approved to replace the former road through the town a narrow lane that wound down—at times very steeply—to an old bridge over the Moine river. "Nothing could be easier," wrote Dupuit, "than improving it further" by diverting it in places and by lengthening it to reduce the slope to 2.35%. Further savings were possible on the new bridge, the demolition work, etc. The new project was approved on 18 April 1846.

4. THE REBUILDING OF THE *PONT DU CENTRE*

With the opening of the two toll bridges on either side of it, a good deal of pressure was taken off the former "Grand Pont" of Angers, which had become known as the "Vieux Pont" or "Pont du Centre". It remained, however, the only "national" bridge, on which converged the

various royal highways that passed through Angers, and was still heavily congested, as the total width between its parapets was a mere six to seven meters and it had only recently (in 1837) been cleared of the last houses that stood on it, the last of them being the house where Grégoire Bordillon was born. (See the illustrations number 4FI 249 and 250 *infra*, p. 323).

The time was therefore ripe for some modernisation work, especially given the irregularity of the multiple slate arches, dating back to the previous reconstruction in 1710. And so, on 29 March 1845, Dupuit presented his broadening project, to build a normal 7-meter wide thoroughfare between two 1.5-meter pavements. The project was approved by Legrand on 7 May 1845. The title was somewhat misleading, however, as this particular "broadening" involved building two new arches in place of four old ones in the middle, and also at the right-bank end, of the bridge, and the broadening—in other words, enlargement—of the other two arches. The contract was awarded on 11 August 1845 for 85,000 francs.³¹

Fortunately, in September 1845 Director General Legrand came to inspect the work and was struck by the Chief Engineer's observations on the irregularity of the earlier stonework, which was due to be preserved. He authorised its demolition and on 31 January 1846 Dupuit presented a new project: the new bridge was to be perfectly regular, with two central arches, each with a span of 13.9 meters, and three arches at either end, spanning 10.36 m; the piers were to be reduced, increasing the total waterway by 137 m², and reducing by 0.45 m the cataract that formed at high water. The total budget rose from 95,000 to 150,000 francs, and the award process had to be repeated, as the first entrepreneur refused to take the task on under the same conditions. The new contract was approved on 30 September 1846 and the work was provisionally accepted in 1848.

In parallel with the bridge broadening project, Dupuit had submitted a request, on 12 July 1845, to broaden three streets—rue Beaurepaire, rue de la Trinité and rue Saint-Nicolas—to 10 m instead of the 8 m prescribed in the regulation of 1826, but the town gave its approval for the first two only. In November 1846 he suggested erecting ten gas lampposts on the bridge; this was accepted. In February 1847 he pro-

³¹ Editor's note: Dupuit's drawings for the various Pont du Centre reconstruction projects are reproduced in Biguet and Letellier (ed.) 1998, pp.78-79 and pp.86-87.

posed, with the consent of the sculptor David d'Angers, that the cut-water on the central pier of the new bridge serve as a plinth for the statue of Beurepaire³² which had been authorised by a royal decree in 1843. This was accepted in principle by the town administration "without prejudging the question as to which of d'Angers' works should benefit from that location".

In May 1848 Dupuit presented, as he always did, a detailed comparison between the initial estimate and the final outlay. Despite the difficulties involved in working on the site of previous structures, the final increase was only 28,000 francs, but little is now known about the exact consistency of the foundations.(See pictures infra).

5. THE REBUILDING OF THE ST MAURILLE AND ST AUBIN BRIDGES AT *LES PONTS-DE-CÉ*

This was by far Dupuit's largest project in Maine-et-Loire. There is no need for a detailed description of the earlier bridges; suffice it to say that the arches, spanning no more than 10 m, had crumbled away in places, to be replaced by wooden platforms. The Pont Bourguignon over the Authion had been rebuilt by Derrien in 1826, followed by five arches of the Pont du Louet, between 1830 and 1836. The two largest bridges had yet to be rebuilt.

Much is known about the bridges, as the work is described in detail in Dupuit's *Traité de l'équilibre des voûtes et de la construction des ponts en maçonnerie*,³³ completed after his death by the faithful Mahyer. On 3 May 1845 the two presented the draft project for the reconstruction of the Saint-Maurille Bridge and the straightening of the road through Les Ponts-de-Cé on the islands of the Loire. With remarkable judgment, Dupuit had proposed abandoning the old crossing and rebuilding the Saint-Maurille bridge some 70 m upstream of the earlier structure. In

³² Editor's note: "Nicolas Joseph Beurepaire, though he actually hailed from Coulommiers, east of Paris, commanded the first Maine-et-Loire battalion and committed suicide at Verdun in 1792 rather than surrender the town to the Prussians without a fight. A heroic figure of the original French Revolution, he had returned to favour since the Revolution of 1830 as the incarnation of the Republican spirit" (Biguet, Letellier, 1998, p.88). Cast in 1889, the statue was melted down by the Germans in 1942, and finally replaced on the bridge in 1987.

³³*Treatise on Arch Balancing and the Construction of Masonry Bridges.*

May 1846, after the project had been refined and approved, funding of two million francs was voted for its implementation, and the works contract was awarded the following August.

Although high water in the Loire in October 1846³⁴ held the work up by more than six months, the project was exemplary in every respect. The Saint-Maurille bridge was to boast eleven 25-meter arches with basket-handle vaulting, and the Saint-Aubin bridge three similar arches. The piers and abutments were to be anchored in a bed of concrete girded by timber and sheet piles, within which the sand was to be dredged up to the non-erodable ditch embankment. Compressibility tests were carried out on the embankment during the forced stoppage, and in practice the foundations were set at a depth of 4 to 5 meters. The Saint-Aubin bridge, built on the site of the earlier structure, with its old foundation piles and collapsed vaults, proved more problematic.

On an anecdotal note, on 4 September 1847 a lead box, containing a handful of coins and a copper plate recording the names of all the participants up to and including Dupuit and Mahyer, was placed in a specially hollowed-out stone, earmarked to be laid as the first stone, but two days later it was spirited away by pranksters. A similar plaque was affixed to the last stone of the Saint Maurille bridge on 31 October 1848. On 2 September 1849 the bridges were blessed by Monsignor Angebault in the presence of the then Prefect, Grégoire Bordillon. The following year, the final account revealed that the initial budget of two million had been overrun by a mere 70,000 francs.

It was during this immensely important project that Dupuit came up with his main innovation: using metal jacks for the striking of the centres, instead of the wooden wedges which previously had to be knocked out with a sledgehammer.³⁵ There was naturally some opposition to the idea, but Séjourné later attested to the importance of this invention. It even led Dupuit to suggest several years later, in the *Annales des ponts et chaussées*, the use of mobile centering with a succession of nar-

³⁴ After observing this phenomenon closely and researching earlier occurrences, Dupuit published his *Etudes théoriques et pratiques sur le mouvement des eaux courantes* (1848) (Theoretical and Practical Studies on the Movement of Running Water) offering original reflections on rivers with shifting beds and on the optimal location and waterway for the bridges that span them.

³⁵ His note on this subject in the *Annales des ponts et chaussées* was reprinted in his posthumous *Traité de l'équilibre des voûtes et de la construction des ponts en maçonnerie*—the leading work in its field in the 19th century.

row rings to build masonry arches, a process which was frequently adopted by Séjourné and, later, for reinforced concrete bridges. (See illustration Plan 1FI 659 infer, p. 324).

6. THE ADVENT OF RAIL IN ANGERS

In planning its first rail route, Angers had a lot of lost ground to make up. In 1832, the first railway project from Tours to Nantes was for a line to run exclusively along the left bank of the Loire, over the river from the town; and while the route submitted to the public enquiry on 26 December 1838 arrived from Saumur along the right bank, after Daguinière the line went straight to Les Ponts-de-Cé, Sainte-Gemmes and La Pointe, merely branching off for seven kilometres after Sainte-Gemmes to serve Angers. Then on 26 June 1845, the Angers town council, after lengthy debate, expressed its wish that the landing stage be sited to the North of the town in the Prairies de Saint Serge and favoured the northern route, crossing the Maine 200 meters to the north of the Haute Chaîne bridge and from there heading straight across the hills to Ingrandes. Finally the route as it stands today was approved, with the station in the former Enclos de la Visitation.

It should be remembered that France's Railway Act of 11 June 1842, drafted in large part by Legrand, had ruled that the new railway infrastructure should be paid for by the state, and therefore built by the state's own services. Prus was accordingly assigned the duty, in 1842, of studying that part of the Tours-Nantes railway which crossed the département of Maine-et-Loire, and then, in August 1844, of actually building the railway, at which point he left his post at the head of the *Service ordinaire* to Dupuit. Fourier succeeded Prus in charge of the railway works in 1848, before taking over from Dupuit himself in 1850.

Under these circumstances, the role that Dupuit was to play in the realisation of this project in Angers may seem surprising. Until, that is, one recalls that he was in charge of Route 152 from Angers to Briare and Route 161 from Angers to Les Sables d'Olonne, and that the planned railway crossed both of these highways as it approached the town. It was for this reason that on 14 August 1847 he presented a report to the Angers town council "on the change of direction in the two highways".

He began by describing the congestion on the road to Les Ponts-de-Cé, which carried 550 horses a day and herds of cattle, reminding the councillors of the major works under way at Les Ponts-de-Cé itself and the straightening of the road from Angers—which had been mentioned in the latest statistical report on the improvement of the highways—the narrowest section of which, the Rue Château-Gontier, was to be aligned to a width of eight meters. He went on to observe that the planned location for the railway station at Angers was to the south of the town, while the highways lead out, and intersect, to the north of the town. And yet it is "indispensable that, in the vicinity of major stations, the highways be directly connected to the railways". He therefore proposed: "To open up a new street in the continuation of the Boulevard des Lices and the Rue d'Orléans, intersecting the Rue Bressigny near the *Maison rouge* and only crossing land not currently in use.... To create a circular piazza at the point where this street meets the extension of the Rue Desjardins.... As for the road to Les Sables, it would start from this circular intersection and continue in one straight line for 3,400 meters as far as the Bourguignon bridge at Les Ponts-de-Cé. This road, 16 meters wide, bordered with pavements and two lines of trees... would make Les Ponts-de-Cé a suburb of Angers. The Maine and the Loire would be united by a promenade that would be embellished with elegant houses and magnificent gardens". As work was already in progress on the railway, a rapid decision was required, and as it crossed most of the new roads at a very acute angle, it was essential that it be covered with a viaduct 80 meters long. (See illustration : Catastrophe 4Fi 176, 4Fi 386, old maps).

A mere three days later, the commission appointed by the town council gave its enthusiastic approval to the project for a new road to Les Ponts-de-Cé; for Route 152, it preferred a shorter variant, one that Dupuit mooted somewhat reluctantly, which would join up with the Rue Bressigny and run alongside the railway line. Finally, "with all due deference to the Chief Engineer's opinions and plans, the Commission suggests that the proposed piazza be given a radius of 40 rather than 30 meters, and that it be given an octagonal or polygonal form in order to facilitate the building of the new façades".

The discussions over the following months centred mainly on which variant to choose for Route 152—the short one, alongside the railway line, or the long one, now the Rue Volney—and on the size and shape of the new piazza. Dupuit produced another report in November 1847 to present the complete planned trajectory for Route 152, which

would leave from the new piazza and reach the Maine via the Rue d'Orléans, the Boulevard des Lices and the Boulevard du Château. He produced a third report On 26 April 1848 following the public enquiry; this time the commission had requested a radius of 40 meters for the piazza, a width of 18 meters, instead of 16, for Route 160 and 14 m instead of 12 for Route 152. There was also a discussion with the railway engineers over the position of the centre of the piazza relative to the tunnel. Many of the landowners affected by the new railway were prepared to concede plots free of charge, particularly as the neighbouring land was becoming highly sought after for construction, but, for the new piazza, André Leroy would cede no land unless the radius was kept within 30 meters.

In submitting the dossier to the ministry, Grégoire Bordillon took the opposite position to the town council, favouring the route that traversed the railway, "in order not to extend the town indefinitely outwards across the fields, in a fresh burst of growth that only benefits certain land speculators".

The Conseil Général des Ponts et Chaussées approved the routes proposed by Dupuit, but with 12 m only for Route 152 and 14 m for Route 161, unless the land necessary for widening was given up freely, which was not to be. It also restricted the opening of the new route as far as the point where it met up with the old road, at the end of what is now the rue Rabelais.

On 14 February 1849 Dupuit submitted the tunnel project, put together by Mahyer, to the Minister. The plan, for a tunnel under a 65-m diameter piazza, was approved on 22 March 1849, and the task was assigned to the engineers of the *Service ordinaire*; it was awarded on 16 April and a credit line was opened on the 26th. On 27 June the French president, Louis Napoléon Bonaparte, signed the decree approving all of the road straightening projects put forward in 1847 by Dupuit. It was high time, as the president visited Angers on 29 July to inaugurate the Tours-Angers railway. The tunnel was completed the following year and the roadworks could at last commence; but further land acquisition problems arose and the work on Route 152, from the roundabout to the so-called *Maison de la Retraite*, was not contracted out until the end of 1855.

7. THE 1848 REVOLUTION

The abdication of Louis Philippe led to no great unrest in Angers. The mayor, Giraud, and his fellow councillors resigned. The new municipal assembly was sworn in on 29 February 1848 by Grégoire Bordillon, the former town councillor whom Ledru-Rollin had appointed commissioner of the provisional government. Shortly afterwards, the Rue d'Orléans was renamed Rue David.

In the administration of public works, Legrand was to some degree sidelined into an honorary position on the Conseil d'Etat, but he was already ill, and died during the summer of 1848. Dupuit emerged from the events of 1848 unscathed, even seizing the opportunity to bring out his hefty hydraulics tome *Etudes théoriques et pratiques sur le mouvement des eaux courantes*. The high waters in the Loire had made a lasting impression on him when he first arrived in Maine-et-Loire in 1843 and 1844. Even more so the high water of December 1846, whose effects in the Loire valley had been dramatic: the dyke at Onzain had burst, leading to flooding at Trélazé in Maine-et-Loire and the interruption of the works at Les Ponts-de-Cé. As ever in Dupuit's work, theoretical reflections go hand in hand with practical considerations. He begins in this case with a theoretical study of the movement of water in canals, questioning the validity of a number of prevailing formulae, and goes on to examine the influence on currents of the constriction caused by bridges, which can vary greatly depending on the depth of the river. The main chapter deals with the regimen of large watercourses and the waterway they require. He demonstrates the importance of treating these issues globally: the high water of 1846, for example, had wreaked havoc in the upper reaches of the Loire and yet had made little impact downstream of the confluence with the Maine, which was at low water. The level of the Maine rose by 3.5 meters in three days, with a head of 10 cm as it flowed downstream from the bridge at Angers. Following the high waters of 1856 and the publication of a paper on the means proposed to stave off a recurrence of the flooding, he published a new edition of his treatise in 1863.

But in 1848, there was a need to provide the workers with charity in the form of paid labour. On 5 May, considering that the workers require good and effective management and that the communal interest

calls for the municipality to be aided by the intellect and experience of a citizen of great authority in such matters, Citizen Dupuit, Chief Engineer of Maine-et-Loire, was made a member of Angers town council by the commissioner of the Republican government. On 21 October, he was congratulated for the good results achieved by these communal workshops.

In January 1849, faced with the situation of 200 unemployed workers in Trélazé, Grégoire Bordillon, after conferring with Dupuit, requested that an emergency works project be funded to lower the side of the Pyramid on Route 152. On 24 January, he received the authorisation from the Minister and on 3 February the terms of the project were approved. Meanwhile, however, on 26 January, Bordillon announced that there was no need for the project, as he had found other work for the men, but "this was the only project that was immediately feasible, presented by the engineer Dupuit, a vigorous and healthy spirit, imbued with a strong sense of duty and accomplishing all of his responsibilities with a rare understanding of the service entrusted to his care".

8. TRANSPORT POLICY: THE *LOI DU ROULAGE*

From the very outset of his career, in the Sarthe, Dupuit took an interest in the conditions under which vehicles travelled the roads, from the viewpoint of the wear and upkeep of road surfaces. This naturally led him to compare the cost of road maintenance with the economic benefits offered by greater mobility. At the beginning of 1849, he published a new paper in the *Annales des ponts et chaussées*, examining the impact of tolls on the utility of transport, *De l'influence des péages sur l'utilité des voies de communication*, supplementing his famous article of 1844. One of his conclusions was that for the railways, a three-class tariff system would yield both higher fare revenues and more passengers than a two-class tariff; by multiplying the number of classes indefinitely, one could get passengers to pay in full for the utility that they derive from the railway.

Hardly surprising, then, that on 20 April 1849 Dupuit was appointed Secretary of the Grande Commission du Roulage, on which also sat several members of parliament, a member of the Académie des Sciences, a number of haulage entrepreneurs, and the President of the Paris Chamber of Commerce. The commission's remit was to settle the long-

standing discussions over traffic regulation. Since the decree of 1806, which had set up weighbridges the length and breadth of the country³⁶ and had set limits on the width of wheel rims depending on the number of horses, various commissions had been formed (in 1814, 1828, 1832 and 1839) in a vain attempt to broker an agreement between the advocates and opponents of such regulation. The most recent—which had heard evidence from Dupuit—had reached a liberal set of findings, but these had been rejected by both chambers of the Assembly.

From April 1849 to January 1850, Dupuit travelled frequently to the capital in the service of the commission. In May, it heard evidence from the chief engineers of every département on the utility of weighbridges and wheel-rim measurements, and in August it convened the presidents of all the regional councils to discuss the same question.

On 7 December 1849, after taking stock of the answers received, and with due respect for the opinions expressed in the commission, Dupuit presented an initial bill limiting the number of horses and setting new minimum requirements for the width of wheel-rims, with exemptions for post wagons and private carriages. However, the majority on the commission voted against this text and decided, curiously, to present it to the Minister as the Secretary's own personal work. More curiously still, the Minister—in the person firstly of Bineau, then Magne—was directly persuaded by Dupuit to press for total freedom of traffic circulation. He made Dupuit an Officer of the Legion of Honour and succeeded, on 30 May 1851, in getting the bill he wanted through the legislature, by 527 votes to 113. The first section ran: "Carriages, whether suspended or otherwise, used for the transport of persons or goods, may travel on national or departmental roads and major local roads without regard to the weight of vehicle nor to the width of its wheels." The new law also replaced the earlier traffic restrictions with a regime of low-level taxes.

³⁶ There was a weighbridge in Angers, initially at the Porte Saint-Michel, later relocated to the entrance of the Rue Boisnet.

9. FROM ANGERS TO PARIS

Before returning definitively to Paris, Dupuit was to witness a catastrophe in Angers: the collapse of the Basse-Chaine bridge on 16 April 1850.³⁷ He was naturally appointed president of the commission of enquiry, with Mahyer as secretary, on 20 April. The suspension bridge had nonetheless been well maintained and monitored by the town authorities: as recently as 1847, a group of concerned town councillors had requested a thorough inspection of its anchorages "to avert a potential catastrophe". Before May was out, Dupuit had presented the commission's report, which settled the question unambiguously³⁸—one can only surmise as to why so much debate, and so many errors, persist on this subject to this day, such as the myth that the soldiers failed to break step as they crossed the bridge... (See Plan: 1 Fi 2692, and two letters in the French Book).

In Paris, Dupuit was attached to the Prefect of the Seine as chief engineer in charge of the municipal department of Paris, a post that he took over from Henry Darcy and in which he was responsible for pavements, water supplies, sewers, planting and all work carried out on the public highway. There followed six years of intense activity, marked by a major expansion of the water distribution system with one-meter diameter pipes, new oval-section sewers, and the large sewers under the Rue de Rivoli and the Boulevard de Sébastopol, and culminating with the publication, in 1854, of the masterly *Traité de la conduite et de la distribution des eaux*,³⁹ reprinted ten years later with numerous supplements.

³⁷ Editor's note: The bridge collapsed during a storm as 730 soldiers of the 11th Light Infantry, bound for Africa, were crossing it, with the loss of 223 lives. For further details see Biguet and Lettelier (1998, pp.154-162), who also discuss the findings of recent research into the causes of the catastrophe.

³⁸ In the report, Dupuit affirms that the collapse of the bridge was caused not only by overloading, but also by oxidation affecting the retaining cables in the anchorage sleeves, despite the fact that these had been filled at the outset with fat lime. He then launches into an argument with Vicat by asserting—rightly, as it happens—that this process cannot guarantee ferrous materials against oxidation.

³⁹*Treatise on Water Supply and Distribution.*

He had not forgotten Angers altogether, however: in 1854 the town council asked him to take charge of a study into the town's water supply. The council had long been planning to create public fountains and had decided, in 1847, to abandon the Maine in favour of the Loire as the source of its drinking water. Dupuit had himself published a paper on the public fountains of Reims in 1843. On 12 April 1854, "Monsieur Dupuit, who was remembered most honourably in Angers", presented his comprehensive project to supply the town with 2000 m³ of water per day from an infiltration gallery to be constructed opposite the Château des Ponts-de-Cé, with a reservoir in the Faubourg Bressigny and a storage basin at the Champ de Mars, for a total estimated cost of 575,000 francs. On 13 November he visited Angers to monitor the progress of the project, once the necessary catchment land had been purchased. The Conseil Général des Ponts et Chaussées had examined the project in meanwhile, requesting an increase in the diameter of the smallest pipes and, to maintain the purity of the water, the replacement of the Champ de Mars basin with a covered tank which could serve as the base for an ornamental fountain. Dupuit then obtained the council's somewhat grudging agreement to erect a two-tier ornamental fountain, to be bordered by lawns and greenery, on the former Champ de Mars, in the alignment of the town hall and the *Mail*, the large tree-lined promenade, linking the latter with the boulevard, although this would prevent the area being used as a fairground or parade-ground. Thus it was that the town of Angers acquired in 1855, for 16,000 francs, the monumental fountain displayed at the Universal Exhibition in Paris.

In January 1856, the water distribution undertaking drew to a close. One year later, Dupuit drew up the final account: a total cost of 800,000 francs, including the major extensions to the initial project.

10. FINAL RECOLLECTIONS OF ANGERS

During the work on Angers' water supply, Dupuit had taken a particular interest in the movement of water through the sands of the Loire and the two drainage galleries built for that purpose. The first was situated in the land earmarked for the plant, but could not be continued any further upstream due to land acquisition obstacles. The second, running obliquely to the large branch of the Loire, was much deeper and more

efficient, as the plant's pumps were then available for use in its construction. Consequently, in July 1857, he presented a paper to the Académie des Sciences on the "Movement of Water through Permeable Soils",⁴⁰ for which he also drew on the consolidation work he had performed on the wells at Grenelle and Passy in Paris. He returned to the subject in 1865 in the second edition of his treatise on water distribution.⁴¹ In his last years he focused on writing for the *Journal des économistes* on a wealth of subjects including food shortages, free trade, and the principle of ownership.

Even in the field of roadworks, he had left his successors in Angers with some unfinished business. Perhaps the most marked example was the road through Louroux-Béconnais, the only flaw on Route 163, a narrow, winding stretch with gradients of up to 7.9%. Improvements had been stuck at the planning stage since 1837. A project presented in 1846 had encountered widespread opposition, and the Conseil Général des Ponts et Chaussées had asked for the possibility of a bypass to be investigated. Mahyer drew up plans for a large bypass—1,160 meters long—and this solution was proposed in 1848 by Dupuit, it being substantially less expensive than widening the existing road, although he was reluctant to divert the highway around what was, after all, the chief township of its district. The inhabitants were asked to make a voluntary contribution to part-fund the through-road, but the sums offered in 1849 were deemed insufficient, and the matter was left pending. Not until 1861 was agreement reached, when a lower level of compensation was accepted, and the existing road through the town was improved. And so Dupuit's bypass was never built, but what a modern bypass it was—it could have been presented, and accepted, as such a century later.

In 1860, Chief Engineer Coiquand was astonished to discover that the decree of 27 June 1849 redirecting Routes 152 and 161 through the Rue d'Orléans, the Boulevard des Lices, the Boulevard du Château and the Quai Ligny had never been implemented. Nor was there any trace of it at the town hall. Dupuit's absence was all too obvious! The matter was

⁴⁰*Mémoire sur le mouvement de l'eau à travers les terrains perméables.*

⁴¹ Two years after the floods of 1856, Dupuit published another work: *Des inondations. Examen des moyens proposés pour en prévenir le retour* (An Examination of the Means Proposed to Prevent the Recurrence of Flooding) in which he demonstrates the futility of having a large number of small dams too far upriver—a solution put forward by some experts—and validates the use of levees parallel to the rivers, while encouraging river-side house-owners to take out insurance unless their effectiveness could be guaranteed.

referred to the ministry, which asked that the situation be rapidly rectified. But the reduction of the slope on Boulevard du Château—at the joint expense of town and state—was not carried out until 1868. The chief engineer of the time once again recalled that the work had been requested by his illustrious predecessor, and wrote in his report on 22 May: "The reduction had been planned by Inspector General Dupuit when, as Chief Engineer of Maine-et-Loire, he had had the boulevard reclassified as part of Route Nationale 152".

To this day, one can hardly take more than a few steps in Angers without brushing against the shadow of Jules Dupuit.

ARCHIVE DOCUMENTS

Manuscripts: Library of the Ecole Nationale des Ponts et Chaussées, 11 « dossiers », classmark MS 3229.

National Archives:

- F/14/1560 Route 23 through Durtal.
- F/14/1562 Improvements in Saumur.
- F/14/1563 Route 160 through Cholet.
- F/14/1564 Route 162 through La Membrolle.
- F/14/1727 Routes 152 and 161, new layouts in Angers.
- F/14/7096 Project to join the Loire to the Channel via the Sarthe.
- F/14/10.964C.G.P.C., 1846, Project to rebuild the old bridge over the Maine at Angers.

Maine-et-Loire departmental archives:

- 1S89 Re-orienting Routes 152 and 161 in Angers. Planting.
- 133S3 Joining the Loire to the Channel via the Sarthe.
- 51alpha 178 Rebuilding the bridges at Les Ponts-de-Cé.

Angers municipal archives:

- 4O13: The Loire water catchment system: extending the infiltration galleries.
- 4O20-21: Installing water-lifting machinery, 1854-1856, 1857-1859.
- 1Fi659: The layout of Route 152 in 1850.
- 1Fi2692: The water lifting plant at Les Ponts-de-Cé.
- Angers town council debates: 1847, 1848, 1849.

KEY TO ILLUSTRATIONS⁴²

Page 19, top and bottom: Angers, the Pont du Centre, or Pont de Verdun, completed by Dupuit in 1848. (Old postcards, Angers municipal archives, 4Fi249 and 4Fi250).

Page 21, top: Pont St Maurille, or Pont Dumnacus, over the Loire at Les Ponts-de-Cé, built by Dupuit (photo J.-P. Simonin, March 2002).

Page 21, bottom: Pont du Centre or Pont de Verdun, close-up view (photo J.-P. Simonin, March 2002). Note the signs of subsidence, due to the poor quality of the foundations.

Page 23: Angers, project for the new layout of Route Royale n°152 from Briare to Angers [Rues Paul Bert and Volney], project for the new Route Royale n°161 [Rue Rabelais, with the roads converging on the Place André Leroy]. Caption: "This plan was drawn up by Monsieur Dupuis [sic], Chief Engineer" for Mademoiselle Paimparé, whose land the new roads crossed. (Tracing paper, black and red ink, wash, 34 by 70 cm, Angers municipal archives, 1Fi659).

Page 25, top: Angers, the Basse-Chaine bridge catastrophe (1850). Reproduction of a steel etching by Théophile Tardif-Desvaux (1850) (old postcard, Angers municipal archives, 4Fi276).

Page 25, bottom: Angers, the Place André Leroy and Rue Paul Bert laid out by Dupuit (old postcard, Angers municipal archives, 4Fi386).

Page 29: Drawing by Dupuit of the "Water project distribution. Plans, sections and elevations of the machinery buildings to be built at Les Ponts-de-Cé, on the Île St Aubin" (10 April 1854). Cloth-lined paper, quill pen, black ink, watercolour, 105.6 by 64 cm (Angers municipal archives, 1Fi2692).

Pages 30 and 31: Letter in Dupuit's hand about the Angers water supply project. It reads: "Paris, 9 July 1854. Sir, The refusal by the Caisse des Dépôts is unfortunate, I have nonetheless no doubt that you will succeed by one means or another in negotiating the loan, but I fear a delay in the underground work, a delay which could set the completion date back by a year, as the work in the infiltration gallery and sump must be performed while the Loire is at low water. If we let the season pass, we will have to wait until the following year. The pipes and reservoirs will have been finished to no avail: we shall have not one drop of water, and will thus lose the benefit of the funds already spent, indeed it would be better to do nothing. To avoid such a delay you could [illegible] quite quickly make available 50 or 60 thousand francs for the completion of the foundation work, either by taking them from some budget item which could be postponed without inconvenience, or by raising a small local loan. In the latter case you could perhaps increase the figure in accordance with whatever advice the bankers in Angers might offer, we would finish the rest later. Besides, you are better informed than I of the local resources, what I wanted to press upon you was the need promptly to make available a certain sum, and that the rest could be delayed without any great inconvenience. I am, Sir, yours most sincerely. Dupuit." (Angers municipal archives, dossier 4O13: Captage des eaux de Loire [Loire water catchment system]).

⁴²J.-P. Simonin.

**I. From engineering calculus
to the theory of utility**

3. Machinery and taxation: Jules Dupuit, political economy and industrial mechanics¹

Bernard Grall and François Vatin

THE engineer Jules Dupuit (1804-1866) is well known to economists. His paper on the measurement of the utility of public works, *La mesure de l'utilité des travaux publics* (Dupuit, 1844), first published in the *Annales des ponts et chaussées* in 1844, was hailed thirty years later by the founders of the neoclassical school as a pioneering text. It has since been regularly reprinted, translated and commented upon, so much so that one might wonder what useful purpose could possibly be served by yet another commentary.² We nonetheless believe that we have some new light to shed on this watershed text. Often portrayed as an "extraordinary" work of genius, it can only be understood by repositioning it in a dual epistemological context: it belongs both to the tail end of classical economics and to industrial mechanics. We argue, firstly, that Dupuit's paper is explicitly part of a debate on the theory of value, dating back, via Rossi, to the debate between Say and Ricardo. Secondly, we maintain that if Dupuit, going beyond Rossi, effectively prefigured neoclassical theory, he did so by importing into economics the models of industrial mechanics.

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² The article has been reprinted three times in French: Jules Dupuit (1933), Jacques Monteil (1966), appendix I (partial reprinting) and Jean-Marc Siroën (1995). Dupuit's theory, severely criticised by Léon Walras but praised by Jevons and Edgeworth, was rapidly incorporated into the pantheon of the founders of neoclassical thought. It was subsequently assimilated by the French tradition of mathematical economics personified by François Divisia and, above all, Maurice Allais (particularly Allais, 1981). The epistemological reading of Dupuit did not begin in earnest until 1958, with an article by R.W. Houghton (1958). The project was taken up by R.B. Ekelund Jr. and R.F. Hébert, notably in Ekelund Jr (1968, 1969, 1970, 1972, 1976, 1985, 1987, 1989, 1991, 2000), Ekelund Jr. and Gramm (1970), Ekelund Jr. and Hébert (1973, 1978, 1999a & b), 10(4), and Ekelund Jr. and Thornton (1991). There have also been significant contributions from François Etner (1982, 1983, 1987) and an article by Manuela Mosca (1996).

1. DUPUIT AND HIS SOURCES

Dupuit, the illustrious civil engineer, is generally cited only for his famous article of 1844. Yet this is just one part of a large body of work, comprising no fewer than seventy titles painstakingly inventoried by Mario de Bernardi (Dupuit, 1933).³ Most of these consist of engineering publications, published mainly in the *Annales des ponts et chaussées* and anchored in the industrial mechanics tradition. They already reveal Dupuit the economist at work when he, like the other engineers of the day, approaches practical mechanics as the "economy of machinery" (Vatin, 1993). He began by taking an interest in issues of road maintenance (the measurement of wear, the choice of road surfaces), which led to some original ideas on the physics of friction⁴ and to his active participation in the debate on the "*police du roulage*": the regulation of horse-drawn transport. This debate touches on a genuinely economic question, namely the advisability of road tolls, and the form they should take. He also contributed to research on hydraulics, examining problems such as the resistance of engineering structures to river flooding, or urban water supplies and how to charge for them.

But in parallel with this techno-economic work, Dupuit, as an active member of the French liberal school, published a whole series of writings in the sphere of political economy proper.⁵ He was a regular contributor to the *Journal des économistes* from 1849 to 1866 and collaborated on the *Dictionnaire de l'économie politique* published in 1853⁶ by Coquelin and Guillaumin. Admittedly, his first contributions to this new field stem directly from his professional capacities. But from 1859 onwards, he also produced articles of general economic interest, covering food shortages, taxation, demography, economic methodology and—above all—liberal doctrine, on which he published a book in 1861 (Dupuit, 1861a).

³Taking the various reprintings into account, these seventy titles represent about fifty different works, articles, reports and memoranda.

⁴ Dupuit developed an original theory of friction, in contradiction with the traditional model then embodied by the work of Coulomb from fifty years earlier; on this point, see David Tabor (1961).

⁵ On French political economy at the time, see Yves Breton and Michel Luftalla (1991).

⁶ In this publication, all references to articles in the *Dictionnaire* refer to the 1854 edition.

Dupuit's thinking on utility lies at the crossroads between these two fields of research. It is expressed in three publications: the famous article of 1844; a second article also published in the *Annales des ponts et chaussées* in 1849, responding to criticism of the 1844 article from another engineer, Bordas (1847); and a third, published in 1853 in the *Journal des économistes*—a summary of the two earlier texts which was originally intended for the *Dictionnaire de l'économie politique*⁷ (Dupuit, 1844, 1849a, 1853). There is much redundancy between the three documents and, from a purely analytical viewpoint, it makes sense to stop at the first, as has traditionally been the case. From the viewpoint of the history of thought, however, the second article, as we intend to demonstrate, has some interesting insights to offer.

When Dupuit published his 1844 article, he was clearly already motivated as much by considerations of political economy as by engineering calculations.⁸ Certainly, the article was published in an engineering journal and triggered a response from another engineer. Moreover, it apparently predates Dupuit's official entry into the circle of the economists, as his first article in the *Journal des économistes* does not appear until 1849, when he answered the criticisms of Bordas. And yet as early as 1844, Dupuit had announced the forthcoming publication of a book entitled *Economie politique appliquée aux travaux publics*, which was never to see the light.⁹ As it was, Dupuit and Bordas were to battle it out for the

⁷ The last article in fact groups together two entries that Dupuit had prepared for the Coquelin and Guillaumin's *Dictionnaire*, although in the end he had to settle for entries relating to his engineering knowledge). Mario de Bernardi's collection includes—in addition to these three texts by Dupuit and the one by Bordas—an extract from the *Traité théorique et pratique de la conduite et la distribution des eaux* (Dupuit, 1854a).

⁸ One need only compare the article with one that he had published two years before in the same journal under the title: "*Considération sur les frais d'entretien des routes*" (Dupuit, 1842). Though rich in fascinating ideas in the sphere of economic calculations for engineers, it displays no academic knowledge of political economy.

⁹ Moreover, in his 1844 article (p.342) he mentions a "toll" article; we do not know what he was referring to. Was it the one he eventually gave to Coquelin and Guillaumin for the *Dictionnaire*? That would suggest not only that he was already in contact with the liberals of the Société d'Economie Politique, but also that the entries of the *Dictionnaire* had already been distributed, at least in part. The first fascicles of the dictionary were not printed until the end of 1850, however, and the first edition was completed in 1853 (Molinari, 1853, pp.420-432), whereas the *Journal des économistes* and the Société d'Economie Politique had been founded in 1841 and 1842 respectively. It is by no means impossible that a first draft of the *Dictionnaire* was already in circulation in 1844, even though we have nothing to attest to this possibility, but perhaps it was an-

mantle of legitimate heir to the tradition of J.-B. Say in the field of political economy: Dupuit cited Say's *Traité*; Bordas cited the *Cours* in reply; in his critique of that critique, Dupuit also cited Say's *Cours*¹⁰ and, above all, the *Cours* of Rossi, Say's successor at the Collège de France.

In 1844, however, Dupuit's economic references were limited. He looked mainly to J.-B. Say, whose *Traité d'économie politique* he quotes twice, as well as the *Épitomé des principes fondamentaux de l'économie politique*.¹¹ He also invokes the Physiocrats (in a footnote, with no reference), and Adam Smith, notably by way of a commentary by McCulloch from the Blanqui edition of 1843.¹² The article of 1849 includes new references. Dupuit continues to cite J.-B. Say (the *Traité* and the *Cours*, but also the *Essai sur le principe d'utilité* and the correspondence between Say and Ricardo);¹³ he also mentions the *Traité d'économie politique* of Destutt de

other planned dictionary, or perhaps Dupuit was simply referring to a chapter of the book on which he was working; the choice of the word "article"—an article or a dictionary entry—would however be a strange one in that case.

¹⁰ He nonetheless insisted that the *Traité*, revised after the final edition of the *Cours*, was the work of reference: "I might reply to Monsieur Bordas that the sixth edition of the *Traité* was revised and corrected by Monsieur Say after the publication of the *Cours*, and that it is therefore in the *Traité* that the author's final opinions—if he had changed them—should be sought" (Dupuit, 1849, p.173). The *Cours*, published in 1828-29, actually dates from later than the last edition of the *Traité* to appear during the lifetime of J.-B. Say (the 5th edition, 1826). The sixth edition of the *Traité*, however, published after Say's death by Guillaumin in 1841 (*Collection des principaux économistes*, vol.9, vol.1 of the works of J.-B. Say), and on which Dupuit based his argument, claims on the frontispiece: "completely revised by the author, and published from the manuscripts that he left". It was this edition that was reprinted with a preface by Georges Tapinos (Paris, Calmann-Lévy, 1972).

¹¹ The *Épitomé* amounts to a sort of dictionary of economic theory which J.-B. Say included in an annex to the second edition of his *Traité d'économie politique* in 1814. It also figures in the Guillaumin edition of 1841.

¹² A. Smith, *Recherches sur la nature et les causes de la richesse des nations* (Germain Garnier's translation of *The Wealth of Nations*, entirely revised and corrected, and with a biographical preface by Blanqui) in *Collection des principaux économistes*, vols.5 and 6, Paris, Guillaumin, 1843. The quotation from Smith, and McCulloch's commentary, allude to the difference between "value in use" and "value in exchange"; Ekelund and Hébert (1976) have rightly pointed out that the reference was a superficial one. We try to shed light on this below with a brief digression on Rossi.

¹³ *Cours complet d'économie politique pratique* (1828-29), repr. vols.10 and 11 of the *Collection des principaux économistes* (vols. 2 and 3 of the works of J.-B. Say), Paris, Guillaumin, 1840. The *Essai sur le principe de l'utilité* and the correspondence between Say and Ricardo were

Tracy¹⁴ and, repeatedly, the *Cours d'économie politique* by Pellegrino Rossi (1843). The 1853 article, summarising the two earlier ones, uses the same set of references.

The main question arising from this admittedly rather sparse bibliography is this: how much influence should we ascribe to Rossi?¹⁵ In 1849, Rossi appeared to be Dupuit's primary reference. Replying to Bordas, who set himself up as the keeper of the Say orthodoxy, he retorts that "Rossi, J.-B. Say's illustrious successor in the chair of the Collège de France, advocated a quite different set of principles, which he believed were now accepted by all who take an active interest in political economy" (Dupuit, 1849a, p.171). He seems, moreover, to imply that Rossi's theories had earlier inspired his article of 1844: "In my article of 1844, I adhered to the notion of utility accepted by Rossi, in contrast to the ideas of J.-B. Say, because I found it to be in conformity with reason, and because I believe, as did that able economist, that when such is the case we must respectfully yet firmly demur from the authority of our masters" (idem, pp.172-173).

As we shall see, the positions defended by Dupuit in 1844 do seem to draw inspiration from Rossi. But this raises a thorny historiographical question: why does Dupuit not cite Rossi from the outset, in his first article? Rossi taught at the Collège de France from 1834 to 1840, and a first (pirated) edition of the first part of his *Cours* (the only part that Dupuit quotes from) was published in 1836;¹⁶ the *Cours* was then printed in 1840-41 and reprinted in 1843.¹⁷ Dupuit could thus easily have had ac-

included in the fourth volume of the Guillaumin edition of Say's works, which had just been published (*Collection des principaux économistes*, vol.12, Paris, Guillaumin, 1848).

¹⁴ Destutt de Tracy, *Traité d'économie politique*, Paris, Bouguet et Lévi, 1823. This was in effect the third French edition of the *Traité de la volonté et de ses effets*; the second (1818) edition of which was recently reprinted (Destutt de Tracy, 1818/1994).

¹⁵ Dupuit quotes Rossi nine times, four of them involving long extracts from the *Cours*, whereas he makes little use of the letters from Ricardo to J.-B. Say. His citation of Smith *via* McCulloch has already been noted. His reference to Destutt de Tracy is a one-off occurrence: he found in Tracy the idea that "the vivacity of our desires" could be measured by "the sacrifices to which these desires impel us" (1849a, pp.181-182). The same extract is found in Destutt de Tracy (1818/1994, p.131). This formula, clearly a felicitous one for Dupuit, might also have been worthy of Say, but in Tracy's usage it does not belong to a conceptual framework even remotely resembling that of Dupuit.

¹⁶ Rossi, *Cours d'économie politique*, course notes, academic year 1835-36, Paris, Ebrard, 1836.

¹⁷(Rossi, 1843). It is to this edition that Dupuit refers.

cess to it in 1844. This opens up two hypotheses: one, that Dupuit had indeed read Rossi in 1844 and omitted to cite him in his references, doing so only in 1849 to support his arguments in the face of Bordas' criticism; two, that Dupuit was unaware of Rossi when he wrote his first article, and, having discovered Rossi between 1844 and 1849, co-opted him into his second article in order to legitimate his own thinking.

Neither of these hypotheses is quite satisfactory. The first is historiographically odd, despite Dupuit's own testimony. If Dupuit knew of Rossi in 1844, why would he have neglected to cite him, given his desire for economic legitimation and the authority that Rossi then represented? The second falls down on a point of theory. If Dupuit had not read Rossi in 1844, one must conclude that he arrived quite independently at the same critical reading of Say. With Rossi, however, the critique of Say stems directly from the confrontation with Ricardo, or more accurately from the original combination of Say and Ricardo that Rossi had developed, and which was partly inspired by Nassau Senior.¹⁸ Dupuit did not have the same wealth of sources; if we limit ourselves to his explicit references, we must accept that he arrived at his conclusions on the sole basis of McCulloch's note on Adam Smith, itself a distant echo of McCulloch's own reading of Ricardo. This seems improbable; in fact, we intend to show that his comments on the McCulloch quotation seem to flow directly from his reading of Rossi. Unless new sources are discovered, historiography can do no more to elucidate the question. We need to examine it from a strictly theoretical angle by returning to the debate between Say and Ricardo, and its interpretation by Rossi.

2. WEALTH, EXCHANGE-VALUE AND USE-VALUE: J.-B. SAY, ROSSI, RICARDO

The debate between J.-B. Say and Ricardois well known to economists. Say, following a French tradition dating back to Condillac

¹⁸ Rossi had personal ties to Senior. The "Lessons" of this British economist, an Oxford professor since 1825, had been published separately from 1827 onwards. A selection of these were compiled and translated into French by Count Jean Arrivabene, also close to Rossi, under the title *Principes fondamentaux de l'économie politique*, Paris, 1836. This French publication actually preceded the first English-language edition of Senior in volume form: *Outline of Political Economy*, first published as part of the Encyclopaedia Britannica in 1836.

and Galiani, held that value was founded on the utility of goods. Ricardo, by contrast, adopting—albeit not uncritically—Smith's theory of value, affirmed that utility (use-value) was merely a necessary condition for a good to have value and that, except in the case of goods of absolute scarcity (precious gems, works of art), the value of a commodity is determined by the cost of its production, and thus, in a first approximation, by the quantity of direct and indirect labour required to produce it. In other words, for Say, exchange-value derives from use-value, whereas for Ricardo, they are two independent and even antagonistic expressions, with only the latter being amenable to study by political economy. Their analyses of the relationship between wealth and value differ accordingly. For Say, the two are practically synonymous, whereas for Ricardo, real wealth—which derives from use-value—is not proportionate to exchange-value.

What originally sparked the debate, subsequently sustained by ample correspondence between the two economists, was the unearthing by Ricardo of an inconsistency in Say's theory of wealth in the context of technical progress. According to Ricardo, if a new process is developed that reduces the cost of producing a commodity, its exchange-value will decrease, but not its use-value; the wealth remains constant, only the value diminishes. By contrast, Say's analysis, by equating use-value with exchange-value, would in this case lead to the illogical conclusion of a decrease in wealth.

It is not our purpose here to offer a historiography, nor even a theoretical analysis, of this debate, but simply to look how it was interpreted by Rossi, which will lead us directly to Dupuit. Pellegrino Rossi (1787-1848), jurist, economist and politician, who led a rich and turbulent life in Italy, Switzerland and France, is today unjustly overlooked as an author.¹⁹ He is remembered only as the successor to Jean-Baptiste Say at the Collège de France, owing his appointment, in 1833, to the patronage of Guizot, who had invited him to Paris from Switzerland for that precise purpose. For most historians of economic thought, Rossi was merely a skilful commentator of Say and Ricardo; Joseph Schumpeter, for example, dismisses him in a single sentence: "All the vast cultural horizons, all the practical insights that show throughout [Rossi's work], do not alter the fact that, analytically, it was diluted Ricardianism plus a little Say" (Schumpeter, 1954/1994, pp.510-511n). This is manifestly

¹⁹For a good introduction to Rossi, see Luc Marco(1988).

unfair, as the combination of Say and Ricardo proposed by Rossi is far from devoid of interest. It is in fact close to that proposed at the same period by Nassau Senior (held, by contrast, in high esteem by Schumpeter), of whom Rossi has occasionally been seen as the French disciple.²⁰ In this sense, like Senior in Britain, Rossi represents in France a pivotal link between classical and neoclassical economics.

From the methodological viewpoint, Rossi, like Senior, adopts a strictly Ricardian position which prefigures Walras. He distinguishes between three levels of social and economic discourse (as subsequently did Walras, probably drawing inspiration from Rossi): "pure" political economy—a purely deductive science analogous to rational mechanics; applied political economy; and, finally, morality and politics. When it comes to his theory of value, however, Rossi, again like Senior, incontestably follows Say: "value is nothing other than utility as it relates specifically to the satisfaction of our needs" (Rossi, 1843, p.54). He pushes this subjective theory of value to extremes, heralding the economic psychology of Gossen: "Value is but the expression of a relationship, and an essentially variable one at that. It is the relationship between things and our needs, and as everyone knows, our needs are both various and shifting; even those that are common to us all by virtue of our organic nature are nonetheless variable, at least in frequency and intensity. Consequently, value is neither a constant object in itself, nor a quality inherent in objects; there is nothing exclusively objective about value. The piece of bread of which we spoke earlier, which has considerable value when a man feels the pangs of hunger, ceases to have any once he has eaten his fill" (idem, p.56).

Defined by utility, value is—for Rossi as for Say, although not for Ricardo—the direct expression of wealth. Rossi, however, formulates the relationship between value and wealth far more precisely than Say; value (yield) is the salient characteristic of wealth (objects): "Thus, value and wealth, while not synonymous terms, are necessarily correlated. Value is not wealth, any more than impenetrability is a body, or weight a stone. The value of a thing is its yield (*rapport*), whereas wealth is the set of all

²⁰ On Senior, see Marian Bowley (1937, p.80). Senior's influence on Rossi is incontrovertible, but should not be exaggerated. Rossi had taken his first steps in political economy while still a student at the university of Bologna under Luigi Valeriani (1758-1828), considered by the Italian tradition as one of the precursors of mathematical analysis in economics (Schumpeter, 1983, vol.2, p.184).

objects in which this yield is realised" (idem, p.71). But Rossi's contribution is not limited to this reformulation of Say's utility theory of value. He enriches it with an original twist on the distinction between "direct" and "indirect" utility, formulated, but not conceptualised, by Say.²¹ The only "direct" utility, in Rossi's view, is that of a good desired by the subject for his or her immediate consumption; any other good is of "indirect" utility. This notably includes any good destined to be exchanged.

Understood in this light, Say's direct/indirect utility dyad coincides with the Smith-Ricardian dyad of value in use versus value in exchange: "With Smith, I call the first kind of utility value in use, the power immediately to satisfy our needs; the second I call value in exchange, the power to obtain, by barter, things which can immediately satisfy our needs" (Rossi, 1843, p.56). For Rossi, Adam Smith's distinction is therefore pertinent (in this he differs from Say), but this must not lead to the concept of utility being discarded from economic theory (in this he differs from Ricardo). Value in use (utility) is the basic category; value in exchange (indirect utility) is simply a derivative category: "Value in exchange is but a form of value in use: it derives from the same principle" (idem, p.57).

By subsuming value in exchange within value in use, Rossi, like Senior, undeniably sides with Say against Ricardo. To ignore value in use, taking value in exchange as the sole object of study, is to traduce political economy, in Rossi's eyes, by reducing it to a science of exchange alone, rather than the science of wealth that Rossi sought to encourage. Nonetheless, he pushes the utility theory of value well beyond Say. He even turns Say against himself, a tactic that directly prefigures Dupuit. He reproaches Say for failing to draw the logical consequences of his own theory of value by assimilating wealth to exchange-value alone: for one thing, this reduces the theory of utility to the theory of exchange; for another, it leads to the dead-end argument denounced by Ricardo over the relationship between wealth and value. Rossi therefore occupies an original position between Say and Ricardo, the very position later devel-

²¹ "Forage cannot satisfy any needs immediately, but it can serve to fatten cattle that we will use for food. Dyes cannot immediately serve either for food or for ornament, but they can serve to embellish the fabrics that clothe us. These things have an indirect utility. This utility makes them sought after by other producers, who will use them to increase the utility of their products. Such is the source of their value". J.-B. Say, *Catéchisme d'économie politique* (1815, reprinted in J.-B. Say, 1996, pp. 316-317).

oped by Dupuit.²² For Say, wealth (utility) can be assimilated to value, which in turn is reducible to value in exchange. Ricardo shares the second proposition with Say and rejects the first: value (exchange-value) cannot be used to measure wealth (utility). Rossi, on the other hand, accepts the first proposition and rejects the second: value (utility) is a measure of wealth, and for this very reason cannot be restricted to exchange-value (indirect utility). He was later to develop this position in his interpretation of the law of supply and demand and, especially, in his theory of monopoly, which plainly foreshadows Dupuit.

For Rossi, supply and demand are not absolute quantities. They are relative quantities: relative to needs, in the case of demand, and to the difficulty of production, in the case of supply. To speak here of supply and demand "functions" would be over-egging the pudding, but Rossi was nevertheless moving in the direction of just such a concept: "*Demand* does not mean only the quantity considered in isolation, but that quantity relative to the nature and intensity of the desire that caused it to be in demand, and relative to the strength of the obstacles which that desire could and would endure in order to find satisfaction. (...) The same is true of supply. *Supply* does not mean only the quantity offered, but that quantity combined with the ease or difficulty of production" (Rossi, 1843, pp.89-90).²³ Seen from this angle, the theory of supply and demand boils down to the utility theory of value, for if demand is an expression of need (utility), then the same is true of supply, which corresponds, as stated above, to the expression of an "indirect" utility that can be realised through exchange: "By examining the question from every angle, one cannot but wonder whether exchange is not something more, for both parties, than the manifestation and effect of a need seeking satisfaction by the indirect means of barter; one wonders if there might not be a

²²Alain Béraud, discussing Dupuit as a critic of J.-B. Say, touches on the same point: "The remarkable and perhaps surprising thing is that in order to criticise Say's analysis, and bring in the notion of marginal utility, Dupuit invokes the old opposition between use-value and exchange-value and draws on the teachings of McCulloch and Rossi—classicists in the Ricardian tradition. The conclusions of the debate between Say and Ricardo have not been lost; they have nurtured the solution to the problem posed by the relationship between wealth and value". (Béraud, 1992, p.403). The Senior/Rossi/Dupuit filiation was identified as early as 1904 by the Russian mathematician V.K. Dmitriev (1968, p.239ff).

²³ It is worth noting that according to Schumpeter (1983, vol.2, p.184), Valeriani, Rossi's Italian master, was a precursor of the concept of supply and demand functions.

more direct, more intimate, cause for price variation than the actual need (...). Must not the value in exchange, in the final analysis, depend upon the needs and, consequently, upon the value in use?" (idem, pp.77-78).

Reformulated by Rossi, the classical theory of supply and demand unquestionably heralds neoclassical thought.²⁴ But, although it seems to him to "contain the solution to the problem", he considers it difficult to apply by comparison with the alternative "production cost" formula, which he explicitly ascribes to Ricardo. He therefore launches into a long and pertinent exposé on Ricardo's theory of value. He criticises it, certainly, but not, as the French liberals were later to do, for its "insufficiency" (they accused Ricardo of defining value exclusively in terms of labour, thereby opening the door to the socialist menace). Rossi's attack goes much deeper, to the very heart of the model—the theory of competition—which he rightly assumes to underpin Ricardo's assimilation of market value with production costs. He levels two fundamental criticisms at Ricardo's theory of value:

"1. As it presupposes costs of production, it applies only to things produced; we have always made a distinction, however, as between natural and manufactured wealth. Not all natural riches are unlimited, and the formula does not apply to those limited and appropriated assets that have a value in exchange although they incurred no cost of production. Up to this point, the shortcoming is admittedly a minor one; such wealth does not play a very significant role in a nation's economic transactions.

2. But there is more: this formula supposes indefinite freedom of choice on the part of the consumers and indefinite freedom of competition on the part of the producers. If these two conditions could always be met, then the formula should admit of no exceptions, nor any limits. But these conditions are neither as general nor as constant as the formula supposes, and therein lies the rub, as Ricardo himself half suspected. He realised that some things were beyond the scope of his rule, but he did not take adequate account of these exceptions: he believed them to be infinitely less prevalent than they actually are" (Rossi, 1843, p.109).

²⁴ Rossi was here developing the "Gossenian" economic psychology that we have already seen at work in his interpretation of utility-value. Instead of the single economic subject of his earlier model, he now had two, in an exchange situation. He went on to formulate the principle of balanced exchange using a mechanical metaphor (of equilibrium between two forces) analogous to the one later employed by Jevons, but in the absence of mathematical formalisation he was only able to consider the situation in its extreme case: that of two infinite utilities with two null costs.

Rossi ultimately rallied, albeit with strong reservations, to the Ricardian formula in his *Cours* of 1837-1838 on the distribution of wealth, published by his sons after his death.²⁵ In this new syllabus, he did not retract the criticisms of two years earlier, but instead interpreted the Ricardian model as the expression of the theory in its "pure" form, which he now assimilated, as Walras later would, to perfect competition. In a Walrassian context, however, Rossi's question becomes irrelevant, as the whole theory of value is swallowed up in the system of prices established by general equilibrium. Market prices—the points at which the supply and demand curves intersect—measure both Ricardo's costs of production and Say's utilities. And yet the Walrassian model could only emerge by overturning the labour theory of value in favour of the new theory of marginal utility, or to some extent, as Jevons implied in 1879,²⁶ by abandoning Ricardo in favour of Say, or more accurately by combining Say's subjective concept of value with Ricardo's marginalist reasoning (as demonstrated in his theory of differential rent). And Rossi provided the instruments for just such a combination in his theory of monopoly, very close to the one developed several years later by Cournot and Dupuit.²⁷

Like many authors of his day, Rossi uses the term "monopoly" in the broad sense of imperfect competition. He follows tradition in distinguishing between two types of monopoly: natural and artificial. But this classical distinction intersects with another, of far greater economic im-

²⁵ Rossi, *Cours d'économie politique*, vol. III, published by his sons, Paris, 1851 (a compilation, in fact, of lecture notes taken in 1837-1838 by M. Porée).

²⁶ "The conclusion to which I am ever more clearly coming is that the only hope of attaining a true system of Economics is to fling aside, once and for ever, the mazy and preposterous assumptions of the Ricardian School. Our English Economists have been living in a fool's paradise. The truth is with the French School, and the sooner we recognise the fact, the better it will be for all the world" (Jevons, 1888, PS.37).

²⁷ Augustin Cournot's *Recherches sur les principes mathématiques de la théorie des richesses* (1838/1980) is often compared with Dupuit's famous article. It is indeed astonishing how these two authors—within the space of a few years and unbeknownst to each other—formulated the function of demand and the theory of monopoly in terms that were to become standard in modern economic theory. Their sources share some common ground: both are inspired by the Say/Ricardo debate and, certainly in Dupuit's case and possibly in Cournot's as well, Rossi's reformulation of that debate; both are familiar with industrial mechanics. However, their methods and, above all, their aims are fundamentally different. We seek to avoid systematically comparing the two authors, but comparisons will inevitably surface here and there (on Cournot, see F. Vatin, 1998).

portance: the distinction between monopolies that supply goods of absolute scarcity (such as works of art), and those where production can be controlled to suit the producer. Adopting the Ricardian distinction between absolutely scarce goods and industrially produced goods (Ricardo, 1821, I.5-6), Rossi maintains, like Ricardo before him, that the theory of production costs does not apply to the first. But Ricardo saw these goods—which he considered to be of negligible economic importance—as the sole exception to the theory. Rossi, on the other hand, drawing on Say's theory of utility-value, holds that a situation of monopoly can exist without absolute scarcity, when there are "entry barriers" to the market. In this case, the scarcity is no longer "absolute", but relative: relative to the inclination of the monopolist. Rossi goes on to formulate the theory of the monopolist that we find in both Cournot and Dupuit: "The more one lowers prices, the more one increases the number of consumers; the producer, while earning less on each item, earns more on the mass of items" (Rossi, 1843, p.122).²⁸

This, according to Rossi, is what we find with industrial monopolies (the possession of machinery and patents), even when they are public in nature (e.g. tobacco). It is just such a situation that Dupuit would later study in connection with the taxation of road use. Moreover, Rossi envisages, just as Dupuit would, the principle of differential pricing as a development of this maximising strategy: "A bookseller asks eight or nine francs for a volume which contains perhaps barely enough material to fill a dozen pages. The price is high, the condition excessive, however much talent went into the writing of the book. But another bookseller cannot offer it to you for five francs, as he does not have the right to

²⁸ What is so original in Rossi's argument is not the idea that demand increases as prices fall (this had already been clearly postulated by Say; cf. notably *Traité*, 1841/1972, p.321), but rather its application to monopoly theory. Rossi may have been inspired by Charles Babbage, who, combining a knowledge of political economy with practical business experience, wrote in 1831 that "The principle that *price, at any moment, is dependent on the relation of the supply to the demand*, is true to the full extent only when the whole supply is in the hands of a very large number of small holders, and the demand is caused by the wants of another set of persons, each of whom requires only a very small quantity. (...) If the supply, or present stock in hand, be entirely in the possession of one person, he will naturally endeavour to put such a price upon it as shall produce by its sale the greatest quantity of money; but he will be guided in this estimate of the price at which he will sell, both by the knowledge that increased price will cause a diminished consumption, and by the desire to realize his profit before a new supply shall reach the market from some other quarter" (Babbage, 1832, II.15.198; our italics).

print it; were he to do so, he would be a counterfeiter. So you must pay your eight francs for the book or do without. And yet we shall have it, in a little while, for a more affordable price. For although his rights in the book remain, the bookseller will take counsel of his own best interest and offer us the book more cheaply, especially if its subject-matter is within the scope of a large number of readers. It is more useful to earn half a franc per volume quickly on ten thousand copies than to earn two-and-a-half francs per volume on just one thousand copies" (idem, p.121).²⁹

Rossi's main analytical contribution is to have made clear the role played by the hypothesis of perfect competition in Ricardian theory. Just as he turned round Say's argument on the relationship between wealth, utility-value and market value, here he turns Ricardo around by extending his theory of rent. Land rent is, for Rossi, the expression of an imperfect market, resulting from a natural monopoly on land; but agriculture, although a special case, is not as exceptional as Ricardo had thought. Monopolies, of varying degrees, are a general characteristic of the market economy. In this context, utility-value can no longer be assimilated to the cost of production. Rossi is therefore proposing nothing less than a theory of "imperfect competition" in his combination of the theories of Say and Ricardo, whereas, paradoxically, the latter both agreed on the assumption of perfect competition. A bold scheme, perhaps, but it is in essence similar to the route that Auguste Cournot and Jules Dupuit were to follow at almost the same time. And as we have seen, Rossi certainly inspired the latter, if not also the former. Unlike them, however, he did not make use of mathematical techniques, and this is probably the main reason why he has been neglected, despite Dupuit's insistence, in 1849, that he was following in Rossi's footsteps.

3. DUPUIT AND THE UTILITY THEORY OF VALUE

Dupuit's starting-point was that of the custodian of public funds faced with a practical question: on what criteria to decide for or against a

²⁹ The objection could be made that this is not a case of differential pricing, as the sale of the book is spaced out over time. However, by specifying "in a little while (*en peu de temps*)", Rossi invites the reader to gloss over the temporal dimension. Dupuit certainly chose to read it this way: he borrowed this example from Rossi in 1849 to support his own theory of differential pricing (Dupuit, 1849a, p.184).

civil engineering project: "The legislator has set out the required formalities for certain works to be declared of public utility, but political economy has yet to define precisely the conditions that these works must fulfil in order to be truly useful; at least, the ideas thus far put forward on the subject seem vague, incomplete and often inexact. And yet the latter question is more important than the former (...) The law should consecrate, as it were, only those facts that have been proven by political economy. But how is this proof to be established? On what data, on what formulae, should it be founded? In a word, how does one measure public utility?" (Dupuit, 1844, p.332). We need to be on our guard here, as Dupuit goes in for some semantic sleight of hand by merging the legal expression "public utility" into the economic concept of "utility", borrowed explicitly from J.-B. Say.³⁰ It might be more accurate to say that for him, *public utility* is just a special case (and not particularly special, at that) of *utility*. Thus the entire first section of his article is given over to a general discussion of utility theory, and only subsequently does he apply his results to public works, stating categorically: "This formula implicitly contains the measure of all kinds of utility, and consequently that of public utility, which in no way differs from any other kind" (Dupuit, 1844, p.346).

The discussion of utility theory is based on his reading of Say, whose theory of value Dupuit, like Rossi, accepts in principle. But, again like Rossi, he understands Ricardo's critique and the insoluble contradiction inherent in Say when it comes to measuring wealth in the context of technological progress: "Let us suppose (...) that some development is introduced in means of transport (...) which has the consequence of cutting the costs in half (...). Are we to conclude that the roads are now half as useful, as the aforementioned precepts would seem to demand?" (1844, pp.333-334). He therefore takes the same position as Rossi in the debate: utility is indeed the cornerstone of value, but value cannot be reduced to exchange-value. Here he invokes the authority of Adam Smith and McCulloch: "We need only recall that this same distinction is to be found in Dr. Smith, who recognises two values in an object: its *value in use*, being its utility as we understand it, the value for whoever

³⁰ Bordas reproached Dupuit for blurring the economic and legal concepts of utility: "I feel that the criticisms which Mr Dupuit has laid at the door of Navier and J.-B. Say are to be ascribed to the difficulty, nay impossibility, of reconciling the meaning of the word 'utility' in the economists' parlance with that which the legislator attaches to the word" (Bordas, 1847, p.259).

needs to consume the product; and its *value in exchange*, being the utility of the same product for whoever needs to sell it" (idem, p.339).

There can be little doubt that this a reference to Rossi: nothing in Adam Smith's text, nor in McCulloch's commentary, suggests that Smith's "value in exchange" should be interpreted as "the utility of the product for whoever needs to sell it". But this is precisely the interpretation for which Rossi argues at length; for him, as we have seen, "value in exchange" is an "indirect" form of utility. This is the essence of Rossi's legacy to Dupuit; from this common basis, of course, Dupuit went well beyond Rossi in proposing a method for *measuring* utility which had never occurred to the latter. What enabled Dupuit to make such headway in this field was his experience of engineering calculus. It is easy to see how Rossi, lacking that insight, was unable to reap the full benefits of the theoretical framework he had developed, and ended up toeing the Ricardian line on the theory of value.

For Dupuit, as for Rossi, Say's error was to think that the market value (the price) measures the utility of a good for the consumer, in so far as it represents the sacrifice that the consumer is willing to make in order to acquire it. But whereas Rossi makes his point and moves on, Dupuit finds in this criticism the germ of a method of measurement: the price may not be the measure of utility, but it is a *minimum*. If the utility is lower than the price, then the consumer will forego the purchase; if, however, it is higher, then he will accept a greater sacrifice. For Dupuit, Say's method contains an unacceptable logical error: "If you take this figure to be a measurement, rather than the lower limit of a quantity the exact size of which you do not know, then you act like a man who, trying to measure the height of a wall in the dark, and finding that he cannot reach the top with his outstretched arm, says to himself: 'this wall is two meters high, for if it were less than two meters high, my hand would have touched the top'. If, however, you say that the wall is at least two meters high, then we are in agreement" (1844, p.334).

Here Dupuit holds the solution to his problem: the utility-value of a good (for a given individual at a given moment)³¹ corresponds not to the price that he is led to pay for it by the prevailing market, but rather to the maximum price that he would agree to pay: "In summary, political economy must measure an object's utility by the maximum sacrifice that

³¹ As we discuss later, Dupuit, following Rossi, looks at variability in utility both between and within individuals.

the consumer would be willing to make in order to obtain it" (idem, p.343). Under this definition, Dupuit preserves Say's idea of using price to measure utility, but rather than an actual price, he uses a "virtual" price, which—though it exists only subjectively, in the consumer's mind—is nonetheless theoretically amenable to experimental measurement: it is the actual sum of money that a consumer would be willing to pay in exchange for a service *with regard to his own resources*.³² This last point is important, for as Bordas was to point out, Dupuit's concept of utility is ambiguous: it does not signify the true intensity of the consumer's desire, only the intensity of "solvent" desires.³³

From his measurement of utility, Dupuit goes on to formulate a theory of "consumer surplus" later picked up on by Alfred Marshall; he distinguishes "absolute utility" (the maximum acceptable price) from "relative utility" (the difference between the absolute utility and the price actually paid—Marshall's "consumer's surplus"). Dupuit does not use the actual words "marginal utility", but the concept is clearly there: for a given individual at a given moment, the (marginal) utility of a good is the maximum price that he would be willing to pay for it, rather than the utility of all the other instances of that good that he may previously have consumed. In effect, Dupuit has inherited from Say and Rossi a subjectivist concept of value, one that takes account of *intra*-personal as well as inter-personal variation in consumer desires. He distinguishes between two levels—what in modern terminology, we might call the "marginal consumer" and "marginal consumption"—which echo two concepts already found in Say: the "social pyramid" and the "hierarchy of needs":³⁴ "This, I believe, is the way it works: several individuals come forward to buy wine; the need which they feel for this commodity is in each case

³² Dupuit sets himself apart from the early neoclassicals by treating money as a pre-established category, rather than starting out, as they did, from a pure theory of exchange: commodity for commodity. In this respect he never strayed from the categories of a public service administrator. His use of monetary terms to measure utility was criticised by Bordas and later by L. Walras (cf. *infra*).

³³ Bordas picked up on this confusion, as he saw it, but Dupuit had foreseen the criticism: "One would be hard pressed to say which is the hungrier: the rich man who would give a million francs for a loaf of bread; or the poor man who, having nothing else to give, would risk his life for it. But political economy, confining itself to questions of wealth, can measure the intensity of a desire only by its monetary expression" (idem, p.40).

³⁴ Cf. J.-B. Say, *Traité*, (1841/1972, p.319ff).

different. Some of them, being rich, or comfortably off, attach to it such utility that they would even buy it at 30 sous, if so obliged by the prevailing market price; others, the less rich, would not spend more than 15; the less comfortable would not go beyond 10; while others, feeling the pinch, would stop at 6, and the poor would not buy at anything over 4. (...) Thus, when one examines the facts more closely, it becomes evident that every object consumed has a utility which varies according to the consumer. But there is more; each consumer himself attaches a varying utility to the same object according to the quantity that he wishes to consume. For example, a purchaser who would have bought 100 bottles at 10 sous each, may only buy 50 at 15 sous and would perhaps even have bought only 30 at 20 sous" Dupuit (1844, pp.336-337).³⁵

In mentioning the concept of marginal utility in connection with Dupuit, we need to be clear about what we are saying. This central idea of the neoclassical revolution was developed out of several different conceptual frameworks. Dupuit's notion, taken directly from Say and Rossi, is based on a subjective but not "psychological" approach to value, namely the hierarchy of needs. This schema was taken up by Carl Menger, who cited, among the authors who "were to exercise a particular influence on (his) mind", Condillac, Jean-Baptiste Say, and Rossi.³⁶ This approach differs fundamentally from the psychological line proper, developed by Jevons and based on Senior's "law of variety", which has little to do with a sociology of "needs" and everything to do with a psychology of "desires".³⁷ So although Dupuit's concept of marginal utility re-

³⁵ Dupuit is conscious of the limits of his example, as wine corresponds to an undifferentiated need; he therefore supplements it with a look at the problem of urban water distribution, which he had studied in a professional capacity. Here we have a genuine pyramid of needs: "We improve the pumps, and, for the sole reason that consumption rises, the price is reduced to 20 francs; you will find that the same individual wants four hectolitres in order to wash his house every day; give them to him at 10 francs, and he will ask for ten, so as to water his garden; at 5 francs, and he will ask for twenty, to keep his bath filled; at 1 franc, and he will want 100 for a continuous stream of water, and so on" (idem, p.337).

³⁶ Also listed are Adam Smith, Louis Say, and Cournot (letter from Menger to Feilbogen, 26 June 1911, cited in Feilbogen, 1911, p.56, note 2).

³⁷ Unlike Rossi, Senior expressed the principle of diminishing utility in psychological terms: "Two articles of the same kind will seldom afford twice the pleasure of one, and still less will ten give five times the pleasure of two" (Senior, 1854, 2.14). Jevons generalised this psychological approach by making it a special instance of Fechner's "psychophysical" law, according to which the response to a given stimulus is a logarithmic

mains incomplete by the standards of modern neoclassical theory, and although it does not plot a "utility curve" to underpin the "demand curve", as did the early neoclassicals, one cannot rightly say that he does not have a utility theory of value. Unlike Cournot, he does not construe the "demand curve" as an empirical hypothesis; instead, he deduces it from an analysis of the nature of value borrowed from Say and Rossi.³⁸

All of which is not to say that Dupuit offers a well-rounded neoclassical theory of demand. In a way, Say's theory is actually more complete; in his *Épitomé* he writes: "These quantities (supplied and demanded) depend on the combined action of the *need* that exists for the product, the degree of *wealth of the consumers*, and the *costs of production*".³⁹ If we accept, as Say does, that in a competitive equilibrium the price is equal to the production costs, then what we have here is a macro-economic theory of demand as a function of utility, income and price, i.e. $D = f(U, I, p)$. More specifically, as the Walrassian theory of general equilibrium would eventually demonstrate, the demand for a commodity cannot be isolated out from that of all other commodities. To this extent, Dupuit's theory was open to criticism from several angles, and it duly came, both from that great exegete of J.-B. Say, Bordas, and later, from Léon Walras.⁴⁰ But Say's theory, though more complete in principle than Dupuit's, ultimately offers no instrument of measure, whereas Dupuit's can, theoretically, be made operational. That is what

function of that stimulus. Oddly enough, Fechner got the idea for the law from the first moral-economic approach to utility, set out by Daniel Bernoulli in 1738 to solve the Saint-Petersburg paradox. (On this point see notably V.K. Dmitriev, 1968, p.239ff.)

³⁸ Here we diverge from Gérard Jorland, who is a little too quick to assimilate the cases of Cournot and Dupuit. Demonstrating that Cournot constructs his demand curve independently of any utility theory of value, he then extends the argument to Dupuit, insisting that: "It is by no means self-evident that Dupuit ranks among the precursors of the utility theory of value. After all, he constructed his entire argument in opposition to Say's assimilation of price with value, and value with utility. In line with Smith and Ricardo, he wanted to restore the distinctions between these concepts" (1980, p.247). We believe we have demonstrated that Dupuit's relationship to Say is more complex: like Rossi, he adopts Say's utility theory of value while taking on board Ricardo's criticism. With this original combination of Say and Ricardo, Dupuit foreshadows, as did Rossi before him, the neoclassicals' utility theory of value. This view was put forward back in 1904 by V.K. Dmitriev, who openly opposed Dupuit and Cournot on this point, before being taken up by R.B. Ekelund and M. Thornton (1991).

³⁹ J.-B. Say, *Épitomé*, section "*Quantité offerte ; quantité demandée*" (1841, p.598).

⁴⁰ Cf. our conclusion *infra*.

lies at the heart of his approach, and to understand it, we must return to his thinking as an engineer.

4. FROM INDUSTRIAL MECHANICS TO ECONOMIC THEORY

How did Dupuit reach this juncture? For insight on that question, we need to take another look at the practical and mathematical mindset of the civil engineer. Dupuit, as we said, bases the first part of his text (discussing the general theory of utility) entirely on his critique of J.-B. Say, but when in the second part he moves on to the issue of public utility, he cites another author—like himself, a civil engineer—Claude-Louis Navier.⁴¹ And behind Say, it was actually Navier that Dupuit was aiming at. In an article published in 1832, Navier had developed an original conception of public works that was both liberal and "industrialist" in its inspiration.⁴² With an unacknowledged quote from Adam Smith, he underlined the importance of transport infrastructures in expanding the "reach of the market, namely (...) the space in which each producer can buy raw materials and sell manufactured products" (Navier, 1830/1832, p.2).⁴³ To encourage economic development, he recommended free access to the roads, as any tax, by restricting road use, would also reduce their *utility*: "The utility of public works designed to establish lines of communication consists above all in diminishing that

⁴¹ Claude-Louis Navier (1785-1836) was one of the originators of the physical concept of labour (on this point, see F. Vatin, 1993). The article cited by Dupuit is "De l'exécution des travaux publics et particulièrement des concessions", *Journal du génie civil*, 1830, reprinted in *Annales des ponts et chaussées*, 1832, pp.1-31. It belongs to the debate of the time on road-use policy. For an overview, see François Etner (1987, p.130ff).

⁴² According to François Etner (1986, p.162), the creation in 1831 of the *Annales des ponts et chaussées* was intended to provide a tribune for the engineers of the Corps des Ponts, from which to counter criticism, from J.-B. Say amongst others, about the high cost of maintaining France's roads in comparison to Britain; the article by Navier that Dupuit cites is a prime example. Dupuit agreed with his forbear on this point, and upheld the legitimacy of the Corps des Ponts against J.-B. Say in the article on that subject that he contributed to Coquelin and Guillaumin's *Dictionnaire* (Dupuit, 1854e).

⁴³ This notion of Adam Smith's was taken up by J.-B. Say (*Cours*, 1840, vol.2, p.307), who concluded, with Navier, in favour of free road use. It is interesting to note that, paradoxically, Smith himself was in favour of the toll principle (1776/1904, V.1.74). Dupuit explicitly supported Smith against J.-B. Say in his article "Routes et chemins" in Coquelin and Guillaumin's *Dictionnaire* (Dupuit, 1854ff, pp.555-560).

part of the costs of carriage which is supported by trade. (...) It would be desirable for the expense of the works in question to be borne by public taxation; this would enable us to refrain from imposing tolls, or at most impose only modest ones, to cover merely the costs of maintenance. These works would then procure all the utility that one might expect of them" (idem, pp.30-31).

Dupuit's concept of "public utility" is easily recognised in this extract. He would apply himself to the same problem in 1844, but would arrive at a different solution: not free access, but differential pricing. And it was clearly his immersion in political economy at the highest level, drawing on J.-B. Say and Rossi, that led Dupuit to this solution: only two years earlier, in his paper on the cost of road maintenance, he had been in full agreement with Navier on the issue. Arguing for carefully managed improvement in road maintenance, he exposes the existing disparity between the cost of maintenance and its social utility, which he measures in terms of reductions in transport costs. Evaluating transport costs at 475 million francs and road maintenance costs at 25 million, he proposes: "Let us suppose that by increasing the costs of maintenance by 5 million, or one fifth, we obtain a diminution of but 1/10th in the costs of transport, a proportion that will seem meagre indeed to anyone travelling on a bumpy road; it is clear that society will make a net profit of more than 40 million, i.e. 800 per cent, a definitive and lasting benefit (...) When one looks at these figures, it becomes evident that the true question for the State is not whether to spend 20, 25 or 30 million on the upkeep of the roads; this figure cannot be expected to vary to any degree of significance for the public wealth; the figure that must be diminished by all means possible is that of the 475 million francs (...) In a word, while transport costs 1.00 franc per ton and per league, maintenance costs 0.05 francs. Is it not strange that all the discussion centres on whether these five centimes might not be reduced to four-and-a-half or four, while no-one asks whether we might not be able to reduce the cost of transport by twenty-five or thirty centimes by improving the roads?" (Dupuit, 1842, p.75-76).⁴⁴

⁴⁴ This demonstration did not however lead Dupuit to join Say and Navier in advocating free road use. Instead he insisted, by referring back to the comparison—already made by Say and Navier—between the French and British traditions, that the toll principle would allow for better allocation of resources: "Fortunately for the toll collector, but unfortunately for the roads, this industry is not subject, in France, to concession fees (*droits de barrière*). Had such fees existed, and had the proceeds been allocated to

And yet it is for using just such a method of calculation—measuring the utility gain "negatively", in terms of reduced spending—that Dupuit, two years later, would reproach Navier. For Navier, a public investment is worthwhile only if the annual saving that it represents for the public purse outweighs the costs incurred by the state (depreciation plus annual running costs). To take the case of a new canal, he measures the saving by multiplying the unit gain by the tonnage carried. In other words, the project is of public utility if the tonnage attains a threshold that balances the equation. Dupuit has no difficulty in demonstrating that this evaluation is unacceptable in his theory of utility. It effectively assigns the same value to every ton carried, whereas the point is that the price reduction will open the way for new freight traffic that was previously impossible, as its utility did not cover its costs. The new tonnage cannot therefore be assigned a utility-value based on the former market value.

Navier's formula therefore leads to a significant over-estimation of the utility of public works: "The error in these calculations (...) is to apply to all the tons carried on the canal a utility figure which is only accurate for a very small number of them, such that the utility of the canal is vastly exaggerated. This leads to totally false results which could have the gravest consequences for the public purse" (Dupuit, 1844, pp.348-349). And Dupuit goes on to show, by quoting a passage from Say's *Traité*, that Navier's calculation is in strict accordance with Say's analyses on the utility of roads and canals (J.-B. Say, 1841/1972, p.508).⁴⁵ Navier thus comes across to Dupuit's readers as a disciple of Say, and the critique previously levelled at the economist seems to apply equally to the engineer. But this is just a clever rhetorical device, one which is potentially quite misleading. In fact—as Dupuit was probably well aware—Navier's calculation, while it accords with the extract from Say, is completely inconsistent

maintaining the roads on which they were levied, then they would naturally have been far better apportioned (...). Perhaps the effect of this circumstance on England's roads has not been sufficiently noted; it certainly has the immense advantage for road maintenance of constantly balancing the resources in proportion to the needs" (id., p.72). This classical conception of toll systems is as far removed from Navier's free road use as it is from the differential pricing he would advocate two years later. It is as though Dupuit, favourable to the toll principle on ideological grounds, had searched around for a form of it that answered the objections previously made by Say and Navier.

⁴⁵ This extract is taken from the paragraph on "spending on publicly-owned buildings and constructions", *dépenses relatives aux édifices et constructions qui appartiennent au public* (J.-B. Say, 1841/1972, pp.506-509).

with Say's general theory of value as criticised earlier by Dupuit. In this calculation the value (utility) of a good is not measured directly on the market, by its price, but indirectly, by a cost reduction. In other words, what Dupuit has put his finger on here is Say's failure to adhere to his own doctrine when it comes to public utility.

This apparent inconsistency in Say can be accounted for at more than one level. There is, firstly, a practical question: in the absence of markets, Say's utility is not amenable to measurement; some artificial mechanism of measurement therefore has to be devised. At a deeper level, it is about the nature and purpose of the state. As a dyed-in-the-wool liberal, Say cannot conceive of the State as a direct producer of utility, since he sees taxation as a form of unproductive consumption.⁴⁶ But the problem goes still wider than that, for, as Dupuit realised, the transport infrastructure is in the end—both technically and economically—just another machine;⁴⁷ the idea of improving this infrastructure is therefore just a special case of the hypothesis of technological progress on which the Ricardian critique of Say's economics was based. The example of public works brings out the unresolved issue of the machine in general. By admitting an indirect measurement of utility for public works, Say unwittingly opens the door to a general critique of his system. In fact, as we shall see, this measurement is in turn merely a special case of the system that Dupuit was about to construct.

This system is primarily based on a standard method of calculation in engineering, namely "substitution calculus":⁴⁸ a machine is "profitable"

⁴⁶ We will return to this point later.

⁴⁷ Technically, a road is a machine, and this was clearly the attitude of France's civil engineers to industrial mechanics. The question is evidently more complex from an economic angle, due to the publicly-owned status of the road infrastructure. But of Dupuit's conceptualisation there is no doubt: writing about the economic role of a canal, or of any other line of communication that reduces the production costs of a commodity, he adds the footnote: "one could even call it a working instrument, or a kind of machine" (1844, p.349, note).

⁴⁸ "Substitution calculus" was a central plank in modern engineering thought during its early development at the start of the 18th century. It contributed to the birth of industrial mechanics, which sought to evaluate the efficiency of machines in terms of "labour" by comparing them with the human labour they could replace (on this point, see F. Vatin, 1993). This method of calculation can be extended to the comparative advantages of two machines, or of any two means of production. It always involves calculating the "point of substitution" at which the new resource becomes preferable to the older one. The engineers of the Ponts et Chaussées made abundant use of this method

only if the new costs that it incurs are less than the "utility" it produces. Such calculations can be performed in industrial mechanics using "units of labour";⁴⁹ here, however, both cost and utility can only be measured in monetary terms. In the case of cost, this is self-evident, but evaluating utility is more problematic, and this is the whole purpose of Dupuit's paper. In keeping with the spirit of Say's theory of value (soon to be taken up by the neoclassicals), utility-value can, for Dupuit, only take the end-user as its point of reference. This leads him to a key criticism of Say and Navier's calculus: that it focuses on transport costs alone, whereas what the consumer is interested in is the total cost of production, of which the transport costs are just a fraction. This common-sense remark may seem trivial, but it is in fact a judicious one, as it leads Dupuit to demonstrate that the main function of a thoroughfare is not necessarily to reduce transport costs. Taking the example of the supply of stone to a town, he shows how a canal can lead to stone being shipped in from a quarry that is further away but more productive; the transport costs will have increased, but the total cost of production will have diminished: "Therefore, the end purpose of any line of communication must be not to diminish the costs of transport, but to diminish the costs of production."⁵⁰It can be perfectly rational to build a road 40 kilometers long to reach a new source for products that were available just 10 km away on another" (Dupuit, 1844, pp.351-352).

From this starting-point, Dupuit goes on to distinguish two scenarios. In the simpler scenario, the new line of communication engenders no new traffic. The resulting utility will therefore be equal to the drop in production costs multiplied by the traffic. If the drop in production costs is due exclusively to the lower transport costs, then the calculation proposed by Dupuit is strictly equivalent to that of Say and Navier, which is then simply a sub-instance of his system. However, this method of calculation (even when extended to production costs) no

when deciding on road surfaces, traction types, etc. (on this point, see B. Grall, in this book and forthcoming thesis). Jules Dupuit's originality was to extend the approach to consumer goods.

⁴⁹ Cost is accounted for as "total labour expended" and utility as "useful labour" (*travail utile*). This amounts to saying that a new machine is only "profitable" when the increase in useful labour is greater than the increase in total labour, i.e. when it improves the "yield".

⁵⁰"By cost of production, we mean that which it costs to render an object fit for consumption" (Dupuit's, 1844, p.352, note).

longer applies in the other—and, in his view, more prevalent—scenario of an increase in traffic. As we have seen, the newly created utility, namely the new traffic, cannot properly be evaluated at the original price, as the demand was not previously solvent at that price. Better still, the new line of communication may improve freight traffic not only in quantity, but also in quality, in which case we no longer have any terms of comparison: "The opening of a new line of communication, if, like the canals, it is very cheap, or, like the railways, very fast, brings hitherto unknown products into the regions through which it passes. Suddenly all the houses in this village have replaced their thatch with roof tiles; further down, in another, the roof tiles have been replaced by slate; (...) How can we measure the utility of these new commodities that were not even in use before the advent of the new communications?" (idem, p.354).

Dupuit now clearly brings out the failings of Say and Navier's calculation: "This eminent economist [Say] asks that we reckon the utility of these products in the same way as for the others, by evaluating the difference in transport costs, as if the new road or canal had never been built, however great that difference might be. The over-evaluation here is plain to see. This slate, unknown before the new canal, and which sells for 20 francs per thousand, might have fetched 200 francs, 300 francs, a thousand even, without it. (...) From the fact that the slate would have cost a thousand francs when everyone did without, and costs 20 now that everyone uses it, are we to deduce that the utility of the service rendered by the canal is of 980 francs per thousand slates?" (idem, pp.354-355). Dupuit then resolves this sophism by introducing a new instrument of analysis: taxation, the only way of directly measuring end utility: "It is easy to persuade oneself of the contrary, as it is perfectly possible that a tax of 10 francs per thousand might reduce the consumption of slate by half; roof-tiles had been abandoned, now one half of all consumers will return to them; if this happens, you can say that for one half of the slate consignments, the utility was less than ten francs per thousand; then, if a tax of 20 francs were to drive slate away from the marketplace entirely, you could say that for the other half the utility was less than twenty francs. This utility of 980 francs, based on the utility that it would have cost, is therefore totally imaginary; there is no utility other than that for which people are willing to pay" (idem, p.355).

By placing taxation at the heart of his reasoning, Dupuit seems to be abandoning the model of the machine. In fact he is doing nothing of

the sort. Once again, however, his argument is a convoluted one, as he analyses taxation on two levels. At one level, he refers to it in the concrete sense of a "tax" to be levied on road use (a toll). This draws him into the ongoing debate between economists on indirect taxation, and, yet again, he comes up against the orthodoxy of J.-B. Say. But, on another level, Dupuit uses taxation as a theoretical metaphor, the abstract instrument of a thought experiment. Looked at the from beyond the confines of public economics, taxation is no different in this respect from any other kind of price, and here we find once more the seemingly forgotten model of the machine.

In addressing the issue of taxation, Dupuit again tangles with the economics of Say. For Say, all taxation corresponds to a transfer of value, i.e. utility, to the state, which will then consume it in the same way as any individual (J.-B. Say, 1841/1972, p.475ff). When the individual consumer buys a taxed product, he pays firstly the market price (corresponding to its utility-value) and then, in addition, a tax with nothing in return. Dupuit does not share this radically negative view of taxation, any more than does Rossi;⁵¹ for him, taxation well spent can benefit the taxpayer. But, for Dupuit, the essence of the argument is not taxation *per se*, it is the theory of value. He counters Say with a common-sense remark: if the buyer agrees to pay the taxed price, he must consider he is getting something in return. To be sure, the tax does not create any utility, but it does bring out a hidden utility—a "reserve of utility"—in the hands of the consumer: "There is no doubt that a tax can add nothing to the utility of product; but when one considers it from the viewpoint of the consumer, it is fair to say that the existence of the tax reveals in the product a utility greater than the costs of production" (Dupuit, 1844, pp.335-336).

Almost imperceptibly, Dupuit has thus entered into one of the key debates in early 19th-century economics. As he points out, following on from Navier, (indirect) taxation weighs less heavily on those who pay it than on those who don't, as the latter can no longer consume: "You are, in effect, only reckoning one class of citizen, those who pay tax; one must also take account of the far more numerous class of those who do not, because they cannot, and who thus can no longer consume. In many cases the base of a tax has a greater effect on public prosperity than the

⁵¹Cf. Rossi, *Cours*, vol. 4 (published by his sons), reprint, Paris, Guillaumin, 1863, (Lesson 1).

rate" (1844, p.367).⁵² For those who pay the tax, there is simply a transfer of value (utility), whereas for those who do not pay it, but cannot consume because of it, there is a net loss of utility. Taking the example of a tax on the transport of stone, he adds: "One could even say that, for the nation, the product of the tax is not lost, as one must assume that it is put to good use. It is merely a change in the distribution of public wealth; there is no loss for society as a whole... But the loss is real for those who would have bought the stone at 16 francs and who, in buying it for 15 francs, would have made a 1-franc profit, if they are now prevented from so doing by the 5-franc tax, even though they do not pay it; likewise the loss of 2 francs for those who would have bought it at 17; etc." (idem, pp.365-366).

This notion of "loss" is taken directly from industrial mechanics. The model of reference is that of Coulomb, whose *Mémoire sur la force des hommes* (1778-1798)⁵³ provided the overarching methodological framework for the practical mechanics of the 19th century. In this model, the "quantity of action" produced (the "useful effect" or, in modern physics terminology, "work") is a two-dimensional quantity, involving the load carried and the height of elevation (or distance travelled), i.e. M (mass) \times D (distance). The aim is to optimise this quantity, which presents a "bell-curve" distribution: if the load is zero, the distance travelled is maximal, but the useful effect is nil; an inversely, if the load is maximal, the distance travelled will be zero and the effect again nil; somewhere on the curve between these two extremes lies an optimal point. The load, then, acts as a "brake" on movement; when it is super-optimal, it causes a net loss of utility.⁵⁴ Dupuit uses exactly the same model when he defines the revenues of the monopolist as the product of tax (analogous to mass) and quantity (analogous to distance): "If one gradually increases a tax from 0 up to the level at which it becomes prohibitive, the tax revenue

⁵² Cournot, who is often compared with Dupuit, took a diametrically opposed position on this point in 1838, refusing to take anything into account that could not be measured in monetary terms (cf. Cournot, 1838/1980, p.51ff). This question is discussed in F. Vatin, 1998.

⁵³ Coulomb's founding text, known by this shortened title, came out in a number of different versions between 1778 and 1798. It is analysed in detail in F. Vatin (1993), and in J. Rousseau and F. Vatin (1991).

⁵⁴ Coulomb also developed a theory of friction (which Dupuit criticised, cf. *supra*). The analogy between the load and the brake is therefore not accidental; indeed it underpins the entire mechanical concept of work.

starts out at nought, then grows imperceptibly to reach a maximum, before progressively decreasing back down to nothing" (Dupuit, 1844, p.370).

Taxation can therefore be thought of as a "brake" in the precise mechanical sense of the word. Just as one can measure the work produced by a machine by tightening a brake at one end until the machine comes to a stop, one could likewise measure the utility produced by a good by taxing it until all economic movement (i.e. trade) ceases. Substitution calculus directly measured the utility produced by a line of communication ("acquired utility"), but presupposed the correct terms of comparison. Taxation measures utility indirectly in terms of loss ("lost utility" or "utility loss"). For Dupuit, this method has the advantage of generality, as it enables all goods to be compared with that universal yardstick of desire: money.

The "taxation as brake" metaphor now takes on the status of a theoretical model, as it can be applied to any kind of price: "The loss of utility that results from any increase in price is not specific to tolls and taxes, it applies even to the actual price of a good, which represents its costs of production, and which could be looked upon as a tax on a natural asset" (idem, p.60). Of course, Dupuit does not conclude from this that all goods should be free. Quite the contrary: the extension of the model to prices in general leads him to reject the principle of free use of public assets advocated by Navier. The moral is that in political economy, as in mechanics, one must distinguish between friction loss (internal to the machine) and loss inherent to the useful effect. In economics, a utility loss equal to the production costs sets the bottom limit, below which one cannot go: "The utility lost as a result of a price which does not compensate for the labour expended plays, in political economy, the role that friction plays in machinery. (...) If you want to raise two kilograms by one metre, do not complain about the one-kilogram force that you must exert, if you only have to travel two meters, for it cannot be otherwise without changing the laws of nature; but if you have to travel three or four meters, then there is friction loss, which mechanics will teach you to avoid or to reduce. Likewise, political economy can teach us to reduce the loss of utility that results from price variation" (1844, p.371).⁵⁵

⁵⁵ Taken at its most literally, Dupuit's brake metaphor raises complex problems to do with the transition from static to dynamic states in mechanics. It seems likely that Du-

So how does one "get people to pay" without losing utility? This brings us to Dupuit's practical conclusion, and the true purpose of his paper: differential pricing. But first we need to supplement and refine the physical model presented above. Coulomb's model uses a classical principle of optimisation: both variables (i.e. distance and load) being given, the aim is to find the load value that maximises the product (load * distance), which can be represented geometrically by a rectangle precisely analogous to the price-quantity rectangle of classical monopoly theory as formalised in 1838 by Cournot (1838/1980, chap. V). But one might equally reasonably consider that, as fatigue increases with distance travelled (itself a function of time), it would be preferable to vary the load over time.⁵⁶ In this case one is no longer trying to find an optimal average load, but a vector of loads that varies according to distance (or time).⁵⁷ In geometric terms, instead of looking for the largest rectangle under the curve, one is looking, in discrete analysis, for the sum of a set of stepped rectangles, and in a limit process, for the integral under the curve. The transition from monopoly price theory to that of differential pricing involves the same conceptual shift: the revenue of the monopolist is now the whole of the integral under the demand curve.⁵⁸

duit adopted the metaphor for rhetorical rather than strictly heuristic ends. However, it is a fair guess that he drew inspiration from a mechanical model of more immediate application: that of materials resistance, an issue he had previously encountered in his work on road maintenance. To take the example of a paved road, the civil engineers of the day found it necessary to define a "maximum support weight" in every way analogous to Dupuit's "maximum accepted price".

⁵⁶ This development of Coulomb's thinking was in fact pursued by the experimental psycho-physiology of the late 19th and early 20th centuries (on this subject, see F. Vatin, 1996).

⁵⁷ The transition from average-based to differential thinking was a key element in the epistemological revolution of the 19th century. It was particularly evident in mathematical functions, which were no longer assumed to be linear in form (and thus reducible to a leading coefficient, which in turn could be assimilated to an average), but rather continually increasing or decreasing, like Fechner's logarithmic "psychophysical" function, a major influence on both psychophysiology and neoclassical economics.

⁵⁸ L. Walras himself presents Dupuit's theory in this way in the 41st lesson of his *Éléments d'économie politique pure* (1876/1988, pp.655-671). The process of "decomposition" of the average had already been used in 1831 by Charles Babbage (1832), who, expanding on Smith's theory of the division of labour, put forward his famous "principle" of creating a hierarchy of tasks in order to make optimal use of each category of labour. This differential reasoning, so central to Babbage, is also at the heart of Dupuit's engineering work. In his *Études théoriques et pratiques sur le mouvement des eaux courantes* (1848

Here, Dupuit believes that he holds the philosopher's stone of political economy. By making everyone pay as much as they are willing to pay, the producer's profit is maximised (even beyond monopoly profit levels) and the loss of utility to the consumer is nil, as no-one is forced to abstain from consumption on account of subjective overpricing.⁵⁹ Not that one can avoid all loss inherent in the price (as we saw, that would be a "physical" impossibility), but one can avoid any "deadweight" loss, such as the loss represented by the non-utilisation of a civil engineering structure, as indeed Dupuit argued on the very same page as the previous extract: "Doubtless the Pont des Arts subtracts 5 centimes-worth of utility from all who cross it, but this is merely a repayment of the initial capital outlay, it is a necessary part of the human condition and of the current progress of the human spirit, and one may as well accept it with good grace. If it were simply a profit for the builder of the bridge, then it would only be a change in the distribution of public wealth with no significant effect on the whole; but it is more than that: this 5-centime toll removes much of the bridge's utility (one could equally say that this 5-centime price removes much of the product's utility), as it forces many people, who ascribed to it a utility of 4 centimes, or 3, or 2, or only 1, to take the long way round via the Pont-Neuf. In this case the loss is total and uncompensated: this is the friction loss we encounter in mechanics" (Dupuit, 1844, p.371).

In its transmission from Rossi to Dupuit, the principle of differential pricing has undergone a radical change of meaning. For the former, it is merely a piece of sharp trading practice. Dupuit does not seek to deny this aspect of it: "This highly variable and mutable utility-value is familiar enough to the business of trade, where it has long been exploited. (...) He (the seller) can draw on innumerable ruses to make each of them (the buyers) pay him the largest possible share of that profit⁶⁰ which he considers to have been made at his expense. The same commodity, presented in diverse guises in different shops, is often sold at very different prices according as the customer is rich, comfortable or poor. It is avail-

pp.81-94) he constructs a rational schema with strong affinities to the one he applied to pricing: he seeks to optimise the structure of the water distribution grid, not by looking for the optimal average pipe diameter, but rather for a set of diameters that "fit" the variations in flow.

⁵⁹ This reasoning, based as it is on isolating a single market, is unquestionably flawed, as Bordas and L. Walras were soon to point out (see conclusion).

⁶⁰ By "profit" (*bénéfice*) Dupuit is here referring to the consumer surplus.

able in fine, very fine, super-fine and extra-fine; all of which, though they came from the same barrel and present no real difference other than the superlative on the label, are sold at very different prices. Why? Because the same object has a very different utility value from one consumer to the next. Were we to have just one average price, there would be a loss for all who forgo the product because they attach to it a utility lower than its price, and a loss for the seller, who would recover, from many of his customers, an all-too-small share of the utility in the service rendered" (idem, pp.341-342). Behind this tradesman's ploy, however, lies a profound truth and ultimately, as in the fable of Mandeville's bees, a public virtue behind the private vice: "God forbid that I should seek to justify all such tricks of the trade; but they reward study, as they are founded on a precise understanding of the human heart, and in many cases one finds in them more fairness than one at first expected, and even some examples worth following" (idem, p.342).

Worth following by whom? By civil engineers, of course, who must break away from the traditional concept of charging on the basis of production costs, and learn to charge according to utility. For Dupuit, everyone would gain from this procedure: the state would maximise its revenue, which would then be equal to the integral under the demand curve, and the public would obtain widespread benefit from a public asset. Besides, as he points out, the practice is already commonplace: "Thus, when a bridge is built and the State establishes a tariff, it no longer takes account of the costs of production: it imposes less tax on the heavy horse-cart that wears down the road surface than on the suspended carriage. Why two different prices for the same service? Because the poor man does not set the same price on the advantage of crossing the bridge as the rich man, and by raising the tariff one would only prevent him from crossing. On the canals and railways, separate tariffs apply to different classes of freight and passenger, imposing highly variable prices on them even though the costs are roughly similar" (idem, p.342).

5. CONCLUSION: BORDAS, DUPUIT AND MARKET THEORY

In 1847, Dupuit's paper came under fire, as noted earlier, from one of his civil engineering colleagues, Bordas. Although Bordas remained impervious to Dupuit's analytical contribution, his criticism is far from uninteresting. A defender of the orthodox Say tradition, he comes across

in some respects as a "better" economist than Dupuit. He demonstrates that the latter, by taking one particular market in isolation, is guilty of what he calls a "fetishist" attachment to monetary measurement. Utility as measured by the "maximum acceptable price" is relative not only to the consumer's revenue (the "revenue effect" that Dupuit had observed) but also to the price of other commodities (the "substitution effect"): "Suppose we are trying to establish the utility of a pound of meat, and we ask somebody to tell us what sacrifice he would be willing to make in order to obtain it. Would he be able to provide us with a categorical answer? Of course not. For the sacrifice depends, does it not, on his personal fortune and also on the current price of other foodstuffs which could be served in place of the meat" (Bordas, 1847, p.278).

Unlike Dupuit, Bordas is clearly aware of the complex chain of effects (revenue and substitution) arising from any change in a market. *Contra* Dupuit, he introduces a global concept of the market, totally absent, as L. Walras also observed, from the article of 1844.⁶¹ Starting out from a general theory of utility, Dupuit arrives at a highly restricted analysis of partial equilibrium. He then advocates differential pricing for public services (and commodities in general) apparently believing that one could tap into the consumer surplus on a given market without affecting the other markets. Bordas may have overlooked the ingeniousness of Dupuit's original idea, but he clearly exposes the absurdity of the final conclusions. At the end of the day, the calculation of the utility of public works put forward by Say and Navier seems—in Bordas' eyes—no doubt imperfect, but at least acceptable as a first approximation, whereas Dupuit's seems totally devoid of common sense.

⁶¹ Unlike Jevons and Edgeworth, L. Walras was highly critical of Dupuit, as is evident from his correspondence, published by W. Jaffé (*Correspondence of Léon Walras and Related Papers*, 1965, vol.1, p.535). He totally disputed Dupuit's precursor status in marginal utility theory, accusing him of having "confused" the concept of "utility curve" with that of "demand curve" (letter 464 to Jevons in March 1880, and letter 913 to Pantaleoni on 2 September 1889). In fact, as we learn from his first letter to Jevons on the subject (letter 379 of 25 May 1877), Walras did not accuse Dupuit of ignoring the question of utility, but of mishandling it, by taking a single market in isolation, and here his criticism converges with that of Bordas: "This theory holds that the measurement of utility lies in the maximum pecuniary sacrifice that consumers are willing to make in order to obtain a product, i.e. in the area of the demand curve. Without doubt, this pecuniary sacrifice depends in part on the product's utility; but it also depends on the utility of other products; and also, in part, on the quantity of wealth, assessed in money, that the consumer possesses".

A great surveyor of thought, Dupuit ultimately constructed a model with a promising analytical future, but which is in itself no more than a "theoretical utopia". As we have shown, his approach grew out of an original encounter between engineering calculus and political economy. In some respects, it can be argued that it culminated in a double failure, as identified in Bordas' critique. As a practical method of calculation, his over-ambitious *Mesure de l'utilité des travaux publics* is not only impracticable, but potentially a source of costly errors; it was never put into application. As economic theory, it remains unfinished, incomplete; Dupuit never managed to integrate it into a coherent body of doctrine—witness the absence of progress between the 1844 paper and final article published in the *Journal des économistes* in 1853. The lack of success of his theories must then be ascribed at least as much to their own weaknesses as to the "obscurantism" of which the French liberal school is often accused.⁶² It is only in retrospect that Dupuit's theory of utility ultimately makes sense.

And yet, reading Rossi's *Cours* might so easily have put Dupuit onto the path towards a theory of imperfect competition, which the economics professor was himself, unable to develop for want of the analytical instrument constructed by the engineer. In a sense, the two authors "failed to connect". Half a century was to pass before Alfred Marshall (who was unaware either of Rossi or of Dupuit) combined market theory and the concept of consumer surplus in his model of partial equilibrium, and yet another before Edward Chamberlin and Joan Robinson were to expound a genuine theory of imperfect competition.⁶³ By then, Rossi had vanished from memory. Not so Dupuit: the neoclassical tradition had built around him, as around Cournot, the myth of the unsung hero. That myth lives on to this day, as though, by their own particular genius, these

⁶² On Dupuit's bumpy relationship with the *Journal des économistes*, see F. Etner (1983). On this point, we ought to clear up the common confusion between the "cases" of Cournot and Dupuit. Cournot was not a member of the Société d'Economie Politique and never contributed to the *Journal des économistes*. His first economics work (1838) was published before the journal was created (1842); his second (1863) was criticised in the journal for its anti-liberal positions. Dupuit, on the other hand, was one of the original members of the S.E.P., in which he espoused ultra-liberal positions. While his theory of utility was not adopted by the profession, neither was it rejected out of hand; after all, Joseph Garnier, as we mentioned, offered him a voice in the *Journal des économistes*.

⁶³ Marshall (1920), Robinson (1933), Chamberlin (1933).

great "precursors" were destined to break free from the ordinary history of thought.

4. From maintaining roads to measuring utility: Dupuit's substitution calculus (1842-1844)

*Bernard Grall*⁶⁴

TWO years before his famous paper of 1844, Jules Dupuit (1804-1866) published an article of some one hundred pages in which he summarised his thinking on the management of road maintenance (Dupuit, 1842). The article dealt with the two main questions then facing road engineers: the choice of road-making technique and the choice of maintenance materials.⁶⁵ To reach a "rational" solution to both questions, Dupuit relied on a "calculus of substitution" aimed at determining the limit beyond which a technique or material becomes more "advantageous" than the alternative production resource.

Substitution calculus plays a key role in the history of the engineers' "pre-neoclassical" thought. It stems from a long tradition of machine evaluation going back to the 17th century, in which the sacrifice represented by the initial outlay for a machine was weighed against the resulting labour savings. This model was developed analytically in the 19th century by a number of engineers—from Heinrich von Thünen to

⁶⁴ This is a revised version of the paper written for the Lyon conference in October 1997 and initially published in the conference proceedings (B. Grall, 2000). It is reproduced here by permission of the *Editions du CNRS*.

Bernard Grall died accidentally in August 1997 before he could present his paper to the Lyon conference. Having followed his work for several years, and being very close to his way of thinking, I took it upon myself to see the task through. For the same reason, I agreed, at the request of the conference organisers, to revise his text for publication. I ironed out the often rather uneven style and, drawing on my close knowledge of his work, did my best to elucidate the points that I found unclear. Due to space constraints in this publication, I had to edit out the final paragraph, which established—rather too allusively, in my view—a comparison between Dupuit's approach and that of the early neoclassicals. I am currently working on the revision, with a view to publication, of the monumental thesis on the management thought of the engineers of the Ponts et Chaussées that he wrote for his economics doctorate under the direction of Pierre Dockès at the University of Lyon II and which, sadly, he was never to defend.—François Vatin, July 1998.

⁶⁵For an outline of the problems involved in building and maintaining roads, see Etnier (1981, 1984, and also 1987, pp.127-136).

Charles Ellet and Wilhelm Launhardt⁶⁶—looked upon as "precursors" of the neoclassicals. In their quest for organisational efficiency, however, all of these authors restricted themselves to cost calculations. Not until Gossen, and subsequently Jevons and Carl Menger, was something like it applied to consumer goods, measured by their "utility".

A comparison of Dupuit's 1842 and 1844 articles brings out the link between the apparently unconnected approaches of the manager-engineers (the *gestionnaires*), with their technical cost calculus, and the early neoclassicals, with their utility calculus. In the 1844 paper, Dupuit attempts to shed light on the question of consumer choice by applying the engineers' cost calculation method that he had used in his article of 1842. An analysis of this earlier article will give us a better understanding of how the management calculus of the engineer, in the person of Dupuit, foreshadowed the marginalist calculus of the neoclassical economists.

1. Road maintenance management and the spending formula

The road-making technique that Dupuit analyses is the McAdam process, which had been introduced into France in the 1830s. According to this novel road-management doctrine, one could achieve a good road surface using poor-quality materials thanks to regular maintenance, carried out by parish road gangs whose job it was to sweep the thoroughfare daily and replace any worn materials. For the engineers who introduced it into France, *le système de MacAdam* allowed for a profitable substitution of materials and labour, as the saving made on the first would offset the extra wage expenditure incurred by daily sweeping.

Dupuit contests this argument, although without rejecting the new technique. In his view, the reduction of the cost in materials, which the accountants had effectively observed when macadamisation was introduced, does not necessarily imply a real diminution in the consumption of materials. The apparent cost reduction may manifest itself through a reduction in the thickness of the road surface, a loss in "capital" which does not appear in the ledgers of the purchasing department (Dupuit, 1842, pp.31-33). According to Dupuit, the advantage of the technique

⁶⁶ It is also touched on, albeit somewhat incidentally, in the work of Émile Cheysson and Clément Colson.

lies not in any net gain in the yield obtained from the material, but in the opportunity it provides to separate the "physical" expenditure—the road surface wear—from the "monetary" expenditure as measured by the highway budget. By profiting from the full thickness of the road surface, one can keep it viable with a budget that would be inadequate to maintain it in a constant state. What Dupuit is proposing is a dynamic, financial conception of management, in place of the static conception founded on comparative spending.⁶⁷ He claims that no engineer had previously succeeded in correctly evaluating the maintenance costs, as they had all failed to differentiate between construction work and maintenance.⁶⁸

For Dupuit, then, any comparison between road-making techniques must be based on the actual consumption of materials and not on an accountant's-eye view of materials procurement. Maintaining a road involves "feeding" its wear and tear. Any evaluation of the real expenditure must therefore be based on a measurement of the effective road wear. Following a line of reasoning inherited from experimental mechanics, he begins by listing the variables which might come into play in road wear, in order to rule out those whose effect he estimates to be negligible (climate, road orientation, width, gradient), until he is left with just four: frequentation, quality of materials, unit price of materials, and the roadmen's rates of pay. From these he derives the following "spending formula": $D = F q.p$;where D (for *dépense*) is the expenditure per kilome-

⁶⁷ For Dupuit, there was another advantage in the MacAdam process. In this method, the road gang's tasks were limited to sweeping a stretch of road and then spreading some new material over it. As their physical actions were regular, this meant that maintenance could be rationalised. He insists on the difference between "maintenance" proper, which involves "feeding" new materials into the road, and the "repair" work that characterised earlier techniques. Unlike maintenance, repairs are irregular operations not amenable to rationalisation. To this extent, Dupuit's 1842 paper signals the emergence of the new "manager-engineer" in place of the "builder-engineer".

⁶⁸ Maintenance (*entretien*) involves "feeding" the consumption, or wear, of the road in order to keep it in working order; construction work (*travaux d'art*) involves modifying the thickness, profile or structure of the road (1842, pp.2-4). If this maintenance logic were effectively implemented, it would obviate the need to amortize the road capital, as it would maintain the infrastructure in permanent good repair.

tre; F is the frequentation in hundreds of tons;⁶⁹ q is the quantity of used (i.e. worn) materials, and p is the unit price of the "used materials".

The maintenance expenditure appears then to be proportional to frequentation,⁷⁰ the quantity of materials worn down at constant frequentation (the inverse function of their "quality" or resistance to wear)⁷¹ and the price of these materials. The cost of labour is built into the formula: as each batch of materials has to undergo the same sweeping and resurfacing operations, it can be assigned a constant labour cost. The "price of the used materials"—the " p " of the formula—is therefore the unit purchase price of the materials plus a unit labour cost assumed to be proportional to the volume of used materials (Dupuit, 1842, pp.59-63).

2. Management choices and boundary calculations

As we saw, the road engineer has two essential choices to make: on the road-making technique, and on the maintenance material. These two choices are in principle indeterminate, as in both cases the optimum de-

⁶⁹ Strictly speaking, frequentation should be measured by weighing vehicles. In fact, the measure used is the number of *colliers* (harnesses, i.e. draught animals), which indirectly determines the tonnage carried.

⁷⁰ According to Dupuit, when the frequentation of a road doubles, so does the road wear, thus doubling the volume of materials to be swept and replaced, along with the quantity of labour required to perform this task. Expenditure is therefore directly proportional to frequentation. He realises that maintenance work on the roadside verge is independent of frequentation, but considers it negligible compared to the maintenance work on the road itself (1842, pp.46-47).

⁷¹ The materials used by road engineers were very diverse, due to the sheer size of the road network and the diversity of supply sources. However, whether they used slate, shale or limestone, the objective was the same: to withstand wear caused by friction from the wheels of vehicles. They accordingly devised a way of measuring the quality of the materials in terms of the quantity of used material per hundred tons and per kilometre of road. The lower the figure, the better the quality of the material. By multiplying this figure by the frequentation, one obtained the total wear per kilometre (1842, pp.47-49). The "value" of materials, as defined by Dupuit, is of the same nature as the "quality" of land as defined by Thünen (Huriot, 1994, pp.28-29). The engineers applied this notion of equivalence to other production resources: coal, foodstuffs, animals, and workers. The notion of "equivalence" as a system of valuation derived from the principle of substitution is a key point of contact between the neoclassical theory of value and 19th-century engineering thought.

depends on the frequentation and on the price of the materials, which will vary from one road to another.⁷² Let us take them separately.

The debate among the engineers about the right road-making technique centred mainly on the relations of substitution between the three key budget items: initial outlay, maintenance materials, and roadmen's wages. Each maintenance technique is characterised by its own budget structure. Paved roads, for example, are more expensive to build than metalled roads, but they cost less to maintain.⁷³ Using fictional data, Dupuit shows how the engineer can choose between these alternative techniques using an economic threshold model. To this end, he calculates, for each level of frequentation, the total spending for each alternative, summing the maintenance expenses and adding capital interest at 5% on the initial outlay. In the example below, 300 *colliers* is the "frequentation threshold" at which "the economic advantage of the paved road" starts to be felt (Dupuit, 1842, p.64).⁷⁴

⁷² Another choice facing the road engineer is how best to allocate spending between labour and materials. According to Dupuit, the decision almost always works out to the advantage of labour, as the consequence of a reduction in spending is asymmetrical. A shortfall in materials will not jeopardise the undertaking in the short term, as there is a "trade-off" in the form of a reduction in the thickness of the road surface. If, on the other hand, there is not enough labour, then the used materials will not be properly removed and the road will rapidly deteriorate (1842, pp.16-21). The example is an interesting one in that it relies on the concept of "normal maintenance", corresponding to the optimal allocation of spending as between materials and labour. In alluding to an optimal ratio that varies as a function of road frequentation and available materials, Dupuit embarks on a line of reasoning that ultimately leads to the notion of the production function.

⁷³ The rationalisation of road management between the 17th and 19th centuries resulted in an increasing tendency to replace spending on initial outlay with spending on maintenance. The transition is most clearly visible in the gradual move away from the classical "Roman road" model of a *belle route*, built to last forever, to the metalled road surfaced only with cobblestones.

⁷⁴ With an initial outlay of Fr 63,000 per kilometre for paved roads and Fr 30,000 for metalled roads, and with maintenance costs, respectively, of Fr 100 and 500 per kilometre and per hundred *colliers* (1842, p.64).

Frequentation in <i>colliers</i> (n° of draught animals)	Annual spending on metalled roads	Annual spending on paved roads
100	800	1 600
200	1 300	1 700
300	1 800	1 800
400	2 300	1 900
500	2 800	2 000

This method reproduces point for point the classical model used by engineers since the 17th century to evaluate production assets, notably the machines that they purchased or invented. The acquisition of a machine, for example a flour mill, reduces the labour cost involved in milling each ton of grain, but represents an investment cost unrelated to the quantity produced.

As with paved and metalled roads, the "point of substitution"—where the machine takes over from of human labour—corresponds to the level of production at which that substitution becomes "profitable".

This model of machine evaluation implicitly contains within it the reasoning that leads to the neoclassical notion of "opportunity cost". In the case of a machine, the opportunity cost concept defines its "real" cost by the utility that would have been produced by the alternative production resource. For the engineer comparing two machines that produce the same quantity, the utility of the machine lies not in its output but in what the other machine would have cost. This decision model is central to the engineers' thinking. It crops up repeatedly in all kinds of evaluations, be they for machines, technical systems or, as we shall see, the "utility of public works". It is also in evidence in the choice of supply sources for road-making materials.

To source the materials for a stretch of road, the engineer has to choose between several quarries located in different places. He must therefore "determine the boundaries between which each type of material must be used", which involves dividing up the road to be maintained into separate "supply sections" (Dupuit, 1842, p.53). But he must also take into account the quality and cost of the materials. For any given point on the road, Dupuit's formula can be used to compare the cost of sourcing materials from each quarry. To use Dupuit's own example, we

have two materials: the first costs 8.50 francs per cubic metre, and wears at a rate of 50 cubic metres per kilometre and per hundred *colliers*, while the second costs 4.50 francs per cubic metre and wears at a rate of 100 cubic metres. Transport costs excluded, maintenance with the higher-quality material therefore comes out as 50×8.50 francs, i.e. 425 francs per kilometre, while using the lower-quality material costs $100 \times 4.5 = 450$ francs.⁷⁵

From any given supply point, the road gangs have to carry the materials to one of the points of use spaced out uniformly along the entire length of the road. The cost of the materials therefore varies as "one moves further away from certain quarries and closer to others". The point that marks a material's boundary of use is the point at which the cost price for the two available materials is equal. In 1871, the civil engineer Jules Le Moyne used the graph method to solve the problem. This was taken up some twenty years later by Émile Cheysson (Cheysson, 1892).⁷⁶ All of these studies adopt a "marginalist" reasoning, although the concept of marginal cost was not clearly defined. The concept is in fact implicitly present in the thinking of the road engineers: the cost prices that they balanced out in order to determine the supply boundaries were, after all, those of the last cubic metres of material used at the most distant points from the two competing sources.

This boundary point model, outlined by Dupuit and taken up by his successors, is central to the pre-neoclassical literature. Heinrich von Thünen (1783-1850) used it to determine concentric rings of agricultural activity by finding the point of equilibrium between the costs of alternative crops on the last plots of land in each ring.⁷⁷ At about the same time

⁷⁵ Frequentation is not a criterion here, as its effect on wear is proportional, whatever material is used.

⁷⁶ See also Carrau (1890), who proposes an algebraic method based on defining section boundaries as points of equality between marginal costs expressed in algebraic form. Émile Cheysson (1892) explicitly adopts Carrau's algebraic analysis, but solves the problem in geometric form. He actually adds nothing new relative to Le Moyne, but does not acknowledge him. E. Cheysson had already presented his model in a lecture on 21 September 1886 under the title *La statistique géométrique. Méthode pour la solution des problèmes commerciaux et industriels*. On this subject, see Hébert (1974).

⁷⁷ The methods of resolution employed by Thünen and by the French civil engineers are identical, but their respective models are based on different assumptions. In Thünen, consumption is concentrated in the town, and production is dispersed, while in the road-making supply model, the supply points cater to a dispersed pattern of consumption. Moreover, in Thünen's model, the cost of transport between the loci of

as Le Moyne, in the 1870s, Wilhelm Launhardt (1832-1918) put into graph form what Thünen, like Dupuit, had expressed in tables.⁷⁸ In his 1849 paper on tariffs, Dupuit also used the boundary point notion to determine the market area for railway lines, following a method of calculation applied previously, and more formally, by the North American engineer Charles Ellet, who had spent some time at the Ecole des Ponts et Chaussées.⁷⁹

The supply boundaries are therefore "points of substitution" of the same kind as those that apply to machines. In the machine model, the limit of use is determined by the quantity produced (or in the case of road-making techniques, by the frequentation). In the spatial model, spending varies as a function of distance. The substitution limit is therefore expressed in spatial terms. However, the choice of supply source depends no longer on the total cost but on the marginal cost. In the machine model, the introduction of a new machine, or the purchase of paving stones, affects production as a whole; the choice is made by comparing the total costs for the two options. In the spatial model, on the other

production and consumption is borne by the producer, whereas in the road engineers' model, it is borne by the consumer. In the first case, with its single selling price, a spatial rent develops to the benefit of the producers. In the second case, the spatial rent benefits the consumer. Finally, Thünen's agricultural production space is two-dimensional, whereas the road is a one-dimensional competitive space, as in the models of spatial duopoly put forward in Hotelling (1929) and Palander (1935).

⁷⁸ On the links between Thünen and Launhardt, see Blaug (1985, pp.735-737). On the model for the location of population centres and lines of communication, see Pinto (1977). We have found most of the methods and results discussed by Blaug and Pinto (boundary points applied to railway market areas; Weber's triangle; the hexagonal structure of conurbations and lines of communication) in the writings of French civil engineers pre-dating Launhardt (see B. Grall's thesis, F.V.).

⁷⁹ See Dupuit (1849a, pp.226-227, 239-240) and, for a presentation, Ekelund and Shieh (1985, pp.483-486); see also Calsoyas (1950), Ekelund and Hooks (1972) and Ekelund's article (1987) in Palgrave. Closely associated with the French engineers, Ellet had been authorised in 1830, at the request of Lafayette, to take courses at the Ecole des Ponts et Chaussées (Dupuit had graduated in 1826). In 1839, one year after Cournot, he derived a demand curve from a spatial model, in which the boundary of the market that determines the quantity is defined as the point of equilibrium between the marginal costs of two alternative means of transport. Like Dupuit, he states the rule for the maximisation of the monopolist's net proceeds. He also applies the graph method to determining market areas for price discrimination, which he demonstrates to be in the general interest. Ellet is the only engineer, along with Dupuit, to take such a firm stance in favour of price discrimination, and to support it with theoretical reasoning. The two authors probably read each other's work.

hand, the space to be supplied is shared between two sources of provision. It is therefore no longer the total cost but the marginal cost which defines the point of substitution. It was this same model that, in 1844, enabled Dupuit to construct his utility curve.

3. From road maintenance to the utility of public works

From a biographical point of view, it is hard to conceive of the 1844 article on the measurement of utility independently from the 1842 article on road maintenance. The 1842 paper is the culmination of more than fifteen years' experience of road maintenance and experimental research into road wear.⁸⁰ The 1844 paper marks the start of a series of articles in the field of economics proper. The earlier paper should therefore offer some insight into Jules Dupuit's journey from road management to political economy.

On the evaluation of public works, the 1842 article stops where the one from 1844 begins. The former is in effect a plea in favour of maintenance spending, for which the argument is based on just the sort of measurement of road utility that Dupuit would present in 1844.⁸¹ The strategic objective of the 1842 paper was to press for an increase in the

⁸⁰ Dupuit started his first experiments on road wear in 1833, five years after graduating from the *École des Ponts et Chaussées*. In 1837, he published *Expériences et essais sur le tirage des voitures*. At the request of the commission in charge of overhauling the road transport regulations, he was summoned to Paris in 1839 to conduct a series of experiments on road wear. In 1842, he published two papers: one on road maintenance in general (the one we have discussed), and another on the drag effect on carriages caused by wheel friction on the road surface. For a biography of Dupuit, see Mahyer (1866) and also Etner (1983), who demonstrates the important part that road management and transport policy played in his life.

⁸¹ The similarity of construction between the 1842 and 1844 texts is striking. The first is in two parts. The first part, "*Examen des résultats économiques des divers systèmes d'entretien*" (1842, pp. 1-45), sets out Dupuit's general conception of maintenance. Only in the second part does he deal with the "particular object of the article", namely, the "evaluation of spending on normal road maintenance" (*ibid.*, pp.45-79). The object of the 1844 article is the measurement of the utility of public works. This is not addressed until the second part, after a first section (1844, pp.332-341) discussing utility from a general standpoint. Both articles conclude with a mathematical annex in which the results are formalised, in algebraic form in 1842, and graphic form in 1844.

roads budget from the administration of the day.⁸² Dupuit justifies high maintenance costs by demonstrating that they allow for a far greater saving in haulage costs: clipping back the government's road maintenance budget—a mere 25 million francs a year—when the costs to the haulage industry represent 475 million is a false economy for the nation (Dupuit, 1842, p.75).⁸³

Using the old machine evaluation method, Dupuit calculates the utility of the maintenance service in terms of reduced transport costs: if a 5-million-franc increase in the roads budget brings about a 1/10 reduction in transport costs, then "the net profit for society will exceed 40 millions". In 1842 then, Dupuit had already defined, under the label "net profit" (*bénéfice net*), the concept of "relative utility" that he was to develop in 1844. But this utility calculus remains, in his view, insufficient: one could still envisage a new transport system that would be more expensive and yet would bring greater "gains". It is, he feels, towards just such improvements that the administration must strive, following the example of those transport companies which "realised that [...] by increasing their costs in order to satisfy the tastes and needs of the public with a faster and more regular service, they would increase their own profits" (1842, p.74-75). Unlike the transporters, however, the state does not sell its production. And so when a public service comes up with a

⁸² There is something paradoxical here, in that Dupuit was, in his own colleagues' eyes, a stalwart liberal—as evidenced by his call for road regulations that would accord total liberty to hauliers. Of course, the paradox is only an apparent one, as both propositions were based on the same observation: whether one restricts haulage weights to keep the roads in good condition, or reduces maintenance spending at the price of less well-kept roads, it comes to the same thing: a small saving for the maintenance budget in return for a substantial increase in transport costs.

⁸³ Dupuit, unlike J.-B. Say (1826), does not cast doubt on the competence of his civil engineering colleagues (cf. Dupuit, 1854e). For Dupuit, the system of public funding does not allow for the optimal allocation of resources. "Had such fees [toll fees, B.G.] existed, and had the proceeds been allocated to maintaining the roads on which they were levied, then they would naturally have been far better apportioned (...). Perhaps the effect of this circumstance on England's roads has not been sufficiently noted; it certainly has the immense advantage for road maintenance of constantly balancing the resources in proportion to the needs" (Dupuit, 1842, p.72). From this perspective, Dupuit again differs from Say, who advocates public funding, arguing that tolls would reduce the frequentation, and therefore the utility, of the roads. The solution proposed by Dupuit is tariff discrimination, in order to levy taxes without diminishing traffic (cf. Grall and Vatin, 1997). Once again, the 1842 article is incomplete in this respect; the answer is to be found in the article of 1844.

"new" asset (such as more effective, but also more expensive, transport system), one needs a way of measuring the resulting "utility" in order to assess the case for new spending. The 1842 argument therefore calls for a measurement of road utility, which Dupuit will try to establish in 1844.

In his 1844 article, Dupuit starts out from the utility assessment method outlined in 1842.⁸⁴ He does not, however, quote his own text but rather from J.-B. Say's *Traité*, which contains a similar measure of road utility.⁸⁵ As he demonstrates—by borrowing the following example from his former applied mechanics teacher, Claude-Louis Navier (1785-1836) (Dupuit, 1844, pp.346-349)—the calculation becomes erroneous when the frequentation increases. A road with a frequentation of F tons is to be replaced by a canal. The new canal will bring down the cost of transport, which will lead to an increase in traffic q . For the initial F tons, the gain derived from the canal effectively corresponds to the difference in transport costs between the canal and the road, in keeping with the machine evaluation model. But the same is not true for the q incremental units, as consumers were not willing to pay the cost of their transport by road. By bringing the "law of demand" into play, Dupuit demonstrates the diminishing utility of the extra tonnage. One can therefore no longer use the reduction in transport costs to measure the utility that the canal derives from the q extra tons.⁸⁶

Dupuit proceeds to demonstrate that substitution calculus can be used to evaluate the utility of the goods transported, if one transposes it onto the choice made by the consumer. To this end, he picks an example much like that of the provision of materials for road maintenance: namely, the supply of building stone to a town (Dupuit, 1844, p.349-354). With the new canal, the cost price of the transported stone will diminish. For the town, the drop in transport costs will make it profitable to source stone from new—more distant, but also more productive—quarries. One can therefore no longer use the difference in transport costs alone to evaluate the utility of the canal; one must measure the total difference in the unit supply cost. At this point Dupuit introduces

⁸⁴ This point, and Dupuit's calculus as described in the following five paragraphs, are discussed at greater length in Grall-Vatin (1997, pp.17-20).

⁸⁵ Dupuit (1844, pp.346-347). The quotation is from J.-B. Say (1841/1972, p.508).

⁸⁶ Dupuit's example is taken from Navier's article (1835, pp.134-135). Although Dupuit does not pick up on the fact, J.-B. Say (1818) makes the same error as Navier when he evaluates the utility of planned canals.

the boundary-point rule on which his calculation of supply areas was based: "We might suppose that the stone could come from still further afield; so long as, via the canal, it comes to less than 20 francs [corresponding to the production cost for road-borne stone, B.G.], it will replace the old stone" (*ibid.*, p. 351).⁸⁷

If the price of stone falls due to the canal, stone consumption rises for two reasons. The first is that the stone will satisfy needs that were previously met by some other material less expensive than the road-borne stone. Dupuit gives the example of the substitution of metalled roads by paved roads, which he had discussed in his 1842 paper: "[Stone] will replace brick and wood; hitherto unpaved roads will be paved, etc." (*ibid.*, p.352). If one knows the substitutions performed by the buyers, one can work out the utility of the canal from a comparison of spending. For example, where brick has been replaced by stone, the utility added by the canal is calculated not, as before, by comparing the production costs for stone, as it were, pre- and post-canal, but rather by comparing the total cost of the stone transported by canal with the total cost of the brick transported by road. What we have here—interiorised by the consumer—is the substitution calculus of the engineer choosing between different materials. But the canal can also carry goods that will satisfy needs that were previously not met at all. Such products, because they do not substitute for anything else, have no "representative in the old pattern of consumption" (Dupuit, 1844, p.354). In this case, the utility cannot be measured by comparing spending. The only solution is directly to measure the "maximum price" that the user is willing to pay for the transportation of each quantum of goods.

Dupuit rounds off his reasoning by demonstrating that that measurement of utility by cost savings is always an approximate affair, and that only rigorous method is that of the maximum acceptable price. As with any machine, the canal is never going to be a perfect substitute for the road: "[...] it is rare for any change in manufacturing that reduces costs not also to affect the quality of the product; the result will be better

⁸⁷ This example of materials provision, of great significance for Dupuit the engineer, is used again in the 1849 paper (1849a, pp.196-202), which contains another spatial application of the boundary-point method.

or worse, bigger or smaller, lighter or heavier, faster or slower, etc., etc." (Dupuit, 1842, p.362).⁸⁸

With this affirmation, Dupuit breaks with the traditional economic calculus of the engineers (from Navier to Thünen and Launhardt), which always comes down to a comparison of objectively measurable costs. For Dupuit, such a comparison is unsatisfactory in that one cannot conceive of any objective equivalence between the goods produced. The only possible equivalence is at the subjective level: the utility interiorised by the consumer. And here Dupuit foreshadows the rift between classical and neoclassical economics.⁸⁹

CONCLUSION

The limited objective of this paper has been to describe how the standard engineering device of substitution calculus contributed to the development of Dupuit's theory of utility. The substitution calculus model, we maintain, is a necessary condition for Dupuit's theoretical invention, but is not sufficient to explain it. To understand the genesis of Dupuit's theory of utility, one must take a wider look at the relationships between industrial mechanics—the discipline in which Dupuit was

⁸⁸ The quotation from Dupuit should be compared with this passage from J.-B. Say: "The close pursuit of this inquiry through all the arts of industry would show, that the advantage of machinery is not limited to the bare substitution of it for human labour, but that, in fact, it gives a positive new product, inasmuch as it gives a degree of perfection before unknown" (1841/1972, p.86; 1855, I.VII.21).

⁸⁹ In this respect, the comparison with Cournot (1863) is revealing. Cournot can conceive of quantifiable economic equivalents for producer goods only, based on their productivity, whereas for Dupuit this objective equivalence is no more rigorous for producer goods than it is for consumer goods. Writing in 1849 about equivalence between materials, he states: "How can limestone and granite be reduced to a common denominator? Only the public is able to assess such a variable degree of utility..." (1849a, p.205). While equivalences based on physical productivity, as was the case for the quality of materials, are not only conceivable but necessary for *gestionnaires* such as road engineers, they are of little interest to the economist of 1844. In fact, Cournot could also conceive of equivalences for workers' consumer goods, based on their objective properties for the "reproduction of the labour force", as Marx would put it. Only for luxury goods would any equivalence be impossible (cf. Vatin, 1998). Bernard Grall is nonetheless right to insist on the essential theoretical difference between Cournot, who never conceived of the possibility of measuring utility, and Dupuit, for whom it was the central idea (F.V).

trained—and French political economy of the day, notably as embodied in J.-B. Say and Rossi.⁹⁰

But looking beyond the "case of Jules Dupuit", substitution calculus is a central part of the manager-engineers' legacy to neoclassical economics. Starting out from the gain/loss model of machine evaluation, it leads to the notion of boundaries that characterises the marginalist calculus, which, along with maximisation, is one of the neoclassicals' two primary tools. And it is precisely in the resolution of management problems such as those posed by road maintenance that the calculus has its roots. The history of the economic calculus of the 19th-century *gestionnaires*—be they road engineers like Dupuit, or agronomists like Thünen—offers us a vital insight into the emergence of neoclassical thought.⁹¹

⁹⁰ Cf. Grall & Vatin (1997). On the relationship between Dupuit and Say, see also Ekelund & Hébert (1976).

⁹¹ My work is largely unconnected to that of Mirowski (1989). I seek to shed light on a method of calculation used by engineers and economists alike, but without erecting analogies or metaphorical cross-references between the two fields of knowledge. Moreover, I am interested in industrial mechanics, intrinsically linked to production and machinery, whereas Mirowski is interested in theoretical physics.

5. Dupuit on domestic water supply and pricing

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INTRODUCTION

The aim of this article is to present, by putting them back into context, Jules Dupuit's ideas on the pricing of town water supplies to individual consumers*. We do so by analysing a chapter of his *Traité théorique et pratique de la conduite et de la distribution des eaux*¹, first published in 1854—while Dupuit was head of the municipal engineering department in Paris—and reprinted in 1865.² In this chapter, Dupuit, as the civil engineer that he was, assesses the various domestic water distribution techniques available at the time and lays down the basis for a system of "rational" tariffs for this service, quite unlike the systems then in place in France.

We proceed in two steps. Before presenting and commenting on Dupuit's economic thinking as applied to water distribution, we offer the reader a succinct overview of the "water question" in France in the first half of the 19th century, in order to situate Dupuit's contribution in its historical context. A particular focus is placed on Toulouse, a pioneering city in the field of water supply in the 1830s and 40s, whose example regularly crops up in the work of Dupuit the engineer. We conclude with a look at the paradoxical legacy of Dupuit's recommendations.

* Our thanks are extended to Jean-Pascal Simonin and François Vatin for their comments on an earlier version of this text.

¹*A Theoretical and Practical Treatise on the Supply and Distribution of Water.*

² Dupuit (1854b, 1865c). The chapter examined here (Chapter 4 in the 1865 edition, "Du mode de distribution des eaux aux particuliers. Du prix de vente") is also reproduced in a compilation of Dupuit's writings in economics (Dupuit, 1933, p.192-203). The quotations and references in this article refer to the 1865 edition.

1. THE WATER QUESTION IN FRANCE, 1800-1850³

1.1. Growing needs

From 1800 to 1850, France underwent a period of intensive urbanisation. The phenomenon affected not only Paris, which was consistently the main engine of urbanisation, and the major provincial cities, but also medium-sized and even small towns. The censuses of 1801 and 1851 confirm that in the space of half a century, the capital doubled its population from 547,000 to 1,053,000.⁴ Sizeable increases also affected the country's other urban centres: Lyon went from 110,000 to 177,000 inhabitants, Marseille from 111,000 to 195,000, Toulouse from 50,000 to 93,000, and Bordeaux, although bringing up the rear, nonetheless saw its population mushroom from 91,000 to 131,000 inhabitants (William B. Cohen, 1998, p.19). The wider data point in the same direction: between 1806 and 1851, the number of townships (*communes*) with more than 5,000 inhabitants grew from 4,158 to 6,774 (M. Roncayolo, 1983/1998, p.58).

The growth in the urban population led to increased water requirements for French towns; water was needed not only for the consumption (cooking and drinking) of a growing number of households, but also to stave off epidemics kindled—according to the hygiene experts of the time—by the masses of migrants huddled in the back yards, attics and cellars of the old urban centres or relegated to the suburbs (Georges Vigarello, 1985/1987; Alain Corbin, 1982/1986; Lion Murard and Patrick Zylberman, 1996). The poorer areas were certainly worse hit by epidemics (most notably the cholera outbreak of 1832, which caused 102,000 deaths in France); these were attributed to lack of light and poor water supply, leading municipal authorities to put questions of water and sanitation at the top of the agenda. And so, as urbanisation forged ahead, there was an increasing clamour for well-swept streets and well-washed bodies.

No mean task. At the beginning of the 19th century, water was a rare commodity in French towns. In 1806, the municipality of Bordeaux

³ On the situation in other countries, see the various contributions in Denis Smith (ed.) (1999), a work which abounds with references.

⁴ These (rounded) figures are taken from Alfred Fierro (1996, p.279).

distributed a daily ration of 3.5 litres per inhabitant⁵ through its public fountains, a quantity which was not raised until the 1840s. Saint-Etienne had only one public fountain at the start of the century, and just three in 1827. Lyon, though far better equipped—at the end of the 18th century there were already 90 public fountains—was scarcely better off: in the early 1830s, its fountains delivered barely 1.33 litres per inhabitant (Cohen, 1998, pp.150-151). Despite its capital city status, Paris was also poorly supplied in water at the dawn of the 19th century. In 1799, the city could only boast some sixty fountains, which were cut off at night; indeed most of them operated only during certain hours of the day (Laure Beaumont-Maillet, 1991, p.125). In 1807 the daily water volume supplied by the city was in the order of 7 to 7.5 litres per inhabitant.⁶

Admittedly, public fountains were not the only sources of urban water supply. Public or private wells,⁷ often contaminated—the common habit of "slopping out" meant that the groundwater nearer the surface was full of all kinds of detritus—cisterns,⁸ or simply pails of water straight from the (often polluted) river, for those towns fortunate enough to be built near a water-course, all helped to supplement the meagre quantities of water that could be pumped from the fountains. We are short of accurate figures on the volumes thus consumed, but the gravity of the situation is clear: town water, available in low quantities, and often mediocre in quality, if not downright unfit for consumption, carried disease and was a cause of frequent "inconvenience" (a precise explanation for the underlying mechanisms was not available until Pasteur's discoveries in the 2nd half of the 19th century).

⁵ By way of comparison: per capita water consumption in France is now in the order of 150 litres a day.

⁶ Philippe Cebon de Lisle (1991, p.99). According to the civil engineer Bruyère, in 1802, average per capita consumption in Paris was no more than five litres a day (André Guillerme, 1984, p.32).

⁷ The only solid data that we have for Paris relates to the year 1870. That year, making provision for the forthcoming siege, the city's water department conducted a census of all the wells in Paris: it found 30,000, very nearly one for each apartment block, of which 10,000 were still in service (L. Beaumont-Maillet, 1991, p.15; Ph. Cebon de Lisle, 1991, p.100). At the end of the 18th century, there were some 2,000 wells in Lyon (W.B. Cohen, 1998, p.150).

⁸ Of which there were 200 in Lyon at the end of the 18th century (W.B. Cohen, 1998, p.150).

The yawning gap between the growing awareness of the beneficial effects of water, even of its determining role in the urban fabric, and the concrete situation facing France's towns did, certainly, stir people into action. But the action, as the figures show, remained relatively limited. The process of installing "modern" water supply infrastructures (the networks that still exist today) was a slow one: by 1892 fewer than half of French towns had a modern network capable of delivering water to homes, and out of 4.5 million town-dwellers, only a privileged few—127,318, to be exact—were effectively connected up to the network (Jean Pierre Goubert, 1986, pp.19 and 198). Be that as it may: even if the first half of the 19th century saw more planning than plumbing, the importance of the projects should not be underestimated. The period 1800-1850 can be seen one of a slow and difficult move away from deeply ingrained patterns of thinking, a period of learning and of the progressive mastery of technical and economic innovations, a process which was to bear fruit only later.

Over the same period, urban growth was compounded by another factor driving water needs ever higher: changes in social norms. During the first half of the 19th century, water consumption forecasts by engineers and medics grew almost exponentially. At the beginning of the century, a quantity of 7 to 10 litres per person per day was deemed sufficient for domestic use. But scientists and public representatives, with an eye to Britain, that pioneer of water supply, progressively adjusted the minimum requirement upwards to 20 litres per person per day, the figure that was generally accepted until 1850. Gradually, non-drinking needs, neglected under the First Empire, began to be taken into account. A municipal decree in Paris in 1846 estimated at about 100 litres a day the water requirement for uses other than strictly household consumption: 75 litres per head of cattle or draught animal, 3 per square metre of vegetable garden, 20 to wash a carriage and 1.5 litres per inhabitant to wash the streets (Guillerme, 1984, p.32; Goubert, 1986, p.51). Between 1800 and 1850, the estimated needs therefore grew considerably (and the trend towards ever higher consumption forecasts was to become yet more accentuated with time).

But where were these vast quantities of water to be drawn from? How were they to be carried to the city, and distributed? And one question remains—not technical, but nonetheless decisive—who was to pay for the work and manage the installations?

1.2. Capturing, raising and distributing water

One solution for supplying a town was to draw spring water. Under the Restoration, the artesian well technique stirred up great enthusiasm, soon to be followed by equally widespread disenchantment.⁹ But above all there was the rivers, from which most French towns could draw the great quantities of water they required. Up until the mid-19th century, river water, considered to be "light" because it was better aerated, enjoyed an excellent reputation among many engineers and scientists, not least Dupuit himself.

And, as if to dispel any misgivings about the natural purity of river water, a number of innovations in water purification technology emerged, with great timeliness, over the same period of 1800-1850. Before the Revolution, river water was filtered through sand and gravel; at the dawn of the 19th century other procedures came on the scene, such as the use of powdered carbon (of animal or vegetable origin). Various combinations of filters were soon developed. In 1806, the first water clarification plant was set up on the Quai des Célestins in Paris, equipped with filters made up of a layer of gravel, a thick layer of carbon mixed with fine sand, and another layer of gravel. We find the same process in use in provincial towns in the 1820s. Subsequent research led to the use of alum (potassium aluminium sulphate) to improve the settling process. Around 1848, yet another method employed filters made of tightly compressed wool. None of these "artificial" filters ever really took the place of natural filtering, which, with its minimal handling and labour requirements, always enjoyed the backing of the engineers (Goubert, 1986, pp.52-54; Guillerme, 1984, pp.36-37; Cebon de Lisle, 1991, pp.221-226).

Always supposing that water was found in sufficient quantity—and in sufficient quality to satisfy the new hygiene standards—the town authorities still faced the task of conveying it to the highest point in the area so that it could be distributed by means of a gravitational system. Once all hope had been given up of finding adequate quantities with artesian wells, only two solutions remained, though not mutually exclusive: bringing the water in from a distance by canal to a high point near the town, or using energy to raise water from the river (if there was one).

The aqueduct, that crowning glory of Roman engineering, could carry a large quantity of water over great distances to the distribution

⁹ On artesian wells, see Goubert, 1986, pp.54-56. For the particular case of Paris: L. Beaumont-Maillet, 1991, pp.157-165; Ph. Cebon de Lisle, 1991, pp.187-189.

reservoirs. Paris had proved as much with the Ourcq canal (1803-1822); other cities, such as Lyon in 1823, gave it serious thought, but were daunted by the expense. Harnessing the power of steam to raise the water had all the allure of new technology but was not without its critics. Noisy, often dangerous, the steam engine was not universally welcome: local residents were extremely wary and many mayors preferred to adopt a cautious wait-and-see approach. Worse, steam engines guzzled quantities of coal, still a rare commodity in France around 1830, were not particularly energy-efficient, and required costly maintenance to prevent breakdowns that could cut off the water supply for days on end. Other ideas for raising the water involved using hydraulic machines such as wheels or turbines to tap the hydraulic energy of rivers.¹⁰ Nor should one forget those traditional sources of energy—horses and men—who often raised water through muscle power alone, by turning pumps or Archimedean screws (Guillerme, 1984, pp.37-40).

Once the water has been captured, and conveyed or raised to the high points of the town, it still needs to be distributed. Two modes of distribution emerged during the Restoration. The first, a legacy from the Ancien Régime, is now, as they say, history; the second, a radical innovation for the time, is now standard practice (at least in the developed world).

The older mode of distribution consisted of channelling the raised water directly to a number of specific distribution points, such as district centres equipped with public fountains. This was done by means of independent pipelines, so independent in fact that they didn't form a system, let alone a network. The second mode, the direct ancestor of our current system, was based on a network logic. "In the new system (...) a main pipe (...) follows, as far as possible, the mid-line of the borough to be supplied; onto this pipe we connect other, secondary, conduits which serve the most important and populous streets. These conduits are accompanied by what we call service pipes, which run parallel to them or which branch off into other streets where there are no other conduits. They thus form a network which encompasses every street in the district" (Raymond Genieys, 1829, p.xii). In this system, the streets of the town are served by interconnected pipes that form a hierarchical network and which, from one or more reservoirs on the heights of the town, dis-

¹⁰ On this point, see the captivating history of the hydraulic ram (Joseph Montgolfier, 1808).

tribute water not only to numerous public installations (monumental fountains, street fountains, fire hydrants, watering pipes, etc.) but also—and this was the key innovation—to *homes*. This point calls for further discussion.

Domestic water distribution already existed under the Ancien Régime. But under the "line" system of distribution of the time, only a few privileged houses, directly connected to the nearest water tower, actually benefited from it, under concessions dating back to the 17th or 18th century. What about the others? To meet their needs, most town-dwellers had two options: either they relied on the water carriers¹¹ who sold water that they collected, in principle, from authorised distribution points designated by the public authorities,¹² or they picked up their pails and went off to fetch the water themselves (those who could afford them would send their servants) from those places where the precious liquid could be had for free (public fountains, the river, etc.) (Julia Csergo, 1988).

The "network logic" represented a paradigm shift. As the network was designed to cover the entire town, the idea of universal (subscription-based) domestic distribution began to take hold among French engineers, drawing inspiration once again from the British model. A number of observation missions sent to Britain in the 1830s culminated in reports on "the art of distributing water to the home".¹³ But although the idea of a universal service based on supply agreements was strongly supported, for reasons of hygiene, from the 1830s onward, the network still—and for a long time to come—had to take account of the older modes of distribution (water carriers and fountains of various kinds, especially street fountains intended for the poorer classes).¹⁴

¹¹ On water carriers in Paris, see Beaumont-Maillet, 1991, pp.207-219; Cebron de Lisle, 1991, p.105-109; Julia Csergo, 1988, pp.213-215.

¹² In Paris, water carriers of both kinds—*à bretelle*, who bore yokes on their shoulders, or *à tonneau*, who transported water in barrels—were entitled to fill up free of charge at certain points along the Seine. The yoke bearers also had free access to public fountains. There were also a number of commercial fountains (set up by individuals or by the municipality, and fitted with filters) where they could buy water for resale to individual customers.

¹³ See, for example, Charles F. Mallet, 1830.

¹⁴ There were still some water carriers in Paris as late as 1880 (L. Beaumont-Maillet, 1991, p.219). In 1873, Paris still had 556 street fountains and 224 push-button fountains (Ph. Cebron de Lisle, 1991, p.387).

Indeed, throughout the first half of the 19th century, the number of customers receiving water in their homes remained very low. House owners (for only they were allowed to enter into supply agreements), unlike the engineers and hygiene experts, were slow in coming forward, for a number of cost-related reasons: the size of the installation costs (to lay down the branch pipe connecting the building to the mains); the fear of damage to their property in the event of a leak; and the inevitably greater frequency with which the cesspool would have to be drained (central sewage disposal didn't make its Paris *début* until the end of the 19th century). These costly operations were all performed at the customer's expense.¹⁵ As a result, the number of customers rose only very slowly from 1800 to 1850. In 1831, for example, there were only 921 Parisian supply agreements, which means that a mere 0.1 % of the population had water delivered to their domicile (if they were lucky; more often it arrived in the courtyard of their apartment building) and even then, this figure includes very few actual households, as the great majority of contracts were for ministries, convents and a handful of businesses and industries (Julia Csergo, 1990, pp.137-38). Domestic water distribution only really made inroads in the second half of the 19th century, and even then in a socially divisive way, with landlords taking pains to ensure that their tenants in the poorer districts were excluded (Guerrand, 1985/1997; Csergo, 1990). In 1854, the year Dupuit's treatise was first published, only 6,229 apartment buildings in Paris—barely more than one in five—were signed up to the water utility.¹⁶ And the situation in provincial towns was even less favourable to this mode of distribution.¹⁷

There may have been few customers until the 1850s, but there were already several types of service to choose from. Water could be

¹⁵ On house-owners' reticence about, even resistance to, water and sanitation network development in Paris (especially in poorer areas), see Roger-Henri Guerrand, 1985/1997 and Gérard Jacquemet, 1979.

¹⁶ In 1854, a total of 7,633 subscriptions were registered, consisting of: 6,229 households, 1,165 miscellaneous industries, 137 bathing establishments, and 102 wash-houses (Beaumont-Maillet, 1991, p.168, and Cebon de Lisle, 1991, p.202). In Paris, subscriptions took off after 1850. 1860: 14,289; 1865: 28,963; 1869: 37,688; 1880: 46,887; 1890: 75,238; 1900: 91,388 (Cebon de Lisle, pp.392 and 612).

¹⁷ At the end of the 1850s in Lyon, only 200 houses out of a total of 10 000 had a domestic water supply. In Lyon and Bordeaux, only one third of buildings were connected to the water network in the 1880s (compared with 58% for Paris in 1882) (Cohen, 1998, p.157).

supplied according to a number of different modes. The *discontinuous* or *intermittent* mode, widely used in Britain, involved supplying all the houses in a street every day for a *limited* time, long enough to fill the tanks. To this end, water department officials known as "turncocks", or in France as *fontainiers*, opened and closed the stopcocks that supplied each street. This system never really took off in France, where the preferred mode was *constant supply*, for which there were two kinds of supply agreement: *à la jauge* (gauge) or *à robinet libre* (on-tap). With a gauge contract, a diaphragm (popularly referred to as a *lentille*) was placed in the customer's branch pipe in order to limit the twenty-four hour supply to an agreed volume. But for a long time the most popular type of agreement was the unlimited *robinet libre*, for which the price was determined by a consumption estimate that took into account a range of criteria (number of taps, people, animals, steam engines, surface area of land to be watered, etc). In 1878, the *robinet libre* system covered 60% of Parisian customers, against 38% for the gauge system (metering, introduced in 1876, and accounted for the rest).¹⁸

1.3. Municipal or private utility?

The final key element of the context in which Dupuit wrote his treatise is the controversy over the public or private nature of the organisation in charge of distributing the water. During the first half of the 19th century, a lively debate pitted the proponents of municipal management of the water service against the advocates of the British model of private concessions. This is not to say that the public-private antagonism precluded the possibility of shared ground between the two sides. The pro-municipal lobby, for example, was in favour of charging for a domestic water distribution service (the very high costs of laying down the network made such a mode of finance a "natural" option). The opposition between the two camps seems to have centred on two main issues: providing free access for the poorer classes (by maintaining the system of public fountains), and meeting the municipality's own water needs (for washing streets or supplying markets, prisons, care institutions

¹⁸Csergo, 1990, pp.145-46. The first water meters in Paris were installed on an optional basis in 1876, at a time when water was becoming scarce, as people (gradually) moved away from river water, "full of dirt and deadly germs", preferring spring water, which, though "clean, pure, and life-sustaining" was also available in limited quantities only (ibid., p.143). By the end of the century, the old gauge and *robinet libre* agreements had practically disappeared, in Paris at least, in favour of metered supplies.

and other public buildings). The advocates of municipal management feared that a system of private concessions would eventually lead to the disappearance of free access and to severe restrictions on the municipality's ability to pursue an active and generous water policy.¹⁹

Opposition was not just theoretical. Already in the 1820s a number of private utilities had been incorporated in France (Jean Gay, 1986, pp.28-32), although it was not until 1853 that France's first large capitalist undertaking was launched with the specific aim of turning urban water distribution into a profitable business. This enterprise—the *Compagnie Générale des Eaux*, initial capital 20 million francs—was awarded a contract first with Lyon, and then with Nantes (1854). In 1860, it set up in Paris:²⁰ the municipality, which retained control over building and

¹⁹ Henry-Charles Emmerly de Sept-Fontaines (1789-1842), state civil engineer, and director of the Paris water and sewerage department from 1832 to 1839, was a stout opponent of all projects to concede the capital's water supply to private concerns, along British lines. Welcoming the "definitive" breakdown of concession negotiations, and thus the continued municipal management of the Paris water system, Emmerly enumerated with great clarity just what it was that the proponents of municipal management so feared: "Here, by contrast [with the British system], we do not levy a charge proportional to rent, a charge levied in perpetuum (...) on every house for the cleaning of the sewers; here it is the Town which institutes a perpetual municipal service to wash with fresh water, three times daily and without charge, all the drains and gutters of all its public thoroughfares. Here we do not have a speculator indiscriminately inflicting charges on each and every consumer, closing all the free fountains to the poor, making it impossible for the Town to have monumental fountains or to consume water on a significant scale, and showing at best indifference to industry, unless, that is, he exploits the suffering therein by means of a monopoly. Here, it is above all the Town which administers for the well-being and greater prosperity of its citizens, not recoiling before the substantial supplies required by markets, prisons, barracks, and hospitals (...) and which intends to remain the sole regulator and sole arbiter of the needs of industry, in order to foster its progress on behalf of all the concessions [in this context, *concessions* referred to the customers] and, if necessary, to oversee any sacrifices required in the greater interest of the City (...)" (cited in Ph. Cebron de Lisle, 1991, p.182).

²⁰ Paris was a prime target for private companies interested in the water utility concession from 1800 to 1850. Talks were held over ten years, from 1814 to 1824, between the town authorities and Lees Brothers, a British company. In the 1830s, a number of (equally unsuccessful) attempts were made to put the service out to tender. (Cebron de Lisle, 1991, pp.164-171 and 180-183; Beaumont-Maillet, 1991, pp.152-153). Back in 1778, the Périer brothers, mechanical engineers, had obtained the royal assent to set up the *Compagnie des Eaux de Paris*, with capital of 1,440,000 livres (1,200 shares at 1,200 livres each), its purpose being to "establish and build, at [its own] expense, pumps and fire-machines capable of raising the water of the Seine (...) for distribution to water carriers, to streets and to houses, at a price to be determined by private agreement". But

maintenance work on the main network, effectively farmed out the commercial services (laying down domestic connections, collecting customer payments, etc).²¹

1.4. Toulouse

Toulouse was something of a pioneer in terms of water supply in the France of the 1830s and 40s:²² it was one of the first towns to provide its inhabitants with clean and pleasant water. The novelist Stendhal himself hailed the accomplishment in these terms: "The water of Toulouse not only has that supreme goodness of the water that one drinks in Rome, but also shares its light and agreeable fragrance" (Stendhal, 1992, p.619). The story began on the eve of the Revolution. A legacy of 50,000 livres left by a former magistrate, Charles de Lagane, who died in 1789, gave the impetus to the first water projects, which were decided by the town council in 1817. Toulouse was to be supplied with 80 litres per head of population per day (20 for domestic use, the rest for washing streets and drains, filling decorative fountains, and fighting fires), a standard far in advance of those prevailing in France's other major centres at the time. After a series of heated debates, the council decided to use water from the river Garonne, raised to the required height by a system of pumps and hydraulic machinery designed and built by the mechanical engineer Abadie; the steam engine option was rejected on the grounds of expense (it was estimated at the time that they would burn 60,000 francs-worth of coal per annum). As the water taken directly from the Garonne was generally felt to be unclean or cloudy for the best part of the year, three natural filters were installed in the 1820s.

the company was short-lived, lasting barely ten years. The Périer brothers' fire-machines outlived their inventors: they were still in regular service in the 1850s (Goubert, 1986, pp.174-177; Cebon de Lisle, 1991, pp.93-99; Beaumont-Maillet, 1991, pp.95-109).

²¹ On the Compagnie Générale des Eaux, see Goubert, 1986, pp.177-183 and Cebon de Lisle, 1991, pp.406-419. Its suburban counterpart the Compagnie des Eaux de la Banlieue de Paris was founded in 1867, and the Société Lyonnaise des Eaux et de l'Eclairage in 1880 (Stéphane Duroy, 1996, p.9).

²² The following information is taken from Jean-François d'Aubuisson de Voisins (1838). D'Aubuisson (1769-1841), an Ecoles des Mines alumnus and senior member of the Corps des Ponts et Chaussées, played an active role in laying down the water supply network for Toulouse and wrote a number of treatises on pipe hydraulics. In the first edition of his own treatise, Jules Dupuit reproduced excerpts from d'Aubuisson's paper on filters (Dupuit 1854b, II, pp.119-129). On d'Aubuisson, see André Thépot, 1998.

After being clarified and raised, water was distributed at 111 different points around the town (monumental fountains, street fountains, etc.). No house within the town walls was more than 200 meters from a free distribution point. Of the 4,000 cubic metres raised and distributed by the town every twenty-four hours, 300 were reserved for delivery to individual paying customers. The mode of distribution employed was the gauge-limited constant supply, with the following system of rates: for a daytime "*concession*" (as the supply agreement was termed), 20 francs per annum for a daily delivery of 100 litres (minimum quantity: 200 litres, minimum length of agreement: 6 years); for a night-time concession (where water would be made available only at night), 10 francs (minimum quantity: 1,500 litres; minimum length of agreement: 6 years). There were also monthly concessions, mainly intended for bathing establishments: with duration of just one or two months, the minimum supply was 5,000 litres and the charge 1 franc per month for 100 litres a day. By decision of the town council in 1826, "all water not taken up by the concessions (...) shall be conveyed and poured out on the public thoroughfare, i.e. in the squares and streets of the town" (d'Aubuisson, 1838, p.314).

The cost of the project, spread over several years (ending on 1st January 1839), came to 1,083,648 francs, accounted for as follows: 506,904 for the plant required to clarify and raise 4,000 cubic metres a day; 474,733 for the town supply and distribution work; 102,011 for the monumental fountains.

What was the annual cost of maintaining the Toulouse water system? Astonishingly little, according to its lead architect, d'Aubuisson: an average of 4,873 francs per annum, to which were added 4,000 francs in personnel costs (one water engineer, three turncocks, the water tower keeper, and one watchman). A total of 8,873 francs a year, in large part covered by the proceeds of sales to paying customers, which amounted to 7,400 francs. In the 1830s, few *Toulousains* chose the domestic supply option, for the very good reason, as d'Aubuisson tells us, that the network of public fountains provided excellent coverage: "our administration (...) was untainted by fiscal motives, or by any thought of speculating on its water. It acted in the opposite direction, to the detriment of its own financial interests, multiplying almost to excess the various water outlets dotted around the town: it deprived itself of the means to sell its water, and therefore sold little. At the outset, the owners of the grander houses almost without exception expressed the desire to have water de-

livered to their home; measures were duly taken to satisfy this demand. But when they saw that they had fresh and abundant water flowing almost at their door, and that they could meet all their needs without incurring the trouble or expense of a private supply, they changed their minds.²³ The administration, far from being vexed by this turn of events, congratulates itself on having served the public so well, and, which was its primary purpose, on having served the inhabitants of all classes in keeping with their aspirations: it merely expresses the wish that the proceeds from private agreements might eventually suffice to meet the expense of maintaining the fountains, and the administrative costs"(d'Aubuisson, 1838, p.314-315).²⁴

2. COMMENTARY ON DUPUIT'S TEXT

2.1. Summary of Dupuit's analysis

Having set the scene, the time has come to examine Dupuit's recommendations on the distribution and sale of water to individual customers, as set out in Chapter 4 of his *Traité* (1865, pp.119-127).²⁵ In this chapter, Dupuit develops the following four-part argument:

(i) He begins by rejecting, on several grounds, the intermittent (or discontinuous) mode of distribution, to a cistern in the customer's house. Firstly, intermittent supply leads to significant wastage: whether the cistern is empty or full, "the tap pours the same quantity of water into it

²³ Significantly, it was the consumers who could have done most to finance a domestic supply who had the least need of it, since they had servants to do the job for them. There is an analysis to be made here of how the persistence of the "service society" from the Ancien Régime acted as a brake on development. Contrary to the received wisdom, it also shows that technical and social innovation can "trickle up" from the less affluent classes and not merely down from the wealthy ones. Another example that springs to mind is public education. (Thanks to François Vatin for that observation).

²⁴ The same situation is found in another French town at the vanguard of water supply, namely Dijon in the 1850s, which distributed between 198 and 678 litres per inhabitant per day (depending on the season) (Dupuit 1854a, p.3). The plethora of public fountains built by the municipality had a direct impact on the number of private customers: a mere 84 (17 on the gauge system and 67 on an unlimited supply, for a total revenue of 8,155 francs) in the mid-1850s, for a town with some 2,500 houses. See Henry Darcy, 1856, p.508-512.

²⁵ For an overview of all of Dupuit's analyses relating to water, see Dupuit's own entry under "Eau" in the *Dictionnaire de l'économie politique* (Dupuit, 1854c, pp.629-637).

every day" with the result that "much of the water runs through the overflow pipe and is lost". To avoid this wastage, customers' cisterns would need to be fitted with ballcocks (along the lines of those used in modern toilet-flush systems), "but the purchase and maintenance of such devices would represent an expense that would prove difficult to impose upon the customer" (ibid.), especially coming on top of the cost of installing the actual cistern. Secondly, the private cisterns were lined with lead to prevent leaks, "and yet it has been proven that water stored in open lead receptacles becomes a highly-active poison by the dissolution of the metal" (p.120). Finally, "opening and closing the stop cocks (...) requires a large staff of turncocks. To limit the expense, these stop cocks are placed only at road junctions". The service pipes, at least in secondary streets, were therefore not kept continuously under pressure, with the notable result that "when a fire breaks out, the customer, and those who come to his rescue, have available to them only the insignificant quantity of water stored in their cisterns: someone must go running to find the turncock to obtain the key to the stop cock, so as to restore pressure to the pipe; by the time this is done, the house has often burnt down" (ibid.). This was a further indirect cost, for the collectivity, inherent in the intermittent system.

(ii) Dupuit therefore advocates the constant supply system, in which all the pipes are under pressure at all times. In the constant supply system, as we saw earlier, the quantity of water to which the customer is entitled can either be limited (the "*à la jauge*" service) or unlimited (the "*à robinet libre*" service). Dupuit rejects the first formula, which involves installing a diaphragm in the customer's connection to restrict the daily throughput to the contractual quantity. For Dupuit, this system offers customers "almost all the disadvantages of the intermittent system" by forcing them to have cisterns. Take the example, he says, "of a daily concession of 15 hectolitres, that of most Parisian houses. If the customer had no cistern, he would obtain from the tap only about one litre per minute; it would take him a quarter of an hour to fill a pail of water" (p.121). (A flow rate of one litre per minute corresponds to 1,440 litres per 24 hours—almost exactly the 15 hectolitres of the private "concession" in the example.) Furthermore, "in towns where several families live in one house, the gauging system forces them into an uneasy solidarity, unless there are as many gauge cocks and cisterns as there are tenants" (ibid.). Finally, he adds, the tariff system associated with the gauge (a regular payment of x francs for a daily supply of n hectolitres, i.e. a con-

tract in which the price varies on the sole basis of the quantity of water actually contracted for) is economically disadvantageous not for only the customer, but also for the local authority or enterprise that supplies the water. For Dupuit, both parties would be better off if the service agreement were differentiated on the basis of the utility each customer derives from the service. To support his case, he points to the example of Toulouse's water supply policy and, without going over it again, his own earlier work on the measurement of utility.²⁶ The economic arguments he puts forward make up the core of the text, and constitute Dupuit's own original contribution to the debate; we will take a more detailed look at them later.

(iii) Considering that "the aim that we must set ourselves in organising the distribution of water, is to make good use of all such water as is available, and to compensate the provider for his initial outlay" (p.124), Dupuit holds that the gauge system must be abandoned. The practice of selling water at a price "fixed by the quantity" stipulated in the supply agreement leads to the inefficient rationing of consumption. "Water should be sold by discretionary agreement, for a price proportional to the utility that the customer derives from it" (p.125). We return to this proposal—a direct application of Dupuit's utility theory—in greater detail at the end of the next section.

(iv) The text concludes, on the one hand, with the claim that free public fountains represent competition for private supply agreements; and, on the other, with this comment, in which Dupuit's unearths a bone of contention with some of his engineering colleagues: "the only objection I have to this system [water supply through public fountains] is the state of illusion in which dwell certain of its proponents, who believe it has the advantage of supplying water free of charge. The only way the State or town authorities can provide something free of charge is by charging more for other services" (p.126).²⁷

²⁶ Cf. notably Dupuit, 1844, 1849a and 1853.

²⁷ The said colleagues defended the principle of the free provision of water to the inhabitants by the municipality, primarily in the name of the "unfortunate classes" (*les classes malheureuses*).

Emmery, for example, made the public street fountain a key element of his policy to assist the poor (from 124 in 1823, the number of street fountains rose to 1,020 in 1839. See Ph. Cebron de Lisle, 1991, p.200), claiming that "Washing the streets is useful, certainly; but only ask the men of our profession, only read the many reports of the health commissions, and they will tell you that it is more important by far to wash the

2.2. The economic foundations of Dupuit's analysis

Utility

Dupuit's analysis of the water question stems from his own economic theory of utility. Utility measures the benefit that individuals derive from consuming a given good or service. But how should that utility in itself be defined?

alleyways of buildings, the small and poorly ventilated courtyards, the water cabinets that are commonly situated there, the ground floor; and they will add that we must, above all, give the unfortunate classes the opportunity freely to multiply their acts of hygiene, be it by washing their feet, their bodies, their private parts, or the undergarments of which they possess so little in proportion to each individual (...). Such is the immense service provided by free use of the street fountains (...)" (Emmery, cited in Ph. Cebron de Lisle, 1991, p.181).

Dupuit's remark seems to be intended also for Henry Darcy (1803-1858), the civil engineer who, as Chief Engineer of the Burgundian *département* of Côte-d'Or, supervised the water supply project in Dijon in the 1840s. Seeking to account for the low number of paying customers in Dijon, he wrote: "The primary cause results from the very principle that guided the distribution of water in Dijon, an eminently liberal principle, eminently favourable to the poorer classes, and one *which must be preserved at any cost*. Their water must not be counted, any more than their air and light is counted. It is, let me add, in their interest that the city tolls levy no duty on corn, and water is no less useful than corn; the supply of water should not be taxed for those whose material life is already so arduous (...). I therefore believe that we must maintain free and unhindered access to street fountains (...)" (H. Darcy, 1856, p.509-510; author's italics).

Darcy, without naming Dupuit directly, was clearly sensitive to the objection that "free" water was free only in name. "One may perhaps object that the city tolls must raise sufficient revenue to provide all the inhabitants, *rich and poor alike*, with the safety and cleanliness indispensable to any conurbation! No doubt. But the manner in which those tolls are levied, and on what goods, are questions which must be studied with the utmost care. In the wrong configuration, tolls will but crush an already weary class; in the right configuration, they apply to those who can, without great difficulty, afford to pay them. Once again, I am asking that we honour that principle which has always prevented the taxation of corn" (H. Darcy, 1856, p.510; author's italics).

We should remember that Dupuit was opposed to the principle of road tolls, as practiced in Britain. The issue, of course, was not whether the service would be free or not—it was always going to be paid for in some degree by the collectivity—but whether it was practical to implement a system of differential pricing. This approach, in Dupuit's view, had the advantage of appearing to be free (by enabling the poor to have access to goods or services) without the disadvantage of not taking money from those who would be willing to pay. Such a system was, he thought, possible for water and for engineering structures, but not for ordinary roads. (Thanks to François Vatin for that observation).

Dupuit²⁸ summed up his answer in the rather glib formula: "there is no utility other than that for which people are willing to pay" (Dupuit, 1844, p.355). The meaning of his maxim was spelt out earlier in that article: "political economy must measure an object's utility by the maximum sacrifice that the consumer would be willing to make in order to obtain it"(idem, p.343). In modern terms, one would say that the utility that an individual derives from the consumption of a given quantity of a given good is measured by their *willingness to pay* for that quantity of the good.²⁹

It is this analytical work that Dupuit applies "as is" to the pricing of domestic water supplies. He proceeds in two stages, firstly demonstrating how the "single rate" can lead to a loss of utility, and then recommending the use of a "differential price" or "graduated tariff" proportional to the utility that individuals derive from water consumption. In so doing, he sees things from the standpoint of the public authorities. Whenever they intervene in the production of a particular good—whether directly, as the producer, or indirectly, as the regulator (when setting tariffs, for example)—the public authorities (state, local councils) are, according to Dupuit, duty bound to create the conditions for obtaining the greatest possible social utility, thereby minimising "lost utility".

The problem with the single rate

Dupuit starts by pointing out the contradiction that arises between the interest of the producer (to maximise revenue) and the "public interest" (to maximise utility) when a service is sold at a rate that varies only on the basis of quantity.

"Suppose that [in a town with an established water distribution system, after a proportion of the available water has been employed] for public use, fountains, washing streets, flushing drains, for wash-houses, drinking troughs, etc., 2,000 cubic metres remain for private consumers. How is one to determine the tariff that will extract the maximum possible benefit from this quantity of water? Suppose that we set a single rate, say 50 francs [per annum] for one cubic metre [per day]; clearly at this

²⁸ Dupuit's theory of utility is expounded mainly in his articles of 1844, 1849 and 1853, cited above.

²⁹ For a brief outline of Dupuit's utility theory, see Olivier Coutard, 1997, p.42-48. For an in-depth presentation of the theory and an analysis of Dupuit's position in the economic debate of his day, and of his real contribution, see Grall and Vatin, 1997 (a revised version is reproduced in this volume.)

price a certain quantity of water will be sold, say 1,000 cubic metres, producing a revenue of Fr 50,000; but 1,000 cubic metres will remain unsold, and will be lost to the provider and to the public. If, to gain greater benefit, one lowers the price to 40 francs, and 1,200 cubic metres of water are sold, the revenue is now only 48,000 francs; the company, as we see, loses 2,000 francs (...). And yet it is evident that the state of affairs created by the second tariff is far more advantageous than the first. The 1,000 customers who now pay 40 francs instead of 50 have clearly gained 10 francs each, for a total of 10,000 francs, and the 200 new customers, who choose to have the water at 40 francs but did without it at 50 francs, have clearly gained, in some cases 9 francs, in others 8, [in yet others 7, 6... or 1 franc] for an average of 5 francs; the public profit can thus be evaluated at 11,000 francs, ample compensation for the loss of 2,000 francs sustained by the company" (pp. 122-123).

And he goes on: "These principles are confirmed by what happened in Toulouse. The selling price of water was fixed at 20 francs per hectolitre, whereas the cost price was (...) only Fr 1.50 (60,000 francs for 40,000 hectolitres); at this price, the town made 7,400 francs from private supplies, in other words it sold 320 hectolitres,³⁰ less than one hundredth part of the water raised. This is, by any account, a complete failure in fiscal or commercial terms. (...) Selling something for 20 francs in Toulouse which it is hard enough to sell for 5 in Paris, the city of wealth and luxury, was no way to overcome the difficulty. Even so, the 20-franc tariff evidently found a certain number of takers; a tariff of 15 francs would clearly have found more, while 10 francs, and 5 francs, etc., would have found still more. And what did the town of Toulouse do with the unsold water? That question is answered by the council decision of July 26th, 1826: 'All water not taken up by the concessions in accordance with Section 1 (at 20 francs per hectolitre) shall be conveyed and poured out on the public thoroughfare, i.e. in the squares and streets of the town.' Thus, we have on the one hand, water that cost only Fr 1.50 per hectolitre, and on the other, people who would be willing to pay 15 francs, 10 francs, 5 francs, for it, and rather than give it to them, the town prefers to pour it out onto the street? How can such a refusal be

³⁰ Dupuit uses the values cited by d'Aubuisson (1838), rounded off. There are inconsistencies in the figures Dupuit reports (a tariff of 20 francs per hectolitre, and revenue of 7,400 francs from 320 hectolitres); clearly, at 20 francs per hectolitre, 320 hectolitres should bring in 6,400 francs (conversely, 7,400 francs would imply the sale of 370 hectolitres). This inconsistency is corrected in the Bernardi edition.

justified? To those who say that at such low prices too much water would be sold, and not enough remain for public uses, I would reply that one should never hesitate to sell for 5, 10, 15 francs that which cost but Fr 1.50, as with such profits production can easily be increased if needed. To those who say that lower prices would have increased consumption, but diminished the proceeds, I would reply, firstly, that such an eventuality is unlikely, and secondly, that with an intelligently graduated tariff, it is impossible" (pp. 123-124).

The main drawback of a flat rate is therefore that by "increasing consumption", and thereby utility, it might "diminish the proceeds", which would conflict with the interests of the company. Dupuit's fictional example in the first excerpt above is a case in point: if, after the company cut its rate from 50 francs per cubic metre to 40, consumption rose from 1,000 to 1,300 cubic metres (instead of the 1,200 in Dupuit's example), then the contradiction between growth in utility and growth in the company's earnings would vanish, as its revenue would rise from 50,000 to 52,000 francs! But if we work on the assumption that the company adjusts its (single) selling price so as to maximise its revenue, then by definition, any decrease (or, for that matter, any increase) in the price will diminish its revenue. This maximum revenue may or may not be sufficient to meet, for example, all the annual production costs (investment and maintenance) or to provide fair remuneration for the company that operates the service. It is in this last eventuality (of "lost utility" resulting from a slump in water sales and a shortfall in the company's revenue)³¹ that price discrimination (Dupuit's "intelligently graduated tariff") comes into its own.

The virtues of price discrimination

To reiterate Dupuit's proposition: "the aim that we must set ourselves in organising the distribution of water, is to make good use of all such water as is available, and to compensate the provider for his initial outlay" (p.124). Only then will there be no "lost utility". It is important to realise that this proposition contains a major assumption, namely that the cost price for water distribution is low compared to the utility that the great majority of consumers derive from the water. In the example

³¹ This eventuality arises when the local characteristics of supply (a function of cost) and demand (the distribution of utility) for water are such that the maximal flat rate at which the entire production could be sold would still generate insufficient revenue.

he cites of Toulouse, the cost of distributing each hectolitre is Fr 1.50, and Dupuit assumes that, at that price, all the available water would be sold.³² The question therefore does not arise as to whether, to make good use of all the available water, the company would be authorised, if necessary, to sell at below cost price. Incidentally, he assumes that public water needs are fixed (2,000 cubic metres in the Toulouse example), which is certainly debatable, although not central to his reasoning.³³ The expression "compensate the provider" is also sufficiently vague for Dupuit to elude the question as to whether the utility operator should simply break even or actually make a profit, and if so, how much. Finally, Dupuit assumes that water resources are unlimited, the reason being that while many engineers at that time advocated using spring water, Dupuit felt that the networks could be supplied with the far more abundant river water.³⁴

To "make good use" of all the available water, Dupuit maintains, on the basis of his own earlier work on price discrimination, that "water should be sold by discretionary agreement, for a price proportional to

³²Which is not to say that the company would necessarily break even.

³³ It does, however, overlook the good use that could be made of unsold water by the town authorities.

³⁴ This was one of the big issues of the day, and was the cause of a professional setback for Dupuit. He advocated using the waters of the Seine (captured upstream of Paris and filtered) to supply the capital, in opposition to the view of Baron Haussmann who, as Prefect of the Seine département, presided over the destiny of the capital from 1853 to 1870 and who favoured deviating water from springs further away. Dupuit based his position on the conclusions of a commission of medics and chemists who published an *Annuaire des eaux de la France* in 1851. In his treatise, Dupuit reproduces the commission's findings: "Despite the several causes which combine to despoil the water of the Seine both upstream and downstream of Paris, it must nonetheless be regarded as among the best waters of which we are aware" (cited in Dupuit, 1865, p.21-22). This disagreement led to Dupuit's departure from the Paris technical engineering department, as is attested by this excerpt from Haussmann's memoirs: "A serious disagreement soon arose between Monsieur Dupuit and myself. The engineer was imbued with the then widespread prejudice that the water of the Seine was the best source of drinking water for the population of Paris. (...) When I expressed my preference for harnessing spring water from afar, rather than the water of the Seine (...), I encountered from Mr Dupuit that same resistance which I had fought patiently, step by step, for eight long years, in the scientific and lay worlds, and amongst officialdom, but which I could not for one instant tolerate from the Director of the Municipal Service" (Haussmann, 1893/2000, p.858; see also pp.977-78). Dupuit was far from alone in advocating the use of water from the Seine; see for example Arthur Mangin, 1861 or Aristide Dumont, 1862.

the utility that the customer derives from it". The two key elements of this proposition invite closer analysis.

Firstly, the quantity of water available to each customer should not be limited. This point is based on Dupuit's analysis of the intermittent service or gauging of supplies. But it also stems from a twofold hypothesis implicit in Dupuit's reasoning. On the one hand, he assumes that unrationed demand is solvable: if customers are left to decide freely on their own consumption, this will never reach a level that could not be profitably satisfied by the operator: "discretionary supply could lead to water consumption outstripping the available quantity. If such were the case, it would only prove that the supply is inadequate (...) and that it needs to be supplemented" (p.125). On the other, Dupuit assumes that water production costs are almost independent from the quantity produced (at least within the capacity limits of the plant corresponding to a given investment).

The second key aspect of Dupuit's proposition is that the price of water should be based on its utility to the consumer rather than on the quantity consumed (p.125-126). It was easy enough for Dupuit to justify his argument with the simple observation that at the time of writing, "there are no meters for measuring water" (p.121): it was effectively difficult to charge for water on the basis of the quantity consumed when, in the absence of metering, there was no way of knowing what that quantity was! But that was not the core reason why Dupuit rejected the principle of a price proportional to quantity. The reasoning he applies is set out earlier in the treatise: "In ordinary trade we are used to seeing goods sold for a price proportional to their quantity. For example, 2 or 3 hectolitres of wine cost two or three times as much as one hectolitre. It was therefore believed that we should apply the same principle to the sale of water, establishing a price in proportion to the quantity. This overlooked two considerations, however: 1) the difference between the cost of producing certain goods and that of producing other goods: in some cases, these costs are proportional to the quantity produced; in others, they are almost unrelated [as we saw, Dupuit placed water in the latter category]; and 2) the fact that, as the sale of water is ordinarily a monopoly, the price is not subject to the law of competition, and one can therefore raise or lower it at will in order to attain a particular result" (p.122). For Dupuit, the first consideration makes it desirable to sell water at a price that reflects its utility for the customer; the second makes it feasible.

The difficulty of assessing utility

This raises the question of how one evaluates the utility on which the price is to be based. If we assume all consumers to be "conscientious" (sincere and disinterested), then the problem is solved: "Let us imagine that all the house-owners in the town conscientiously declare the maximum price that they would be willing to pay for a discretionary supply. By establishing the tariff for each customer on the basis of his response, the provider would obtain the full utility of the product and the maximum possible revenue; a revenue which could far exceed the due recompense of his sacrifices. But if, instead of obtaining the entire sum declared by the house-owner, one obtains only a fraction, a quarter, a third, or a half, or however much is required to bring the revenue into proportion with the initial outlay, then it is evident that there will be no loss of utility; the utility will be shared out in full between the supplier and the supplied" (p.125).³⁵

The notion of conscientious individuals is clearly an unrealistic hypothesis. In practice, if one were to proceed in this manner, the prospective customers would have a strong incentive (i.e. low water bills) to under-declare the real value of the utility. Some other method therefore needs to be found to evaluate the utility derived from a domestic water supply. There are, however, a number of factors that influence this utility: "It is clear that the sacrifice that a house-owner is willing to make for a water supply will depend on the number and wealth of the occupants, on the nature of their occupation, and on the difficulty they otherwise have in obtaining water" (p.126). Two of these factors are of particular concern to Dupuit in his treatise: the proximity of public fountains providing free water, and household income. On the first, as we saw earlier, he cites d'Aubuisson when he links the failure of water marketing in Toulouse to the large number of public fountains installed there. On the second, he states that "in certain towns of England, the water rates, being adjusted on the price of house rents, naturally descend to a level within reach of those who could not afford large sacrifices (...)" (p.126). Dupuit's analysis leads him to come out in favour of the British system of discretionary supply, with tariffs based on rateable value, in preference to the French system, in which the most widespread arrangement is also

³⁵ B. Grall and F. Vatin (1997) analyse this reasoning, so characteristic of Dupuit, as a "thought experiment" in which the model of taxation acts as a "theoretical metaphor" (p.46).

a discretionary supply, but where the price is based solely on a standardised consumption level, determined by the number of taps (faucets) and occupants supplied.³⁶

CONCLUSION: PRESENT-DAY RESONANCES OF DUPUIT'S ANALYSIS

Dupuit concludes his argument with two practical questions. One, should the quantity of water made available to the customer be measured (in both senses of the word: gauged by volume and/or limited)? Two, should water be sold for a price proportional to the quantity consumed (the estimated quantity in Dupuit's day, before reliable metering; the metered quantity in our day) or proportional to household income? The debate clearly continues to have resonance, although the context has changed radically now that, in the rich world at least, domestic water supply has become the rule rather than the prerogative of a small urban elite.³⁷ The debate today centres on two questions which substantially echo Dupuit's: should consumption be measured or not? Should the price of water be made proportional to household income?

In Britain, for example, flat fees (unrelated to the quantity of water actually consumed), based on the rateable value of the property, as described by Dupuit, remain the most common arrangement: in May 1999, 82% of British households were still covered by this system. But it is

³⁶ In Paris in 1830, for example, the *robinet libre* supply was the most common, but the price was determined according to a standardised quantity of water, estimated on the basis of the size of the installation, but unrelated to the customer's actual consumption: "a fixed rate of 45 litres per occupant per day for the flow from a single tap fitted over the stone slabs of a kitchen sink, and of 33 litres per occupant per day for any additional tap situated in the water cabinet, bathroom or powder room" (J. Csergo, 1988, p.232).

It is a fair comment that the number of people in the household, and the number of taps installed, do provide some indication of the utility that the customer derives from the water supply; and that less affluent households, for example, can reduce the price of their supply by having just one tap fitted, which will automatically limit their consumption. But it is one thing to scale the *quantity* of water a household receives to its revenue, quite another to scale the *price* to that revenue—the familiar problem of those nefarious taxes, like the window tax, which were based on "external signs of wealth".

³⁷ On the arguments developed in the conclusion to this article, see Olivier Coutard, 1998, 1999, 2000.

gradually being abandoned in favour of a single-rate system, based exclusively on the volume consumed. In France, where volumetric systems have long been the norm, the question of the "social pricing"³⁸ of water has been on the public agenda for some 20 years, kept there notably by charity organisations in reaction to the growing number of households living on the poverty line (or perhaps the growing awareness of the phenomenon) and to the substantial increase in the price of water. This debate raises issues in two areas—efficiency and equity—on which Duit's analysis sheds some welcome light. Astonishing as it may seem, no government is seriously envisaging the widespread implementation (or preservation) of a tariff system in which the price of water would be proportional to household income.

Efficiency, metering and price discrimination

The flat-fee system of (unmetered) domestic water supply is, as we mentioned, gradually being abandoned in most countries in the name of efficiency: the emphasis is on encouraging the "efficient" and "sustainable" use of water resources. This approach is, however, open to criticism. First of all, in every country, most of the water is consumed by the agricultural sector, under tariff conditions which generally do little to reflect the need for sustainable management of water resources. Additionally, a number of studies have suggested that domestic water consumption is not "price-elastic", in other words, it does not really tend to diminish when the price is raised, except in the case of massive price hikes, which are usually not "sustainable" politically; this implies that water usage does not fit the canonical model of economic rationality. Finally, charging for water on the basis of the quantity consumed requires a sophisticated system of measurement (i.e. meters), billing and collection (including managing unpaid bills); the cost of this metering, billing and collection system is traditionally considered to be high relative to the cost of the actual service (the water supplied), which goes a long

³⁸ "Social pricing" refers to a tariff system in which the price of a service is adjusted (with varying degrees of refinement) to the resources of the paying beneficiary (it could also be called progressive pricing, by analogy with progressive tax). In France, social pricing applies to a number of public services (pre-school care, school canteens, etc.), but this has not traditionally been the case for network services (water, electricity, telephone); this is rather oddly justified on the grounds of equal access to public services, although it is not entirely obvious why the principle of equality should apply in one way to water supplies and in another to school dinners.

way towards explaining why, internationally and historically, household consumption metering has always been the exception rather than the rule.

If we restrict ourselves to the last two points—those that particularly concern domestic water consumption—we find that they are discussed in Dupuit's analysis. On the one hand, he observes that a discretionary supply does not seem to encourage the excessive consumption of water: "in Paris, as in London, there are thousands of discretionary customers, and as far as Paris is concerned, I can state with certainty that abuse is extremely rare" (p.125). On the other, he on several occasions cites the significant cost of metering as an argument for not introducing it, or at least for questioning its timeliness: we saw his comments on ball-cocks above (2.1(i)), and, of a meter invented by a British engineer, he wrote that "it achieved highly satisfactory results in the experiments which we performed upon it. It remains to be seen how much it will cost to maintain, how it will react to limescale, etc., etc." (note 1, p.121).

What then has changed, in the economics of water, to justify the abandonment of flat-rate charging on the grounds of efficiency? It is, essentially, the fact that water production costs are no longer, as one could safely assume in Dupuit's day, "almost unrelated" to the quantity produced. Due largely to ever stricter health and environment regulations, the cost of treating water upstream and downstream of the domestic, urban and industrial customer—a cost roughly proportional to the volume of water treated—represents a growing percentage of the total cost of water at the tap.³⁹ This is what is driving the authorities in most countries to opt for a tariff system based on the volume of water consumed, with the aim—in the current jargon—of encouraging consumer responsibility for the cost to the community of domestic water consumption.

Equity and socially differentiated tariffs

The current debate tends to preclude consideration of the solution that Dupuit would have proposed for the second aspect of this discussion, namely that the price of water should be made proportional to household income—and, through income, to the utility derived from the

³⁹ The cost of water treatment also accounts for the lion's share of the considerable increase in water prices over the last ten or so years.

water—an issue which is largely separate from the question of whether household water consumption should be metered. This proposal is condemned as heresy on the grounds of efficiency, the reason being that each cubic metre of water consumed or flushed away costs the same, whether the consumer is rich or poor. One could offer the objection that at constant price, the rich consumer will be less inclined to be parsimonious with water than the poor consumer, since the water bill represents a smaller share of his budget.⁴⁰

What is more surprising is that this proposal is not given serious consideration in terms of equity.⁴¹ The debate on equitable pricing, or on equitable access to public services, is a complex one; in France in particular, it hangs on the interpretation of the constitutional principle that all citizens are equal before the law. The basic question is simple: since these are public services (and thus considered to be essential), and since these services are provided on a market basis (the price has to reflect the cost of production), does the principle of equality then demand that the price of each service be the same for all or, on the contrary, that it take account of ability to pay? As we noted above, for certain services, such as school dinners, we in France have accepted that the principle of equality was compatible with—and perhaps even required—social pricing. For network services we have taken the opposite position. The bottom line is that, as long as bills are low (and especially if they are getting lower while household income is rising) then the question is of little importance. But when the bills start to rise, and if—to make matters worse—the income of the least affluent households starts to diminish, and water or electricity debts start to build up, then the question palpably (and politically) takes on a whole new meaning.

A certain conception of equity would demand that the price of water be correlated to a household's ability to pay. But this simple idea is

⁴⁰ This efficiency argument is distinct from the one proposed by Dupuit, for whom the (public) monopoly should differentiate the tariff on the basis of individual utility values in order to minimise the utility loss for the collectivity. Both arguments are however based on the same economic property, namely the relative indeterminacy of the cost of supplying water to any individual customer, given the existence of fixed costs common to all users. Moreover, it is these fixed costs which give water distribution the characteristics of a "natural monopoly", as Dupuit himself recognises.

⁴¹ In these concluding remarks, we use "equity" (*équité*) as a generic term, reserving "equality" (*égalité*) specifically to designate one of the dimensions of public service in the French legal tradition.

rejected by most governments, even those who have explicitly made the impact of tariff system reform on low-income groups a core concern. These governments are then led, in the name of equity, to subsidise in full or in part the fixed element of the charge, or to impose preferential tariffs for consumption below a certain threshold, which supposedly corresponds to the essential domestic water requirement. And so, instead of discriminating in favour of low-income households, they discriminate in favour of low-consumption households, which is not necessarily the same thing.

But it was not the aim of this article to offer a detailed discussion of the current debate on water pricing. We therefore conclude with the observation that the good doctor Dupuit's tariff recommendations are, paradoxically, no longer pertinent to that debate.

6. The "monautopoly" controversy:¹ Dupuit and the issue of intellectual property

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The French civil-law notion of *droit d'auteur* is frequently contrasted with the common-law notion of copyright, which is closer to the concept of patent law. In the Anglo-Saxon system, all of the assigned rights are exclusive and transferable, which, according to the theory of property rights, enables them to be more efficiently valued. The word copyright itself—the right to copy—refers explicitly to an economic function rather than any notion of authorship. Copyright is aimed at encouraging creation, in light of the difference in cost between the conception and the reproduction of an original work. It is not necessarily held by the author; it can be the property of an employer or producer. Under French law, conversely, the *droit d'auteur* does not derive directly from the economic conditions under which the work is offered to the public. It appeals instead to the idea of the author's "natural right" in his or her own work, which cannot be alienated by economic considerations of market efficiency. In particular, the author's moral right, which confers control over the future uses of the work (integrity, disclosure, even retraction, etc.), can come into conflict with economic efficiency.

The debate between these conflicting notions of rights in intellectual works—as the author's natural ownership of the work or as an efficient contract designed to foster creation—was especially virulent in France in the second half of the 19th century. This debate was part of a wider deliberation on the underpinnings of property rights, which the liberal economists defended in response to the socialists' questioning of

¹J.-B. Jobard invented the expression "monautopoly" in 1844 to describe intellectual property rights held *in perpetuum*.

² I would like to thank Arnaud Diemer, Jean Pascal Simonin and François Vatin for their helpful comments on the first drafts of this text.

the notion of property.³ It was against this backdrop that in 1861 Jules Dupuit published, in the *Journal des économistes*, a two-part article on property rights in which he argues for a Benthamite conception of copyright, contrary to most of the liberal economists of the age. The article takes the form of a critical appraisal of a book by Passy, Modeste and Paillottet (1859) in which the authors defend a Lockean position on intellectual property, of which Jobard's theory of monautopoly is the most radical illustration. Léon Walras had also reacted to the book in 1859, notably by enquiring whether intellectual property was a form of social wealth,⁴ and Proudhon's *Majorats littéraires* was again a response to Modeste et al.⁵

The purpose of this contribution is to present the main terms of the intellectual property debate as it unfolded in the pages of the *Journal des économistes* in the mid-19th century. The current relevance of the issues involved, the personality of the protagonists, and the echoes of Dupuit's position in the recent literature, are all worthy of interest today. The first section outlines the context of the debate and its main players. The second analyses how the authors' positions on property inform their positions on intellectual property rights. In the third section, we develop the arguments presented by the various parties on the question of how long the protection of the author should be maintained. We conclude with a look at the current state of play in the debate, with particular regard to Dupuit's position.

³ As a sign of how important the debate was at the time, the *Dictionnaire de l'économie politique*, published in 1853, contained a 16-page entry on invention patents, a 14-page entry on property and another, of 6 pages, on literary property.

⁴ In 1880 L. Walras (1880/1990) published another article, *De la propriété intellectuelle*, in the *Gazette de Lausanne*.

⁵In his book, Proudhon mocks the authors in these terms: "When I finally have time for some light relief, I shall treat the public to a performance of Frédéric Passy's *Propriété intellectuelle démontrée par la métaphysique* followed by Victor Modeste's *Jurisprudence absolue* and Mr Paillottet's *Voyage à l'île de Robinson*, a prose comedy in three acts, with a prologue by Mr Jules Simon" (1868, p.2). And so as not to leave out Jobard, he describes him as "(...) that old wag Jobard, whom I know well, and who believed in intellectual property as he believed in spiritism: like a true Norman, half-heartedly" (idem, pp.9-10). [French humour, even today, burdens the people of Normandy with a reputation for being pathologically non-committal—Translator].

1. THE INTELLECTUAL PROPERTY DEBATE: CONTEXT AND PROTAGONISTS

1.1 The context

The French economists' thinking on intellectual property rights is embedded in the turbulent context of the 1848 Revolution and the attack on the notion of property by the various socialist movements, notably in the writings of Proudhon⁶ and Blanc. As Schumpeter points out, "the Parisian scene was colored until 1848 by the activities, literary and other, of socialist groups to an extent for which there is no contemporaneous parallel anywhere else" (Schumpeter, 1954/1994, vol.2, p.490). In this context, the Société d'Economie Politique and the *Journal des économistes*, founded respectively in 1842 and in 1841, rapidly evolved—especially after 1848—into tribunes for the liberal economists. The great majority of contributions on intellectual property published in the journal begin, for example, with a defence of property in general.⁷ The mainstream position within the group was that property is a natural right and the role of legislation is to uphold that right. On this point, Jules Dupuit, who supported the conflicting idea of property as a legal construct, comes across clearly as an opponent: so much so, that the *Journal des économistes* took pains to distance itself from his position in a footnote to the first part of his 1861 article.⁸

⁶ Proudhon, whose first volume on property (1840) had an enormous impact, was loathed by the most of the members of the *Société d'Economie Politique*. Frédéric Passy (1859, p.397), describing him as an obscure writer and a plagiarist, recalled the outcry that followed the publication of the notorious slogan "property is theft". Proudhon was nonetheless on friendly terms with Joseph Garnier, who published a critical but courteous review of his work in the *Journal des économistes* in October 1843, and was an admirer of Rossi (cf. Sainte-Beuve, 1948, pp.268 -275).

⁷ As Charles Le Hardy de Beaulieu remarked: "A few years ago, economists were too busy defending property in general against communism and legalised theft (...) to give close attention to the quite subtle distinctions between material property and intellectual property, and between literary property and the ownership of inventions" (1862, p.74).

⁸ The footnote ran: "It is no doubt unnecessary to reiterate here that in including this paper by one of its eminent contributors, the *Journal des économistes*, as a collective organ of science, takes no responsibility for the views of the author, who has put himself forward as the advocate of a view opposed by the majority within this publication". For an overview of the various positions taken up by members of the Société d'Economie

The debate on intellectual property rights heated up still further after 1858 as a result of two events. The first was the Brussels Congress of September 1858, which brought together delegations of booksellers, publishers, writers and academics from around Europe.⁹ Several members of the Société d'Economie Politique were actively involved. The participants in this convention were concerned by the spread of international copyright infringement, especially in Belgium, and recommended that the European nations' legislation on intellectual property be harmonised. They also pressed for authors to have temporary property rights over their own work.¹⁰ This clashed with the predominant view among the liberal economists, who were still debating the issue within the Société des Économistes. The second event was the publication in 1859 of *De la propriété intellectuelle* by Passy, Modeste and Paillotet, setting out the dominant position. Its impact was significant enough for Dupuit and Léon Walras each to publish their own in-depth criticism of the work in the *Journal des économistes*.¹¹

1.2 The protagonists

Part of the interest in retracing the debate on intellectual property in the *Journal des économistes* resides in the personality of the contributors.¹² In addition to Dupuit and Léon Walras, the leading liberal economists of the hour all had their say: Frédéric Bastiat, one of the staunchest advocates of perpetual intellectual property rights, whose complete works

Politique on the issue of intellectual property, a useful source is the debate that followed the publication of Dupuit's article (S.E.P., 1862d).

⁹ The line-up included, in the British delegation, John Stuart Mill and Charles Dickens, and in the French delegation, Lamartine, Hachette, and Montalembert.

¹⁰ The convention adopted the following resolution: "The authors of literary and artistic works shall enjoy, throughout their lifetime, the exclusive right to publish and reproduce their work, and to sell, distribute or otherwise cede all or part of the property or of the reproduction rights. The surviving spouse shall conserve the same rights, likewise throughout his or her own lifetime, and the author's heirs or beneficiaries shall enjoy the same for fifty years as from the death of the author, or as from the extinguishment of the spouse's rights" (*Congress on Literary and Artistic Property*, 1858, pp.99-100).

¹¹ Dupuit's review makes no reference to the one by Walras, published two years earlier.

¹² This article does not expound on Blanc and Proudhon's positions on intellectual property rights, which they expressed elsewhere than in the *Journal des économistes*. Blanc (1850) devotes three chapters of his *Organisation du travail* to the question of literary labour. Proudhon (1868) devotes the whole of his book *Les majorats littéraires* to that theme.

were compiled by his disciple Prosper Paillotet, co-author of the work that had provoked reactions from Walras and Dupuit; Hyppolite Passy, a member of the Institut de France and former finance minister; Gustave de Molinari, a Belgian economist, professor of political economy at the Belgian Museum of Industry, who penned the entry on intellectual property in the *Dictionnaire de l'économie politique*; Joseph Garnier, professor of political economy at the Ecole des Ponts et Chaussées, and one of the most internationally renowned French liberals (to whom we owe the French edition of Malthus' Essay on Population, and who produced the manual of reference on political economy, from 1850 to 1880); and finally Louis Wolowski, member of parliament and director of the Crédit Foncier de France.

The debate also drew in professionals from the legal and publishing worlds: these included Renouard, a senior judge of appeal; Jules Simon, professor of philosophy at the Sorbonne; the publisher Louis Hachette, and the original and highly controversial Jean-Baptiste Jobard,¹³ surveyor, importer of lithography into Belgium—and father and unflagging advocate of the monautopoly.

These protagonists, in all their diversity, are representative of the Société d'Economie Politique at that time. Defenders of liberalism, engaged in political life, often journalists, they were more interested in the politics of economics than in economic analysis. In this respect, the contributions of Walras and Dupuit stand out markedly.

¹³ Joseph Garnier, expressing the general view of the Société des Économistes, said of him: "Jobard shuns the old political economy; rather than waste his time learning about it, he prefers to invent a new one", quoted under the entry for "Jobard" in the *Dictionnaire de l'économie politique* (1854, vol.2, pp.4-5). Jobard and Garnier certainly had some heated exchanges within the pages of the *Journal des économistes* on the merits of open competition with regard to inventions. In 1855, Jobard put twenty questions to Garnier on the principle of competition, to which Garnier replied item by item (Garnier, 1855a). Jobard came back at him with a second letter (Jobard, 1855). Unsatisfied with Garnier's answers, he wrote in a final letter: "He [Garnier] expostulates on the surface, while I attack the issue [of intellectual property rights] at its foundations" (*Il épilogue sur l'épiderme, et nous attaquons le sous-sol de la question*) (Garnier, 1855b, p.139).

2. FROM THE QUESTION OF PROPERTY TO THAT OF INTELLECTUAL PROPERTY

The intellectual property debate presupposes a reflection on the very nature of property. Here, two different conceptions came face to face: a Lockean conception of property as a natural right—very much the majority view within the Société d'Economie Politique, and the one upheld by Frédéric Bastiat—and a Benthamite conception of property, defended mainly by Jules Dupuit. Léon Walras, for his part, saw property as the inverse of exchange, and questioned whether intellectual wealth was amenable to appropriation.¹⁴

Frédéric Bastiat was one of the most ardent defenders of a conception of property as prior to the law. In explicit opposition to Rousseau's notion of the social contract, he proclaimed that "man is born a proprietor (...). Law is the result of property, and property the result of human organisation" (Bastiat, 1847/1862a, p.329). If "all production belongs to him who created it, and *because* he created it" (id. p.333), then it stands to reason that the author is the natural owner of his work. To question this conception of property was to jeopardise the very existence of property, as it would then become dependent on the consent of the legislator. The liberals—at a time when property was felt to be under threat from socialism—rallied to this position in strength. Molinari, Frédéric Passy, Garnier, Baudrillart, all adopted this vision as the only way of guaranteeing social order. Molinari, in particular, reiterated these arguments in his entry on intellectual property in the *Dictionnaire de l'économie politique*.

Hardly surprising, then, that Jules Dupuit found himself in a marginal position within the Société des Économistes:¹⁵ the theory he was espousing was diametrically opposed to the majority view. His began to give form to his views on the subject during the exchanges that preceded and followed the Brussels Congress of 1858,¹⁶ developing his position at greater length in his two-part article of 1861. In the proud tradition of

¹⁴ In this, Léon Walras was following in the footsteps of his father Auguste, who approached economics with the mindset of a lawyer.

¹⁵ At the beginning of his first 1861 article, Dupuit nonetheless claims that his analysis is shared by Courcelle-Seneuil and Cherbuliez.

¹⁶ Cf. Dupuit's speeches in a debate in 1855 (S.E.P., 1855a) and in the debate that followed the Brussels Congress (S.E.P., 1858, pp.143-146).

Pascal, Montesquieu, Bentham and Mirabeau, he rejected the idea that property results from a natural right prior to the law. For Dupuit, property is a social construct, of which the origins are to be sought in its social utility. In this respect he appears to be one of the precursors of welfare economics. "The purpose of society is the welfare of its members. Society can exist only through certain laws or conventions. (...) The principle of these conventions is to procure the greatest sum of welfare for the generality of its members. When things are organised along these lines, nobody has the right to complain, since whatever his share, it could not be increased save by reducing the general wealth by far more than he would stand to gain..." (Dupuit, 1861b, p.53). The true basis of property is therefore utility, and it is with reference to utility that the question of intellectual property should be debated.¹⁷

Wolowski occupies a half-way position between these conflicting conceptions, seeing property as a principle of natural right, one which society merely endorses. Likewise invoking Montesquieu, for whom "the law is the palladium of property" (S.E.P., 1858, p. 146), he distinguishes between two components of intellectual property rights: rights in the product and rights of reproduction. Rights in the product correspond to a natural right of ownership over the work as an object (a manuscript, a table, etc.) while rights of reproduction are not property rights as such but rather a "right of easement over the free exercise of the human faculties; it can only be governed by law" (id. p.148). This distinction allows him to argue for reproduction rights of limited duration without undermining the idea of property as natural and prior to the law.

Léon Walras, like Dupuit, links the theory of property to the theory of value, but places the issue of intellectual property within the framework of his theory of social wealth. "If an author's works, be they

¹⁷ Henri Baudrillart, chief editor of the *Journal des économistes*, devotes a chapter to the principle of property in his *Manuel d'économie politique*. For the most part this is a reworking of the introduction to the political economy course he taught at the Collège de France, and which was published in the *Journal des économistes* (Baudrillart, 1855). He expounds at great length on the social utility of property, in line with Dupuit, but is bluntly opposed to the Benthamite conception of property: "If we accept that the law is the foundation, and not simply the guarantee, of property, and that it can therefore modify it indefinitely, in accordance with its variable utility, real or imagined, as construed by the legislator, then we run the risk of mistaking all the excesses legally committed against property for the wrongs of property itself, and have thus tarnished its name in the eyes of the masses" (Baudrillart, 1857, p.42).

motivated by gain or by generosity, be they good or bad, constitute social wealth, which can be evaluated, appropriated and exchanged, then to what extent do the principles and definitions of natural right allow us to declare the author to be the owner of that wealth? That is the real question of literary property. And looking beyond literary property in particular to intellectual property in general, we must ask ourselves: 1) What is intellectual wealth? Can intellectual wealth be evaluated and appropriated? Can it be exchanged? Is it, in a word, a form of social wealth? 2) If intellectual wealth is indeed social wealth, which then can possess over it a natural right of property?" (L. Walras, 1859, p.394).

For Walras, property and exchange-value spring jointly from the scarcity of utility. Things that are unlimited in quantity are not social wealth: they have no exchange-value and cannot be appropriated. By contrast, "wherever there is exchange-value, there must be property and wherever there is property, there must be exchange-value" (id. p.395). For intellectual labour to count as social wealth, it must be both useful and limited in quantity. "If intellectual wealth is in its entirety useful and limited in quantity, then it can be evaluated and appropriated; it can be possessed, it can be exchanged, and it is urgent that we develop the theory of intellectual property" (id. p.396). Having laid down these conditions, Walras returns to the question of what intellectual wealth actually is, and defines it as the body of intellectual capital and the resulting revenue. If his theory of property implies that the owner of a capital asset has a right to the revenue proceeds, then the key question is this: Can intellectual wealth always be appropriated? Walras' answer is no: for example, "the common pool of ideas can neither be evaluated nor appropriated, nor can it be exchanged; it is not social wealth; it is perhaps, at most, a form of natural wealth. It is beyond property" (id., p.404).¹⁸ Walras' thinking on this issue lies at the root of the legal separation between ideas, which are unprotected, and works which, being both useful and scarce, can be appropriated.

Recognising that intellectual capital can, in certain cases, be appropriated does not however tell us who the owner should be. Walras distinguishes two main modes in which property is exercised—private (individual) property and public (common) property—and wonders "(...)

¹⁸ This distinction between "natural wealth" and "social wealth" comes from J.-B. Say, who developed the idea in response to Ricardo's criticisms of his theory of utility-value. The Say-Ricardo debate was also the seed of Dupuit's theory of utility.

whether certain kinds of intellectual wealth, the works of great writers, by example, might not be more amenable to the second mode than to the first" (id. p.405).¹⁹

And here he touches on the next major issue addressed by the economists: that of how to protect the author.

3. FROM THE QUESTION OF INTELLECTUAL PROPERTY TO THAT OF ITS DURATION

In the mid-19th century, legislators across Europe opted for granting authors intellectual property rights for a limited duration. This was, indeed, one of the recommendations of the Brussels Congress of 1858. But the unanimity of the legislators was not matched among the economists, who displayed a wide diversity of opinion. One of the first doctrines to emerge ordained that authors should enjoy intellectual property rights in perpetuum (the theory of monautopoly). This doctrine was contested by Dupuit, for whom the duration of property rights should be defined by law in the greater public interest: a literary creation, or an invention, was a form of collective good, which called for a "*régime communiste*"—meaning the collective ownership of intellectual property.

3.1 The theory of monautopoly

The partisans of exclusive and perpetual intellectual property rights (monautopoly) argued from two directions: on principle, and on economic grounds. If one accepted the idea that the author was the natural owner of his work, then why should that ownership be anything less than total? For Frédéric Bastiat, "either literary property is a right which is higher than the law, in which case the law should simply reflect the fact; or the work of literature belongs to the public, in which case there is no reason why the author should enjoy the usufruct" (Bastiat, 1847/1862a, p.336). The author, or inventor, must therefore have full ownership of his own work, and it must be possible to inherit or sell the

¹⁹ He does not, however, answer his own implicit question in the 1859 article. The article of 1880 takes the matter further (cf. infra).

copyright without impediment. The owner should also have the right to modify or destroy the work if he so pleases.²⁰

This argument on principle went hand in hand with an economic argument. To limit the duration of protection would result in mediocre works or inventions being protected to the detriment of creations of great quality. After all, only great works or inventions actually have a lifespan longer than the legal period of protection. Therefore only great authors or inventors would suffer any loss. Protection consequently encourages them to specialise in "minor creations", which demand less effort, but from which the proceeds can at least be extracted in full. "Is it not obvious", objected Bastiat (1847/1862a, p.337), "that the more one limits the usufruct, the more one incites the author to write hurriedly, to pander to fashion?" This argument was developed at length by Molinari with regard to inventions.

The logical corollary to this rejection of limited protection in time was a desire not to limit protection in space. Molinari put forward a stridently argued case for an international system of intellectual property rights, to apply in every country in order to avoid counterfeiting. "As a general rule, mediocre works stay within a narrow radius. Only those works that are remarkable for their thought or style carry over long distances. If the radius within which copyright is acknowledged and guaranteed is artificially limited, shall we not see (...) genius and effort punished, while mediocrity and improvisation are encouraged?" (Molinari, 1855b, p.526). Open frontiers, coupled with perpetual intellectual propertyrights, are all the more vital for *serious* works in at that—as Molinari recognises—their market is by its very nature narrower than that of the *light* works that follow fashion and attract the masses. Foreign markets are therefore an indispensable complement for the author who seeks a fair return on his initial investment.

To criticism from the opponents of monautopoly—who, in the name of liberalism, warned of the monopoly rents that would be engendered by a perpetual system of copyright—Molinari replies with arguments based on the expectation of utility. He begins by invoking the law

²⁰ Replying to Modeste's criticisms with regard to Pascal's *Pensées*, Dupuit expressed concern about the consequences of his theory of property: "If he were the owner of the works of Pascal, Victor Modeste would not hesitate to rekindle the stake on which the *Provinciales* was burned, in order to cast upon it the philosopher's *Pensées*" (Dupuit, 1861b, p.332).

of the equalisation of profit rates in order to make the point that if the occupation of author or inventor was financially very rewarding, it ought to attract an increasing number of individuals. Conscious, however, of the hit-or-miss nature of success, he postulates that individuals act in reference to an average profit, which takes account of unpredictability and is equivalent to profit in other industries: "As with pearl-fishing, if we are to maintain the overall profits of the invention industry in equilibrium with those of the other branches of production, must not good fortune be allowed to procure high profits in order to offset the losses incurred over time through risk?" (id. 1855b, p.422). The rents generated by the patent thus represent fair payment for the risks taken by the inventor.

The stance on property rights adopted by the proponents of monautopoly logically precluded them from distinguishing between inventor's patents and author's copyright, which were treated as strictly identical. Their opponents insisted, to the contrary, that different forms of creation called for different systems of protection.

3.2 Against monautopoly: linking the system of rights to the nature of the work

Dupuit was evidently far less isolated in his critique of monautopoly than he was on the property question. And yet his argument is the logical continuation of his conception of property.²¹ The rule that should dictate the characteristics of the intellectual property system is social utility. And creative works, after all, have certain of the attributes of a collective good. Pointing explicitly to the non-rivality that characterises the consumption of such products, he sets out the advantages of applying "communism"—in his word—to works of the intellect. "The products of a book or invention are not destroyed by their enjoyment. That enjoyment is unlimited: one man's use of it does not preclude others from using it, nor does today's use prevent tomorrow's. The enjoyment of the product is at its greatest when the book or invention has fallen into the public domain. Personal appropriation diminishes the

²¹ If one adopts the "Lockean" doctrine on property, then "monotaupoly" is its logical corollary. The mainstream liberals were—as Dupuit was fond of pointing out—inconsistent in not following their approach through and accepting limited-duration rights on practical grounds. The arguments they put forward to justify this inconsistency are presented later.

products; it does not improve a book, it compromises its very existence" (Dupuit, 1861b, p.54). He especially emphasises how works in the public domain dispense with rents and expand the culture of the masses. "To improve the condition of the man of letters worthy of that title, we must spread good literature around in profusion; its light, as free as that of the sun, illuminating and penetrating the masses, should create a public capable of understanding and appreciating what is good and what is beautiful. We will not achieve this by locking our masterpieces away inside the speculations of private interest" (id., p.43).

It is likewise in the name of the public interest that he seeks to restrict the rights associated with individual ownership of the work. If the author has full ownership of his work, then he can sell it to whomever he pleases. The acquirer can then decide to amend or even destroy the work, thus depriving the public of the original creation. Incensed by Frédéric Passy's contention that it is up to owner of a work to remove, if he feels necessary, the weak passages of a book, Dupuit recommends that the task of preserving works in their original form should be entrusted to the state: "If Mr Passy wants to read an expurgated version of Gil Blas, without the episode of the Archbishop of Grenada and many others beside, that is his privilege; there are, however, a good many readers who want to read Les Plaideurs and Gil Blas just as Racine and Lesage wrote them. I would not wish to impede anyone's freedom to wield the scissors, but I insist on this condition, that the freedom of those who do not want to wield them be respected. (...). The public domain is therefore the safeguard of their [the works'] preservation, of their immortality" (id. p.40).

Although Dupuit insists on the advantages of putting creations in the public domain, he is not opposed to the temporary appropriation of intellectual works if it serves to stimulate creativity.²² What matters is to

²²Dupuit's analysis is well illustrated by his proposal that the preamble to the 1791 statute on invention patents be amended from: "*The National Assembly, considering that all new ideas of which the manifestation or development may become useful to society are the private property of whomsoever conceived them, and that not to regard an industrial discovery as the property of its author would be an attack on the very essence of the rights of man...*" to read: "...*considering that new discoveries and inventions increase the public wealth all the more when they are more numerous and available to the greatest number; also considering that in addition to the natural incentives that drive certain persons to seek out new processes or inventions, it may be useful to the public to grant artificial incentives, in order to increase the number of discoveries; and that the least socially harmful means that has thus far been found is to grant the inventor the temporary enjoyment of his invention...*" (1861b,p.46).

weigh the advantages and disadvantages in terms of the efficiency of the system of property rights. This pragmatic position leads him to propose separate regimes as between inventions and works of art or literature. A characteristic of inventions is that they proliferate and disseminate their benefits almost instantaneously. Citing the example of the Daguerreotype,²³ Dupuit observes: "An invention can be supplemented, modified, perfected in a thousand different ways, by borrowing principles or processes from sciences and industries that sometimes seem quite unrelated, but where they may be already be familiar and in common use, although unknown to the inventor, who cannot know everything" (id. p.44). Limiting the spread of innovation by a system of patents would therefore be especially damaging to the public interest, as it would slow down the rhythm of technological progress. Moreover, adds Dupuit, the patent system implies transaction costs that increase with the length of protection, a position pithily summed up by the Spanish economist Gabriel Rodriguez, a fierce opponent of intellectual property rights for inventions: "How can one make progress, how can one so much as work, when for the least industrial operation one must request endless authorisations and pay equally endless fees" (Le Hardy de Beaulieu, 1862, p.85).

Dupuit's rejection of monautopoly was shared by a number of figures who had opposed him over the property question. To justify the division of property rights between private and public interests, they resorted to indirect arguments, foremost among which was that contention that in every creative work there is one part that belongs specifically to the author and another that belongs to society. Every work is made up more or less directly of borrowings that reflect the author's debt to society. It is therefore only fair that the property rights should be shared between the author and the state. This was the reasoning behind the limited duration of protection, notably as argued by Frédéric Passy.

The other commonly advanced argument was derived from Wolowski's distinction between rights in the product and rights of reproduction. If one accepts that the right of reproduction is not a right of property, then it can be shared, or restricted, on the grounds of public

²³ His choice of example was far from accidental: the patent for the process invented by Niepce and Daguerre was acquired by the state. Arago, unveiling the invention officially in 1839, donated it to the public domain. From then on it sparked off one innovation after another. Ultimately, it was a process invented in Britain by Talbot at almost exactly the same time, the calotype (a negative image on paper), that gave birth to photography.

interest. Joseph Garnier goes on from there to justify a differentiation between ideas and forms: "it is essential to distinguish the idea, which cannot be appropriated, from the form, which is easily appropriated, as it is limited, defined, visible and palpable" (S.E.P., 1858, p.142). Here he joins Léon Walras in advocating separate treatment for inventions as compared to literary and artistic works.

In his 1859 article (cf. *supra*), Walras merely speculates about the possibility of collectively-owned intellectual property rights, while confessing that, to a large degree, he shares the ideas of Modeste, Paillotet and F. Passy in favour of inalienable intellectual property. In his article of 1880, however, he adopts a position on the public interest that is very close to Dupuit's. "It is surely contrary to the general interest that useful things, unlimited in quantity, should be transformed into monopolies, so that instead of having them freely, we are obliged to pay the most profitable price. Yet it is also contrary to the general interest if intellectual workers cannot profit from their ideas; for then it is certain that the search for scientific theories, the pursuit of industrial inventions, and the composition of works of art and literature would be, if not entirely abandoned, at least substantially neglected. (...) A convention must be established between the author or inventor, on the one hand, and society on the other, under which, when the first party publishes an idea, the second provides him with the means to exploit it as a monopoly for a certain period of time, after which time it will fall into the public domain" (L. Walras, 1880/1890, p.219). This convention could take the form of a copyright agreement, or alternatively a lump-sum payment to the artist or scientist by the state, which would then place the work or invention in the public domain.²⁴

CONCLUSION

The debate on intellectual property in the *Journal des économistes* foreshadows the leading positions and arguments to be found in the

²⁴ For scientific discoveries, for example, Walras recommends a system of teacher-researchers as practiced today in the public education system: "[The teacher's] salary should include both the price of his lessons and that of his discoveries, which will fall immediately into the public service as soon as they are made" (*id.*, p.220).

present-day literature on intellectual property rights.²⁵ Dupuit, whose position was in large part adopted by Léon Walras in his article of 1880, clearly emerges as a precursor of the welfare-based analysis of intellectual property systems, as later exemplified by Arrow (1962) or W.M. Landes and R.A. Posner (1989). The system of copyright is presented as a "second-best optimum" in which the pros and cons of protecting artistic creation hang in the balance. Far from rejecting out of hand the idea of public intervention, Dupuit emphasises the inability of the market to guarantee the general interest when it comes to intellectual property, as creative works have certain attributes of a collective good. In this he foreshadows Samuelson's theory of public goods. He even goes beyond the classical vision of the liberal state as a device to correct the imperfections of the market, notably when he assigns to the state the role of curator and custodian of original works, which points more towards the theory of merit goods. Finally, he proposes a contractual approach to intellectual property rights when he underlines that these goods can be appropriated in countless ways, nearly all of which "demand special knowledge outside the realm of political economy, which merely provides a common principle for all solutions: that the appropriation be made with the consumer in mind, namely in such a way that the sum of riches be made as great as possible" (Dupuit, 1861b, p.54). Although Dupuit was principally attacking intellectual property rights for heirs, his argument also holds for the authors themselves, who enjoy no immunity from the principle of the maximisation of the public interest.

Bastiat and Molinari, by contrast, "enshrine" the author or inventor in the name of a natural right of property, prior to the law. In the present context, their arguments fly to the aid of those artists who complain that their rights are being trampled by market logic. They protect authors (and their heirs) from the dictatorship of utilitarianism by allowing them to act against "the general interest" if they so wish. In so doing, they uphold the moral right of authors over their own work, a moral right that Dupuit would gladly have entrusted to the state.

²⁵ On this subject, see Moureau and Sagot-Duvaurox, 2001.

7. Jules Dupuit and the subsistence problem¹

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Though evident in a number of debating speeches and letters published in the *Journal des économistes*, Jules Dupuit's thinking on the subsistence question is expressed mainly in two articles. The first, a long article entitled *Des crises alimentaires et des moyens employés pour y remédier*² published in two parts in the *Journal des économistes* in 1859, discusses the problem of food crises not long after the two shortages of 1846-1847 and 1853-1855. The second, *Des causes qui influent sur la longueur de la vie moyenne des populations*,³ published in the same journal in 1865, is essentially a reaffirmation of Malthus' principle of population and an attempt to verify it empirically.

From the outset of the first article, Dupuit focuses his attention on public policies designed to counter the effects of "high subsistence prices", contrasting those inspired by what has since been called "the moral economy" (Thompson, 1971) with those recommended by economic theory: "...the ills of society are like those of the individual: to heal them, it is not enough to consult one's heart and obey its generous inspirations, one must first understand the illness, the patient, the remedies and their effects" (1859a, p. 161).

"How difficult is the role of political economy when society is in the throes of a crisis that afflicts most of its members! Our science can scarcely invoke the teachings of experience, since social facts are so complex that to be observed, understood and appreciated, they need to be explained by theory; it has no other means of persuasion than logic and reason. But where will reasoning find an audience in such hard times? As the old saying goes: 'an empty stomach has no ears'..." (idem, pp. 161-162). Here we find the conflict—between the moral economy and the formal rationalisation of economic

¹ François Vatin's friendly but insistent remarks were an invaluable aid in the writing of this paper.

² "Food crises and the means employed to curb them": largely reprinted in *La liberté commerciale* (1861, Ch.21).

³ "Causes that affect the mean length of life of populations".

knowledge—whose evolution throughout the 18th century has been described and analysed by Philippe Steiner (1998, pp. 69-120).⁴

Before analysing public policies, Dupuit analyses the causes and effects of subsistence crises. The first two sections of this paper examine these two points in turn, with the aim of positioning Dupuit's analysis relative to the theories of famine and other approaches to subsistence crises advocated at that time,⁵ while seeking to identify the various influences that can be detected in his text (despite the total absence of references to other authors), to assess the consistency of his approach and, where possible, to suggest formalisations which might explain or evaluate his reasoning. The third section, focusing on the 1865 article, situates his analysis of subsistence crises within the wider framework of the relationship between population and subsistence production.

1. THE CAUSES AND EFFECTS OF SUBSISTENCE CRISES

At first sight Dupuit's analysis seems to belong to the explanatory model for famine that Amartya Sen (1981) called the "food availability decline" or "F.A.D." approach. This approach has often been placed in opposition to Sen's own analysis (1981) of famine as the result of "entitlement failure", i.e. the loss of the afflicted individuals or groups' rights to subsistence. However, as Osmani (1995) has pointed out, what Sen's approach proposes, in its most finished version, is not so much an alternative to the F.A.D. approach for explaining the causes of famine, but rather a wider analytical framework into which a possible explanation in terms of overall food availability can be integrated. Sen thus accepts that a particular famine might be explained by a decline in overall food availability, but refuses to apply this explanation to famine in general. This refusal is founded on the multi-causal nature of famine and on the asymmetry of its impact. On the first point, a famine can break out without any fall in overall food availability, when a group can no longer obtain enough sustenance because of insufficient resources ("endow-

⁴ Condillac saw it as "the rights of man against the rights of property" (1776/1980, p. 330).

⁵ For a panoramic overview of economic thought on the issue of subsistence, see Alain Clément (1999).

ment loss"), insufficient output ("production failure"), unfavourable relative prices ("exchange failure") or the loss of social transfer payments. On the second point, the fact that famines affect certain social groups more than others cannot be explained in terms of overall food availability, but can be explained in terms of entitlement. Famine is thus essentially "a social phenomenon which can be understood only by focusing on the institutions and arrangements which determine the access to food of different classes and groups in society" (Ghose, 1987, p. 290).⁶

For Dupuit, whose reasoning starts out from an isolated economy, subsistence crises can only be caused by a temporary shortfall in the harvest relative to the population's needs: "...the problem lies not in the quantity as such, but in the variations that it undergoes. There can be neither permanent plenty nor permanent scarcity, but it is clear that given constant means of sustenance, the population would become constant and would not suffer in one year any more than another" (p. 162).⁷ Subsistence crises are then explained by the fact that cereals, the near-universal means of subsistence, have three disadvantages: "1. Their annual yield is variable (...); 2. They are difficult and expensive to store; 3. (...) They have scarcely any other use than as food for human beings. It follows that annual consumption can only with difficulty exceed the yield from the harvest, and that the harvest surplus, when there is one, cannot be put to good use"⁸(pp. 162-163).

The poor harvest is only problematic because of the asymmetry of its impact, which Dupuit describes in a lengthy paragraph: "If, when the shortfall in the harvest is of one tenth, everyone were to reduce his consumption by one tenth, there would doubtless be privation; however, (...) the suffering would nowhere be too extreme; but this is not how things happen: however expensive bread may be, it remains, for the rich and comfortable classes, the most economical food, and for them the high price of bread is never a reason

⁶ The same author concludes that "The same set of forces generate mass poverty over time and famines in certain periods. Mass poverty results from long-term changes in social production and distribution mechanisms; famines result from violent short-term changes in the same mechanisms" (Ghose, p. 290).

⁷ The relationship between population and subsistence levels is the subject of the 1865 article analysed in the third section.

⁸ Condillac concluded that "Production [of corn] is therefore, in ordinary years, always in proportion with consumption; consequently the quantity relative to the need is, in ordinary years, always the same" (1776/1980, p. 164) which led him to believe that corn was the best measure of value. His reasoning, based as it was on utility-value, was clearly very different from the labour-value based thinking by which Adam Smith (1776/1904, I.5.17) arrived at the same conclusion.

to eat less of it.⁹The rich or comfortable household that spent 400 francs on bread would spend eight hundred, if the price were to double,¹⁰ even if they must thereby diminish by 400 francs their spending on other items of their budget (...).If, in times of scarcity, half the population consumes the same quantity of bread as in times of plenty, then the privation will fall entirely upon the other half. The shortfall is then no longer one tenth but one fifth, and (...) such a reduction in food (...) will be spread very unequally among the lower classes, in accordance with their available resources;¹¹ the bread shortage will lead to other shortages, as, in order to satisfy the imperious demands of hunger, (...) the poor sell their clothing, blankets, mattresses, go without wood and light, and thus suffering from hunger, cold and damp, fall prey to sickness, and

⁹ This does not fit the reading made by Ekelund and Hébert (1999b, p. 314) and by Ekelund (2000, p. 14), according to which the rich could adapt to the higher price of bread by substituting other goods in its place. The substitution option is however mentioned by Molinari (1851, p. 117). The breakdown of the population into several categories, with bread consumption by the rich remaining stable, had already been suggested by Louis-Guillaume Ternaux (1819, pp. 6-7) in an attempt to explain trade crises in terms of poor harvests. Dupuit's hypotheses find an echo in Mannequin (1868), for whom: "In ordinary times as in times of crisis, the consumers' resources limit the consumption of corn" (p. 371). He divides "corn consumers into two groups, one, relatively low in number, which always consumes the same, or nearly the same, quantity of corn in any circumstance, and another, infinitely more numerous, which consumes more or less corn according to circumstance, and whose ranks are swelled by all who progressively become corn consumers as the public wealth increases, or as they win a larger share of that wealth. Variations in corn consumption, it will be seen, are due to this second group; and the necessary equilibrium of production and consumption is consequently also due to this same group" (idem, p. 371).

¹⁰ This 100% price rise, well above the figure proposed in Davenant's table (1699, p. 83)—where a 10% harvest shortfall is associated with a 30% price rise—seems improbable. Dupuit is here following a proud tradition of pronouncements on the King-Davenant law: not so much an attempt at measurement, more a theoretical fiction devised for expository purposes (Simonin, 1996a). This shortfall of 10% was widely considered at the time to be the maximum possible, a supposition contested by Lavergne (1865, p. 91) when he pointed out that the 1853 harvest was only 57% of the 1857 harvest, and that the 1861 harvest was 64% of that of 1863, with variations in price being proportionally as large as the variations in yield. According to Horii (1984, p. 375), the corn harvests of 1846 and 1853 represented 84.5% and 76.4% respectively of the average harvest for the ten previous years. According to my calculations, based on official reports, the price of corn in 1847 and 1854 was respectively 42.12% and 50% above the average price for the ten previous years (a relative variation respectively 2.72 and 2.12 times that of the harvest).

¹¹My underlining.

only in death find an end to their sufferings.¹² So it is that the fatal laws of political economy say to the wretched: 'Go, you are too many at the feast of life'. Above these lowest classes, that succumb to hunger, others endure at the price of sufferings great and small (...) and by making sacrifices in their secondary needs, live on in the expectation of better times. Finally, in the comfortable classes, not only are there no privations, there is even an increase in consumption. For, even as the lower classes are forced to rein in their consumption of certain objects, these objects, of which the output has not diminished, are offered to the wealthier classes at a lower price,¹³ thereby compensating the additional expenditure that they must lay out in order to acquire bread. We should not lose sight of the fact that, in this phenomenon of the distribution of wealth, we must always arrive at a result where consumption is equal to production. We have assumed that there is no diminution in output except in one item, cereals, and the fact is (...) that in times of scarcity the poorest classes are forced to give up any other spending except that on food; in such circumstances, the other classes must consume that which the poorer classes cannot. (...) Again putting the corn producers to one side—we shall examine their situation shortly—I say: 1) that the shortage is borne entirely by the poorer classes of society, and even between them it is borne in a highly unequal manner; 2) that for the poorest, the lack of food is compounded by a host of other privations, such as a lack of clothing, and heating...; 3) that these latter privations are the only ones suffered by the slightly more elevated classes; and 4) that the rich classes, far from suffering privation of any kind, are able to consume more"(pp. 163-164).

The tone here is closer to "moral economy" than to "formal rationalisation"; the content invites several remarks. Firstly, it allows us to situate Dupuit's analysis relative to Sen's approach. Although for Dupuit all subsistence crises originate in a general food shortage, he accepts that famine is not triggered by the shortage itself, but by the asymmetry of its impact: the crisis only afflicts the poorer classes, whose resources ("endowment set" in Sen's terminology) are insufficient. His analysis of the crisis and its effects integrates perfectly into Sen's approach. The 1865 article presents another mechanism also found in Sen, in the form of "exchange failure": "This is what happens in moments of shortage, that is, in moments where subsistence diminishes, and the population discovers itself relatively too numerous. At this point not only does the price of subsistence goods rise, which is not hard to imagine, but—and this is less easily observed—the price of labour decreases. This is because necessity pulls individuals down

¹² Similar lines of reasoning are to be found in J.-B. Say (1840, vol. 2, p. 142).

¹³ This idea had already been expressed by Cherbuliez (1854, p. 561).

from the less comfortable class and into competition with ordinary workers, and because the workers, harassed by want, are less inclined to take voluntary leave: labour, being in greater supply, is less well rewarded"(1865a, p. 29).¹⁴

Dupuit was not however the only author of the day to articulate elements of the entitlement failure approach., Cherbuliez, distinguishing scarcity (*disette*) from famine (*famine*), wrote: "The word *disette* (...), applied to foodstuffs, (...) signifies an insufficiency of available provision, i.e. the current supply of said foodstuffs, relative to the needs of the population (...) and to the demand, which is the expression of these needs. (...) It is then synonymous with the word *cherté* which indeed takes its place in other languages (...) although the latter properly denotes an effect of which *disette* is the cause."¹⁵

When, for a more or less considerable fraction of the affected population, a *disette* goes so far as to make it impossible for them to procure the quantity of foodstuffs necessary to their subsistence, it takes the name of famine"(1854, pp. 555-556).

Famine is therefore associated with the loss of entitlement for the afflicted fraction of the population, although the mechanism of this loss is not made clear. Certainly Cherbuliez points out that "If, at a given moment, those who have corn in supply (...) were to refuse to sell it or make it available at any price, the immediate consequence would be high prices for that commodity on the domestic market; there would be scarcity, perhaps famine, for the classes of society foreign to agriculture and to the grain trade, and in general for anyone who does not have a supply of corn greater than his needs"(1854, p. 558).¹⁶ But this argument, close to certain modern entitlement-failure approaches (Desai, 1989; Fogel, 1996; J.-P. Simonin, 1999b, 2000), does not apply, according to Cherbuliez, in a free-trade economy, where producers would have no incentive, other than the prospect of a genuine shortage, to regulate supply over time. By contrast, the hurdles placed in the way of free trade by various types of public intervention—legal price fixing, the obligation to sell at that price on public markets, export prohibitions, public provision—could have just

¹⁴ Dupuit is picking up here on a leitmotiv from the economic literature of the foregoing centuries, and which was still being hummed in 1882 by F. Passy and Juglar (S.E.P. 1883, pp. 462, 467-468). Its theoretical validity seems dubious.

¹⁵ *Cherté*: literally, (a period of) high prices; more generally, a scarcity. The English word *dearth* evolved in a similar way from its initial meaning of 'deariness'. Cherbuliez may also have had in mind the Italian cognate *carestia* (famine)—Translator.

¹⁶ Compare this passage from Turgot: "If fewer subsistence foods are produced, someone must die of hunger, and it will not be the grower: before telling anybody about his harvest, he starts by taking what he needs" (1770/1997, p. 334).

that effect by artificially increasing the gap between supply and demand (pp. 558-559).¹⁷ Indeed, for Cherbuliez, when a scarcity causes an industrial crisis, its victims include the workers "whose wages, reduced perhaps even below the ordinary rate, will be completely absorbed by the primary necessities of life. This class of society must therefore find itself cruelly affected by the scarcity" (1854, p. 561). Once again we have before us an example of "exchange failure".¹⁸

Dupuit's analysis is comparable to the line taken by Malthus in his *Essay on the Principle of Population*. In this approach, which, along with that of Adam Smith, dominated British thinking on the subject, Malthus reprises the idea developed in *An Investigation of the Cause of the Present High Price of Provisions* (1800), according to which the soaring grain prices observed in England in 1799-1800 were proportionally larger than the actual shortfall in the 1799 harvest, due to aid distributed by the parishes, which enabled the poor to maintain their level of grain consumption unchanged.¹⁹ "the price of corn in a scarcity will depend much more upon the obstinacy with which the same degree of consumption is persevered in, than on

¹⁷A radically different position to that of Fogel (1996), who justifies state intervention in the grain market of early 17th-century England by the need to force producers to supply the market. Cherbuliez was in fact echoing the distinction (recalled in the conclusion) made by Adam Smith between the causes of high prices and the causes of famine. Cherbuliez' position is also found in Ambroise Clément (1854, pp. 61-63).

¹⁸ A debate that was held after Dupuit's death brought together several elements of the entitlement-failure approach. Villiaumé attributed the famine in Algeria in 1867 to overtaxation: "the unfortunate natives are ruined and quite unable to buy subsistence goods" (S.E.P., 1867b, p. 301). Foreshadowing Sen, he links famine to political oppression: "one always avoids famines when one leaves citizens their liberty; but, once you have oppressed them, famine arrives" (p. 302). For Clamageran, in addition to guaranteeing free trade, the state must ensure that "populations afflicted by shortages are able to pay a fair price for the foodstuffs they need" (p. 304). Taking the example of 1848, Dussard submits that "there are two sorts of famine: those that result from a scarcity of foodstuffs, and those that, in the midst of plenty, can strike down the workers through lack of work" (p. 308). Later, during the siege of Paris, Molinari insisted that the government should feed, free of charge if necessary "that part of the population whom the siege has robbed of their daily means of existence" (Molinari, 1870, pp. 90 and 93; S.E.P., 1870a, p. 102; S.E.P., 1870b, p. 231) and must let the market and speculators take care of other people's consumption needs.

¹⁹ This was the position followed by Stewart (c.1800/1994, vol. IX, p. 140) and Tooke (1838/1972, p. 14).

the degree of the actual deficiency.²⁰ A deficiency of one half of a crop, if the people could immediately consent to consume only one half of what they did before, would produce little or no effect on the price of corn. A deficiency of one-twelfth, if exactly the same consumption were to continue for ten or eleven months, might raise the price of corn to almost any height. The more is given in parish assistance, the more power is furnished of persevering in the same consumption; and, of course, the higher will the price rise before the necessary diminution of consumption is effected"(1826, III.V.9).

The reasoning in the essay is formally analogous to Dupuit's, but it applies to a different relationship. Malthus is interested in the impact of the harvest shortfall on the price of corn—as it were, dearth in the etymological sense of high prices—whereas Dupuit is interested in its impact on the sufferings of individuals, i.e. on the gravity of the famine: if everyone reduces consumption proportionally to the weaker harvest, then according to Malthus the price of corn should not vary²¹ (but in that case—as an excerpt from Dupuit (p. 165), cited below, shows—why reduce consumption?), whereas according to Dupuit "the suffering would nowhere be too extreme". The divergence widens as the text goes on: for Malthus, prices rise because the poor, whose purchasing power is maintained by parish aid, continue to consume corn at the same rate, whereas for Dupuit, the poor are reduced to famine because the rich continue to consume their subsistence at the same rate. In all fairness one should note that Malthus' pamphlet of 1800 pointed out the unequal distribution in the effects of scarcity, with the poor being the designated victims of want: "I know of no other definition of a scarcity than the failure of the usual quantity of provisions; and if a great part of the people had but just enough before, they must undoubtedly have less than enough at such a period".²²In reply to those"who say that it is quite impossible that there can be a

²⁰ This phrase was attacked by Pareto: "What Malthus calls *obstinacy* is simply the phenomenon observed during the phase in which the poorer classes are gradually forced to refrain from eating high-quality foods and make do with bread" (1897/1964, p. 339) which corresponds to what Marshall called the Giffen effect. Pareto does not use this term and explains the effect, not, like Hicks, by the interplay of substitution and revenue effects, but rather by the interaction between budget constraints and a biological constraint (this point has been widely analysed, including in J.-P. Simonin, 1980, 1988a & b). Pareto's criticism seems to be wide of the mark.

²¹ Malthus' conclusion is incorrect, as Annex 2 demonstrates.

²² A similar analysis, by Bastiat, takes us closer to the concept of entitlement failure: "When, in the case of a nation or a class, the means of existence fall to that lower level at which they become one with the means of mere subsistence, (...) the least fluctua-

real scarcity, because you may get what quantity of corn you please, if you have but money enough" he continues: "if they, or I, had a great deal of money, and other people had but little, we could undoubtedly buy what quantity of corn we liked, by taking away the shares of those who were less rich; but that if all the people had the same sum, and that there was not enough corn in the country to supply all, we could not get what we wanted for money, though we possessed millions"(1800/1970, p. 21). Due to the unequal distribution of revenue, consumption adjusts to the harvest by excluding the poorest classes (rather than by reducing consumption uniformly), but Malthus insists that the problem stems from the general deficiency of the harvest.

Contrary to Dupuit, Rossi held, in his defence of Malthus' population principle, that an egalitarian distribution of revenue would only make scarcities worse: "any non-essential expense would soon be suppressed by the paucity of wealth and the growth of the population, and the country could no longer call for its subsistence on that reserve fund to be found everywhere else in those foodstuffs normally destined for the feeding of livestock or for the satisfaction of luxury. Any shortage would then become a terrible calamity, as no class would have any surplus with which to meet the needs of the others, and all would be equally dispossessed of a part of their basic necessities. Then there would be no rescue, no pity, just a common misery, and a remorseless egotism. A ship full of people, but devoid of provisions, weighed down by an inexorable stillness in the immense solitude of the ocean: such would be the land of equal fortunes"(1843/1884, vol. 1, p. 267).²³This view rests on the assumption of surplus consumption (probably highly elastic to subsistence prices), which is ruled out by Dupuit when he posits that cereals are used as human sustenance only and that there is no gainful use for any harvest surplus.

tion in population or food supply is recorded in the mortality rate. (...) For a long time now Europe has not experienced a famine, (...) the means of existence have risen, by reason of social progress, far above the means of subsistence. When years of scarcity come, many satisfactions can be sacrificed before any curtailment of food is rendered necessary. Such is not the case in China or in Ireland. When men have nothing except a little rice or a few potatoes, with what will they buy other foods if the rice or the potatoes happen to fail them?" (Bastiat, 1850/1860b, p. 470; 1850/1996, 16.97). A similar argument had previously been presented by J.-B. Say (1840, vol. 2, p. 145). Regarding the effect of the surplus of means of existence over means of subsistence, Bastiat's comment is correct at the group level but he is mistaken when he extends it to society as a whole, deducing, in the process, a critique of the population principle (Bastiat, 1850/1860b, p. 471).

²³ The ship metaphor was a recurrent image for Dupuit and for other economists of the time, as we will see later.

To analyse Dupuit's ideas in greater detail we need to focus on the three aspects of shortages that he himself enumerates: the unchanging consumption level of the rich, the diminution by the poor of purchases of other goods in order to maintain their subsistence purchases, and the elimination of the poorest from the subsistence market.²⁴ These three phenomena each play a different role in the mechanism of scarcity, and we shall examine each one in turn.

The first point can be formalised using a simple model that I originally proposed (J.-P. Simonin, 1999a) by way of an alternative analysis to Malthus, in demonstrating that the rise in grain prices is explained not by the fixed consumption of the poor, but by the fixed consumption of the rich.²⁵ The economy consists of n_1 rich people—each of whom consumes a fixed quantity of subsistence \bar{e}_1 ²⁶—and of n_2 poor people. Each poor person spends his entire wages w_2 on subsistence goods; when these go up in price, he has nothing else to sacrifice and is obliged to consume less, even if he is not excluded from the market. His consumption e_2 is therefore variable. The equilibrium between the size of the harvest q and the consumption values of corn is expressed as

$$(1) \quad q = n_1 \bar{e}_1 + n_2 e_2$$

The budget constraint of the poor is written:

$$(2) \quad p e_2 = w_2 \text{ or } p = \frac{w_2}{e_2}$$

where p is the price of corn. This gives us a model with two unknowns, e_2 and p ,²⁷ for which the solutions are

²⁴ The division of the population into three categories, from the destitute to the rich, had been put forward by Rossi (1843/1884, vol. 1, p. 269) in his analysis of Malthus' principle of population.

²⁵ At the time of writing I was unaware that the equivalent effects of these two practices on the price of corn had been pointed out by Mannequin (1868, p. 381).

²⁶ In Mannequin's opinion (1868, p. 362), the hypothesis that corn consumption does not vary from one year to the next was probably derived from the constant consumption observed among the rich. The same hypothesis was used, for example, by Quesnay (1757) to compile his price-harvest tables.

²⁷ If consumption by the poor were set at the vital minimum r then the unknowns would be p and n_2 , the number of poor people capable of surviving, which solve to $p = \frac{w_2}{r}$ and $n_2 = \frac{q - n_1 \bar{e}_1}{r}$. This raises the problem of determining which of the poor

$$(3) \quad e_2 = \frac{q - n_1 \bar{e}_1}{n_2} \quad (4) \quad p = \frac{w_2 n_2}{q - n_1 \bar{e}_1} .^{28}$$

Equation (4) expresses the relationship between price and harvest, indicating that the price is equal to the expenditure of the poor divided by the quantity of corn not consumed by the rich. This is the equation for a curve that plots the relationship between the price of corn and the harvest for a given total expenditure by the poor. According to this equation the proportional variation in price is greater than in the harvest (King's law) due to fixed consumption by the rich; this is confirmed by the associated elasticity of grain demand relative to the grain price, which is equal to $-y_2 = -(1 - y_1)$, where y_2 represents the share of the initial grain demand that emanates from the poor and $y_1 = 1 - y_2$ the rich counterpart.²⁹ Dupuit's figures do not fit into this model. According to the elasticity formula, since the rich consume half of the harvest ($y_2 = 0.5$), a shortfall of 10% should entail a price rise of 20% and not 100%. Since an elasticity calculus cannot account for such large variations, another approach is called for. If, following a poorer harvest q' , the price rises to p' in accordance with equation (4), we obtain:

survive and which do not. This problem, which only exists because the distribution of revenue postulated here is discontinuous, explains the position expressed by Steuart and discussed later in this article.

²⁸ This equation, like equations (7) and (15) and the Quesnay/Steiner equation analysed in Annex 4, adheres to the general form of corn demand as proposed by Jevons (1888, IV.121): $p = \frac{a}{(q-b)^n}$, here with $n = 1$, whereas Jevons posited $n = 2$ in his study of King's law.

²⁹ This model offers a perfect fit with the reasoning set out by Pareto, who, after invoking King's law and Davenant's table, writes: "When the price of staple commodities changes, the consumption of the richer classes generally varies little, if at all. The quantities consumed by these classes remain constant, only their expenditure varies. For the poorest classes, the reverse happens. These classes spend almost their entire revenue to buy essential items. In their case it is the total expenditure which remains roughly constant, while the quantity consumed varies" (1897/1964, pp. 340-341). The direct price elasticity of demand from the rich is therefore nil, while that of demand from the poor is -1, giving a direct price elasticity for overall demand of $y_1 \cdot 0 + y_2 (-1) = -y_2$. This point elasticity formula is identical for equations (4), (7) and (15). The model shows that, contrary to J.-S. Lenfant's (2001, p. 1617) reading of Pareto, the demand behaviour of the poor cannot lead to atypical demand at the aggregate level.

$$(5) \quad \frac{p'}{p} = \frac{q - n_1 \bar{e}_1}{q' - n_1 \bar{e}'_1} = \frac{1 - y_1}{\frac{q'}{q} - y_1} = \frac{e_2}{e'_2} \quad ^{30}$$

Dupuit's figures, $y_1 = 0.5$ and $q' = 0.9q$, would then entail $p' = 1.25p$ and not, as he posits, $p' = 2p$. By contrast, consumption by the poor e_2 does indeed fall by 20% as in his example.³¹

Factoring in the poorer classes' sacrifice³² of other commodities in order to buy subsistence goods accentuates the impact of King's law. This much is clear from a remark Dupuit inserts after his description of

³⁰ Annex 1 shows that this formula is identical to the one derived from Whewell's formalisation (1850): y_1 corresponds to Whewell's coefficient m . Equation (5) represents a movement along a price-harvest curve associated with a value for expenditure by the poor, rather than a displacement of the curve associated with a variation in the amount of this expenditure.

³¹ To transcribe Rossi's position into this formalisation, one posits that the rich reduce their consumption from \bar{e}_1 to e'_1 in the event of a scarcity, while the poor continue to spend $n_2 w_2$. Equation (4) would then be replaced by

$$\frac{p'}{p} = \frac{1 - y_1}{\frac{q'}{q}(1 - y'_1)} \quad \text{where } y'_1 = \frac{n_1 e'_1}{q}$$

Clearly if $y'_1 = y_1$, i.e. if the rich reduce their consumption proportionally to the harvest, then price and harvest will vary in the same proportion. In this case, the rich always spend the same amount on corn, which is in line with Sen's hypothesis (1981, pp. 174-179) when he models Malthus' position on the effects of poor relief (J.-P. Simonin, 1999a). Direct price elasticity of corn demand by the rich is therefore, by this view, unitary: zero elasticity of demand for pure subsistence would imply very strong elasticity in absolute value for other uses of corn. With a less elastic overall demand for corn, we would be back to King's law. If demand by the rich is totally inelastic, we are back with Dupuit's analysis.

³² This notion of sacrifice needs to be related to Dupuit's earlier writings: "political economy must measure an object's utility by the maximum sacrifice that the consumer would be willing to make in order to obtain it. I say political economy, because this is not a strict measurement of the capacity of things to satisfy mankind's needs; one would be hard pressed to say which is the hungrier: the rich man who would give a million francs for a loaf of bread; or the poor man who, having nothing else to give, would risk his life for it. But political economy, confining itself to questions of wealth, can measure the intensity of a desire only by its monetary expression. It bakes bread only for those who can afford it, and leaves to social economy the task of supplying bread to those who cannot pay" (Dupuit, 1844/1995, p. 65; 1853, pp. 13-14). As Grall and Vatin point out in their contribution, Dupuit's concept of utility "does not signify the true intensity of the consumer's desire, only the intensity of 'solvent' desires".

the asymmetric effects of the poor harvest and before analysing the price-harvest relationship: "If we now consider the relationship that develops between the quantity of corn harvested and the price of bread, we will easily recognise that the enormous price increase in times of scarcity has no limit, save in the sacrifices that the poorer classes are able to make in order to obtain food"(1859a, p. 164).³³These sacrifices can be formalised by positing that,

³³ The idea of sacrifices made by poor salaried workers in times of high prices, already voiced by Turgot (1770/1997, pp. 303-304) can also be found among Dupuit's predecessors. According to Cournot, for "staple foods, those which are the very basis of our diet", "enormous variations in price correspond to small differences in the quantities produced, for this reason, that the poor classes find themselves obliged to sacrifice all other demands to the demand for the foodstuffs in question" (1838/1980, p. 107). Later Cournot repeats the first part of the phrase but pursues with: "for the poor will renounce all other forms of consumption, and commit even their meagre capital and future resources, in order to procure the staple commodities" (1863/1981, p. 195). Such liquidation of assets and borrowing should increase the spending potential of the poor, leading to a rise in the corn price beyond that indicated by equation (7). For Molinari: "...a small deficit in the harvest, i.e. in the quantity of corn brought to market, is enough to cause a considerable increase in the price (...). When a deficit occurs in the production of a commodity and the price rises in consequence, the demand for that commodity diminishes (...). It decreases, in the first instance, because other foodstuffs will be consumed, which have become relatively less expensive; and in the second instance, because the price will rise beyond the reach of the most miserable section of the population. But since everyman is willing to assent to the greatest sacrifices before dying of hunger, the rivalry between corn consumers will nonetheless remain very brisk, and the gap between the quantities of corn and of money offered in exchange will become ever wider. The last few thousand bushels will probably sell at an excessive price" (1851, pp. 117-118). Block, on the other hand, suggested that the poorer classes' capacity for sacrifice was limited, and that they were rapidly forced to reduce their consumption of bread, which brings us back to the first model: "It is widely believed (...) that rivalry between buyers will follow the price rise to its final limits, or even, that those who possess the corn will lay down the law. Well, this is a mistake (...). We must not forget that bread, precisely because it is the staple food of the entire population, is consumed mainly by the poor or less affluent classes. The individuals that belong to these classes will as far as possible rein in their other spending, and will only decide to reduce their habitual consumption of bread as a last resort. But this last resort arrives all too quickly for many of them, and all the more so, because a great many persons are obliged to diminish their other spending, thereby causing a slowdown in industrial production. (...) Imagine a family of workers that spends Fr 1.60 every day for 4 kilos of bread. When prices are high, it will manage to find Fr 2 or Fr 2.50 for that vital commodity. But if the price rise continues, it is still only Fr 2.50 that it will bring to the baker, but now it will take home 3-and-a-half or even 3 kilos of bread instead of four. From this *abstention* comes a very considerable diminution in consumption which limits the price increase, and prevents it from going beyond the relatively extreme point that the most populous classes can yet attain, albeit at the cost of great efforts or great pri-

when the harvest is normal, the poor will spend the sum $s_2 w_2$ on bread, where $1 > s_2 > 0$ corresponds to share of their overall budget allocated to bread. The model reutilises equation (1), while the budget equilibrium for the poor is now:

$$(6) \quad p e_2 = s_2 w_2.$$

The unknowns are once again e_2 and p , implying that s_2 is exogenous.³⁴ The value of e_2 is again given by equation (3), while the price of corn in normal years is

$$(7) \quad p = \frac{n_2 s_2 w_2}{q - n_1 \bar{e}_1}.$$

If, for a poor harvest $q' < q$, the entire revenue of the poor is spent on bread, then the budget constraint for the poor is again equation (2) and the price of corn $p' > p$ is defined by equation (4), giving

$$(8) \quad \frac{p'}{p} = \frac{1}{s_2} \left(\frac{1 - y_1}{\frac{q'}{q} - y_1} \right) = \frac{e_2}{e'_2 s_2} > \frac{e_2}{e'_2}.$$

The influence of King's law is here accentuated by comparison with the first model, which corresponds to the case where $s_2 = 1$. For any given harvest deficit, the lower the value of s_2 , the higher the value of p' relative to p : the lower the initial share of spending on bread—i.e. the higher the wages of the poor relative to the price of corn in normal years—the greater will be the possibility for the poor to sacrifice other

variations" (Block, 1861, p. 353). Despite the limit placed on the price rise, the model shows that King's law must hold.

³⁴ Positing s_2 as unknown would imply that p was exogenous. The exogenous nature of s_2 is expressed by Modeste in these terms: "the consumer (...) is driven by a number of different needs at any one time. (...) depending on its present intensity, each need claims its share of the resources. There comes a moment when, after the other necessities of life have been pushed to the absolute limit, (...) bread is allotted only its available share, and shall obtain no more" (1856, p. 45).

³⁵ Equation (7) is formally identical to (4) and corresponds to a price-harvest curve situated under the curve for (4), since $s_2 < 1$. If the value of s_2 remains constant, then the variations in q and p are supplied by (8) and correspond to a movement along a price-harvest curve.

³⁶ Equation (8) corresponds to a displacement of the price-harvest curve resulting from a variation in the amount spent on corn by the poor, and is incompatible with Wheelwell's formalisation.

goods in order to buy bread in times of scarcity, and the more the price of corn will rise.³⁷ This model would be perfectly compatible with Du-puit's figures in the case where the poor devoted 62.5% of their spending to bread ($s_2 = 0.625$) in normal years.³⁸

The phenomenon of exclusion can be formalised by introducing into the model the class of the very poorest, consisting of n_3 individuals whose revenue w_3 is spent entirely on corn in normal years. The equilibrium between harvest and corn consumption in normal years is written:

$$(9) \quad q = n_1 \bar{e}_1 + n_2 e_2 + n_3 e_3$$

and the budget equilibrium of an individual from each of the poorer classes:

$$(10) \quad p e_2 = s_2^* w_2; \quad (11) \quad p e_3 = w_3 .^{39}$$

If the unknowns in this 3-equation model are p , e_2 and e_3 , we obtain the consumption formulas

$$(12) \quad e_2 = \frac{s_2^* w_2 (q - n_1 \bar{e}_1)}{n_2 s_2^* w_2 + n_3 w_3}, \quad (13) \quad e_3 = \frac{w_3 (q - n_1 \bar{e}_1)}{n_2 s_2^* w_2 + n_3 w_3}$$

which indicates that, for either category of the poor, their share of the subsistence left over by the rich is equal to their share of spending as a proportion of the total spending on corn by the poor. The price of corn in normal years is defined as

$$(14) \quad p = \frac{n_2 s_2^* w_2 + n_3 w_3}{q - n_1 \bar{e}_1} .^{40}$$

³⁷ Equation (7) therefore corresponds very much to West's phrase: "the higher the money wages of labour as compared with the usual price of corn, the more will the price be enhanced by the same deficiency of supply" (1826, p. 54). This point is confirmed when one formalises or represents graphically West's numerical example (1826, pp. 54-55) (J.-P. Simonin, 1999a).

³⁸ Duveau (1946, p. 329) shows that, for the same quantity of bread, a labourer from the *Centre*, region of France, spent 35% of his wages in 1864 (a low-price year) and 63% in 1868 (a high-price year). Duveau also describes the standard of living of the various categories of workers, and their conditions in times of high prices or unemployment (pp. 329-415).

³⁹ $s_2^* < s_2$ is posited since, for any price that does not actually exclude the poorest, the "middle" class devotes a smaller share of its overall budget to bread.

⁴⁰ Equation (14) is formally identical to (4) and (7). The associated price-harvest curve will be situated above the one for (7) if $n_3 w_3 > n_2 w_2 (s_2 - s_2^*)$; otherwise it will be below. It will be situated above the curve for (4) if $n_3 w_3 > n_2 w_2 (1 - s_2^*)$ and otherwise below.

If the high prices induced by a poor harvest lead to the exclusion of individuals of class 3 only ($e'_3 = 0$) and oblige individuals of class 2 to increase the share of their spending on bread from s_2^* to s_2 , the new price of corn is determined by equation (7), which gives us

$$(15) \quad \frac{p'}{p} = \frac{s_2}{\left(s_2^* + \frac{n_3 w_3}{n_2 w_2}\right)} \left(\frac{1 - y_1}{\frac{q'}{q} - y_1} \right)$$

which is equivalent to displacing the price-harvest curve for (14) to the curve for (7). Comparing this result with equation (8) shows that the exclusion of the poorest tends to reduce the impact of King's law, due to the fact that their purchasing power can no longer be exercised on the subsistence market. This reduction is all the greater in that the initial subsistence spending of the excluded poor is large compared to that of the "middle" classes. This effect can offset that of the increased spending by the intermediate class and thus check the influence of King's law⁴¹ if the expenditure of the excluded poor as a whole is very large in normal years, which may well be the case if the poor are very numerous.

If prices continue to rise, forcing even the intermediate class to devote its entire budget to bread ($s_2 = 1$), the budget constraint of an individual of this class returns to equation (2) and the new price of corn is determined by equation (4), giving

$$(16) \quad \frac{p'}{p} = \frac{1}{\left(s_2^* + \frac{n_3 w_3}{n_2 w_2}\right)} \left(\frac{1 - y_1}{\frac{q'}{q} - y_1} \right) = \frac{1}{\left(1 + \frac{n_3 w_3}{s_2^* n_2 w_2}\right)} \frac{s_2}{s_2^*} \frac{1}{s_2} \left(\frac{1 - y_1}{\frac{q'}{q} - y_1} \right).$$

⁴¹ This was the hypothesis floated by B.A. Lenoir (1828) when he compared years of plenty, during which the rural poor could consume cheap corn, with normal years, when they could no longer afford to consume it at all. The hypothesis was taken up by Mannequin (1866, 1868), who had a different explanation for rural behaviour: "it is in the rural areas that we find the largest number of corn consumers; it is also there that consumption can diminish most sharply, since it is there that, in times of plenty, corn is consumed in the ways that are most easily forsaken, such as for animal fodder; finally, it is there that people have an interest in depriving themselves of corn, since every grain they can spare from their own consumption is sold for a handsome price" (1866, p. 383). By this view, contrary to Fogel (1992), rural grain consumption is elastic (J.-P. Simonin, 1990, 1999b).

Looking at the right-hand part of the equation, the first term, less than one, represents the effect of the exclusion of the poorest. The next two terms, both greater than one, represent the effects of the successive increases (from s_2^* to s_2 and then to 1) in the intermediate class's bread budget as a proportion of its overall spending, while the fourth and last term represents the effect of maintaining the consumption level of the rich. Once again, the exclusion of the poorest could offset the effect of increased spending by the intermediate and rich classes, thus preventing King's law from coming into play. This result could explain the conclusion arrived at by Malthus or Tooke—although, as we shall see, from different hypotheses—according to which the upwards pressure on prices exerted by the increased spending of the rich and intermediate classes may be offset by the exclusion of the poorest. This is very different from Dupuit's position, which associates a 10% shortfall in the harvest with a doubling of prices. In this case, if equation (15) did not obey King's law, then the overall result would imply a fracture in the price-harvest relationship corresponding to movements on successive price-harvest curves.⁴²

Equation (16) enables us to reproduce Dupuit's figures, for example in the case where $s_2^* = 0.25$, $s_2 = 0.5$, and $w_3n_3 = 1.5s_2^*n_2w_2$, the effect of consumption by the rich being 1.25, that of the sacrifices made by the middle classes is 4 and the effect of the exclusion of the poor 0.4, which gives us a price multiplied by 2.⁴³ From these figures, the most important factor in the price rise is the size of the sacrifice made by the middle classes: the effect of maintaining the consumption of the rich is here more than offset by the exclusion of the poorest. If, however, there is

⁴² Just such a fracture was suggested by Lenoir (1828, p. 9), who situated it within normal harvest conditions in the opposition between the low elasticity of urban consumption relative to its normal level and the high elasticity of rural demand, which consumed corn only in years of plenty. The same fracture is alluded to by Mannequin when he posits "that the need for corn is more pressing than that of other products, and it is never entirely satisfied for everyone. The requirement is such that, in order to satisfy it, the price will be pushed as high as possible when corn is scarce; and the impossibility for many consumers fully to satisfy their requirement, even in normal times, means that demand for corn rises swiftly when [the price of] corn falls, and this prevents it from falling very far" (1868, p. 374). For an explanation of this asymmetry in free trade, see Bouniatian (1927, pp. 69-71).

⁴³ In this example $e_2 = e'_2$ i.e. the exclusion of the poor allows the middle classes to maintain their corn consumption unchanged.

enough food to provide the vital minimum r for everyone, then maintaining the consumption level of the rich can be analysed as causing the exclusion of the poor. This is the case if

$$n_1\bar{e}_1 + (n_1 + n_2)r > q' > (n_1 + n_2r + n_3)r$$

This condition corresponds perfectly to Dupuit's contention that the poorest perish, whereas everyone could have survived.⁴⁴

Dupuit's analysis on the one hand fits into the income pyramid model of Garnier and J.-B. Say and, on the other, presents analogies with a tradition that goes back to James Steuart (1767), notably incorporating the analysis of Malthus found in Stewart, Tooke and West.

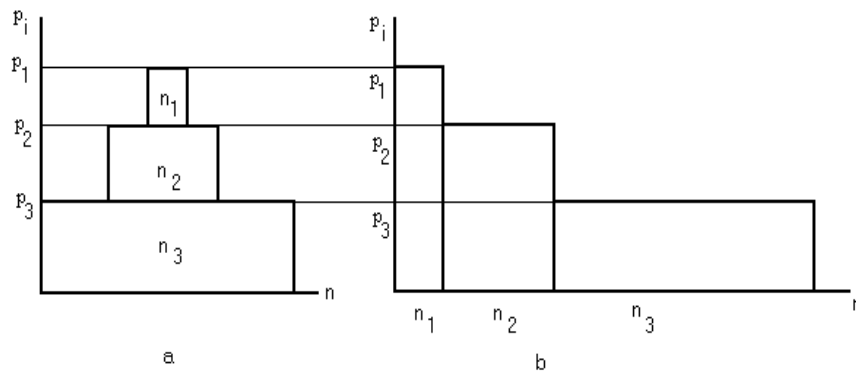
Firstly, Dupuit's ideas recall the Garnier-Say income pyramid,⁴⁵ according to which, due to the pyramidal distribution of revenue, a rise in the price of a good prohibits it to a certain number of consumers in the lower levels of the pyramid, whose income is too low for them to be able to afford it. Say clearly has famine particularly in mind, as he writes: "When, unfortunately, this happens with a commodity of basic necessity, then part of the population perishes" (1841/1972, pp. 322-323). The same metaphor is found in Dupuit (1844, p. 368) in the form of a pyramid of cannonballs, to illustrate the convexity of the demand curve for a good and his measurement of the utility loss caused by taxation, as well as to anchor his theory of price discrimination; the analogy between this last point and his analysis of scarcity is brought out in François Vatin's contribution. As my colleague also points out, on a different point, Dupuit's argument of 1844 is here being used the other way round. From the pyramid notion Dupuit deduced that "when the price of an object falls, ever more numerous consumers find other ways of using it, not to mention that the existing consumers use it in greater quantity" (1844, p. 368).⁴⁶ In the present instance, the price rise excludes the poorest, but does little to reduce consumption among those who remain.

⁴⁴ This situation is analogous to those defined in a number of entitlement failure models (Desai, 1989; J.-P. Simonin, 1999a,b and c).

⁴⁵ J.-B. Say (1819/1996, pp. 105-106; 1841/1972, pp. 321-323). As Ekelund and Hébert (1999b, pp. 95-96) remind us, the pyramid metaphor can be traced back to Germain Garnier (1796). Later, A.-E. Cherbuliez (1862, vol. 1, pp. 349-352) made an explicit attempt to model the demand curve for a commodity using Say's pyramid.

⁴⁶ Compare this phrase from Pareto: "When the price of a commodity falls, consumption generally rises. The main part of this rise is usually due to the commodity becoming accessible to the less affluent strata of the population" (1897/1964, pp. 331-332).

However, the metaphor best suited to this excerpt from Dupuit, and to his analysis of 1859, is surely neither J.-B. Say's pyramid nor his own pile of cannonballs. Say's pyramid is reflected in Graph 1a⁴⁷ which represents three classes of individuals differentiated by income. The length of each horizontal rectangle corresponds to the number of individuals n_i able to afford the price of corn p_i indicated by the top bar of the rectangle. When the price is low, for example p_3 , corn is consumed by all classes, and classes 1 and 2 will devote part of their revenue to other goods. A rise in the price of corn to p_2 excludes the base of the pyramid—class 3—from corn consumption. This graph, while interesting as an image, is impractical on the analytical level as it cannot be used to derive the demand curve for a good as defined in Dupuit's phrase. This corresponds instead to Graph 1b, in which the top of each vertical rectangle indicates the price level p_i while the horizontal dimension, as before, indicates the number n_i of individuals who can afford that price. At p_3 all individuals can afford bread, whereas at p_2 , class 3 is eliminated. This graph cannot however be interpreted as a total demand curve for bread in that the quantities consumed are not specified, which means that unlike the actual modelling of Dupuit's theories, it cannot be used to determine the price of corn but only to reveal the effects on consumers.



Graph 1

⁴⁷ In fact Say drew a triangle rather than a series of steps as shown here.

Furthermore, when Dupuit asserts that the only limit on the rise in the corn price is the capacity of the poor to make sacrifices, he is using a formulation which is not only already present in other French-language economists, but which belongs to a British tradition that Stewart (circa 1800/1994, vol. IX, pp. 137-140) ascribes to the *Political Economy* of James Steuart (1767)⁴⁸ and which has echoes in Malthus, Torrens, Tooke and West. Some of these authors contended that the rapid exclusion of the poor could annul the effect of King's law. Tooke, for example, following the reasoning of Malthus' pamphlet, writes: "supposing a given deficiency, the degree in which the money price may rise, will depend upon the extent of the pecuniary means of the lowest classes of the community. In countries where the pecuniary means of the lowest classes are limited to the power of obtaining a bare subsistence in ordinary times, (...) a proportion of the population, according to the degree of scarcity, must perish, or suffer diseases incidental to an insufficient supply of food, or to a substitution of inferior and unwholesome diet. And the increased competition of purchasers being thus limited to the classes above the lowest, the rise in price may not be very considerably beyond the defect of quantity" (1838/1972, pp. 13-14). Their reasoning can easily be formalised using numerical examples from Malthus (1800) and West (1826).⁴⁹ Suppose that the number of individuals n is divided up between the three classes defined above, with each individual

⁴⁸ "Sir James Steuart was long ago led to say, that in the case of the necessaries of life there is a limit determinately fixed to price by the faculties or means of the lower orders" (Stewart, c.1800/1994, p. 137-138). Stewart later cites Steuart's directly: [the standard price] "must depend upon the faculties of the buyers; and these again must be determined by the extent of those of the greatest number of them; that is to say, by the extent of the faculties of the lower classes of the people. This is the reason why bread, in the greatest famine, never can rise above a certain price; for did it exceed the faculties of the great classes of a people, their demand must be withdrawn, which would leave the market overstocked for the consumption of the rich; consequently, such persons who in times of scarcity are forced to starve, can only be such whose faculties fall, unfortunately, below the standard of those of the great class. Consequently, in countries of industry, the price of subsistence never can rise beyond the powers to purchase of that numerous class who enjoy physical necessaries; consequently, never to such an inordinate height as to starve considerable numbers of the people, – a thing which very commonly happens in countries where, industry being little known, multitudes depend merely upon the charity of others, and have no resource left as soon as this comes to fail them" (pp. 139-141).

⁴⁹ The Malthus example is scrutinised in Annex 2. For present purposes a formal outline will suffice.

consuming the minimum vital ration r .⁵⁰ In normal years all three classes consume corn, so equation (9) is replaced by

$$(9') \quad q = (n_1 + n_2 + n_3)r = nr$$

which implies that a famine can only arise out of a general subsistence crisis and not from an entitlement failure. Corn spending for each group, which for group 3 is equal to its entire income, is written:

$$(10') \quad pr = s_1w_1 \text{ and } pr = s_2w_2$$

$$(11') \quad pr = w_3.$$

As the consumption levels are fixed, the unknowns in this model are p , s_1 , s_2 and the number of surviving poor n_3 , which gives us the solutions

$$n_3 = \frac{q - r(n_1 + n_2)}{r}, \quad s_1 = \frac{w_3}{w_1}, \quad s_2 = \frac{w_3}{w_2}, \quad p = \frac{w_3}{r}.$$

The last expression corresponds to the position of Malthus and West: "the price of every commodity therefore will be fixed by the wants and means of the lowest class to whom the supply extends" (West, 1826, p. 29).⁵¹

In a shortage year where $q' < q$, if the poor are excluded by the price rise and if the middle classes spend their entire income on bread, the model rewrites to

$$q' = (n - n_3)r = (n_1 + n'_2)r$$

$$p'r = s'_1w_1 \text{ and } p'r = w_2$$

which yields the solutions

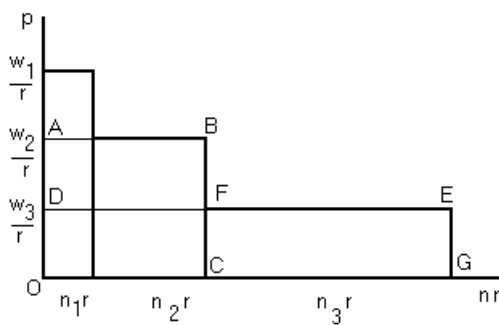
⁵⁰ This is in line with Adam Smith's affirmation that "The rich man consumes no more food than his poor neighbour. In quality it may be very different, and to select and prepare it may require more labour and art; but in quantity it is very nearly the same" (1776/1904, I.II.59), a position followed by a number of the authors cited.

⁵¹ If the scarcity is extreme, the price will accordingly be determined by the means available to the wealthiest class. Thus Batbie's example to illustrate the idea that price rises in times of scarcity are a sign of general opulence: "Drinking water suddenly becomes very rare in a besieged town (...). If the price of a glass of water rises to Fr 50,000, this astronomical price shows that there are many in the town who can pay 25, 30, 35 and even 45,000 francs. It is a sign of wealth. Now suppose instead that in the same town, the price of a glass of water does not exceed Fr 10; are we to conclude that the two towns, suffering the same privations, are equally prosperous?" (S.E.P., 1864b, p. 468).

$$n'_2 = \frac{q' - n_1 r}{r}, \quad p' = \frac{w_2}{r}, \quad s'_1 = \frac{w_2}{w_1}.$$

From the above results it follows that

$$\frac{q}{q'} = \frac{n}{n - n_3} \text{ and } \frac{p'}{p} = \frac{w_2}{w_3} = \frac{1}{s_2}.^{52}$$



Graph 2

King's law emerges if

$$(15^*) \quad \frac{p'}{p} = \frac{w_2}{w_3} > \frac{n}{n - n_3} = \frac{q}{q'}^{53} \text{ or } \frac{q'}{q} > s_2$$

which means that the exclusion of the poor will not prevent a rise in corn expenditure, i.e. the additional expenditure by the non-excluded as a result of the price rise is greater than absent spending of the excluded. In other words, overall spending on corn in shortage years, $w_2(n_1 + n'_2)$, is higher than in normal years, $w_3 n$. This result is described by Graph 2 which represents the price of corn in the y-axis as determined by the income of the poorest class "to whom the supply extends" and, in the x-

⁵² This result is easily verified as being the one arrived at by equation (15) if $e_1 = e_2 = e_3 = r$. Once again we find West's position on the effect of wage levels on the price of corn. Dupuit's figures can be reproduced in this model by positing $n_3 = 0.1n$ and $w_2 = 2w_3$ (or $s_2 = 0.5$).

⁵³ This result is applied to Malthus' numerical example in Annex 2 (1800/1970, pp. 8-9). West's example cannot be used for these calculations, as it does not specify the size of each class.

axis, the quantity of corn in demand on the market, i.e. the individual ration multiplied by the number of buyers.⁵⁴ The graph shows that, when the price of corn rises from $\frac{w_3}{r}$ to $\frac{w_2}{r}$, the quantity purchased diminishes only on account of the exclusion of the poorest, since individual demands are fixed. Overall expenditure is diminished by the lost spending of the excluded class, i.e. the area CFEG, and is increased by the additional spending of the other classes, i.e. the area ABFD. King's law applies if overall expenditure rises, i.e. if OABC is larger than ODEG. The price and the harvest vary in the same proportion only if the exclusion of the poor is sufficient to keep spending on corn stable, i.e. if

$$\frac{w_2}{w_3} = \frac{n}{n-n_3} \text{ or } \frac{q'}{q} = s_2.$$

The variation in price is proportionally less than the variation in the harvest if the exclusion of the poor leads to a reduction in corn spending, i.e. if

$$\frac{w_2}{w_3} < \frac{n}{n-n_3} \text{ or } \frac{q'}{q} < s_2.$$

⁵⁴ This graph is derived from Graph 1b by multiplying the values measured in the x -axis by r ; it can be seen as defining a form of market demand. In this one can follow V. Smith (1951, pp. 249-250) and Rankin (1980, pp. 244-245) who see Malthus' example as a rudimentary market demand curve. The comparison with Graph 1a shows that, contrary to Ekelund and Hébert's assertion (1999b, p. 97), J.-B. Say's diagram cannot be considered superior to English texts, such as those of Malthus, on the subject of demand.

⁵⁵ This situation corresponds to part of Pareto's analysis of scarcity. After indicating that the consumption level of the rich is stable, he writes that "From the form of the revenue curve it is clear that a reduction limited to those classes with the very lowest income is sufficient to reduce the total consumption considerably" (1897/1964, p. 341). This he illustrates with an example ill-suited to the problem of scarcity, and which is actually more relevant to the effects of indirect taxation. However, by keeping the parameters of Pareto's law as used in that example we obtain the distribution function:

$$F(w) = 1 - \left(\frac{400}{w}\right)^{1.5}$$

where $w > 400$ stands for the income level. Supposing that each individual consumes the same quantity of bread (in line with Pareto's view that "In general, spending on bread stays roughly constant within certain income limits" (1897/1964, p. 342)) and that the poorest spend their entire income (400) on bread, then a 10% decrease in the harvest would result in 10% of individuals being excluded, namely those with an income below

The over-restrictive nature of the hypotheses in this model, and its inability to take account of famines caused by entitlement failure, underline the relevance and originality of Dupuit's ideas, and their superiority over concurrent approaches.

Dupuit's text continues with the assertion that a considerable increase in the price of corn is inevitable. Having just written that this increase is limited only by the sacrifices of the poor, he now states "We should not lose sight of the fact that it is through the price of bread that the hardship caused by the failed harvest is imposed upon the population. There is one inevitable and necessary result, namely that consumption cannot outstrip the quantity of corn available. On a ship, or in a fortress, when supplies start to run low, the officer in command seizes the remaining provisions and hands out rations calculated according to the available quantity, so that consumption is regulated by force.⁵⁶ In the regime of liberty in which society lives, there is no other moderator or regulator of consumption than the price of the good, which naturally rises to the level required to maintain the equilibrium between the quantity consumed and the quantity available. (...) There is therefore a neces-

429, which would be equivalent to a price rise of 7.27%. This result, inherent in the convexity of the revenue curve, is contrary to King's law (it would imply a direct "price elasticity" of 1.375 in absolute value), but corroborates the findings of the models presented here, namely that the exclusion of the poor goes against King's law.

⁵⁶ The contrast with the authoritarian management of supplies on board a ship had already been evoked by Adam Smith (1776/1904, IV.5.42) and echoed by Stewart (1800/1994, vol. IX, p. 50) and Torrens (1808/1993, p. 67), although they used the example in different ways: for Dupuit this mode of management stands in opposition to the role of prices in the equilibrium of supply and demand on the corn market, while for Smith and his successors it is in opposition to the role of speculators in maintaining that equilibrium throughout the harvest year. The image was already present in the writings of Boisguilbert: "one does not supply a great and naturally fertile kingdom as one would a town or a ship, wherein grow no grains." (1704/1966, p. 858). As for Bastiat, he quipped that the idea of pegging wages to subsistence prices was like saying that "in a ship with no supplies, everyone has just such a ration of biscuit, regardless of whether there actually *is* any" (1845/1862, p. 252). The ship image was taken up by Mannequin—following Rossi, as we saw—to make the point that society "is not isolated like the crew of a ship at sea" (1866, p. 383). Finally Jevons (1888, III.63) stresses the problem of optimal daily rationing given the uncertainty about the length of the voyage. Thereafter the metaphor sinks without trace, doubtless because the advent of the steamboat dispelled such uncertainties. Dupuit assimilates the ship example with that of a town under siege. During the actual siege of Paris, this assimilation was rightly rejected by Block (S.E.P., 1870a, pp. 95-96) but defended by Bénard (S.E.P., 1870b, p. 231), while Molinari (1870a) implicitly assimilated the situation in Paris with a conventional scarcity and advocated that the city's supplies be managed by speculation and the open market.

sary relationship between the price and the quantity produced, (...) one which varies for each type of commodity, but which for corn, and for staple goods in general, has this particular characteristic: a slight diminution in production corresponds to a large increase in price. This must indeed be the case for it to bring hardship that engenders such great suffering; one only does without bread when one cannot do otherwise, and almost everyone would do otherwise if the price rise were but a small one. An abundant harvest, by contrast, causes a great fall in the price of cereals; the reason being (...) they have scarcely any other use than as food for human beings, and bread is a food on which no-one surfeits; however cheap it may be, people no longer eat it once their hunger is sated. So, if the production has exceeded the quantity required to satisfy this need, then corn will not find a buyer except at cut-price. Thus for corn, the slightest rise or fall in quantity produces a very great variation in price" (1859a, pp. 164-165).

Dupuit then, like most of the authors cited here, sees the King-Davenant law⁵⁷ as a consequence of what would now be called the low direct price elasticity of corn demand.⁵⁸ Demand for corn is relatively inelastic because there are no substitutes for corn and no alternative uses. Given equality between the quantity consumed and quantity available, i.e. equilibrium in the corn market, the direct correlation between the quantity demanded and the price of cereals implies Dupuit's "necessary relationship" between the price and the quantity produced.⁵⁹

⁵⁷ Dupuit had already mentioned this law in his article on tolls, "Péage", in the *Dictionnaire de l'Economie Politique*: "for corn, great differences in price correspond to harvests that differ little in quantity" (1854b, vol. 2, pp. 340-341). Unlike his contemporaries, however, he never refers to King. Nor does he cite Molinari's curious formulation of the law: "when the ratio between two commodities varies arithmetically, the price varies geometrically" (1851, p. 119), which was aired again in the following century by Guyot (1911, p. 4) and Bouniatian (1927, p. 63).

⁵⁸ Dupuit does not use this term. But Modeste, writing at the same time, mentions—on the issue of whether bread should be left to find its own price-level—that one of the counterweights to the suppliers' arguments is "the contractility of demand, and also its potentially indefinite elasticity" (1856, p. 47). Cherbuliez also observed "that elasticity of consumption, which concurs to increase the actual demand when there is a fall in the price" (1862, vol. 1, p. 352). Mannequin, at the end of an article similar to Dupuit's, in which he insists on the equality between harvest and consumption, concludes that the "mobility" of the price "is due to the elasticity of wants, and the obstinacy of those doing the wanting" (1868, p. 372). The notion of the elasticity of wants is found again in Marshall (1920/1974, p. 86), as the title to the Chapter of *Principles* introducing the elasticity of demand.

⁵⁹ In its simplest formulation, King's law states that the relative price variation is equal to the relative variation in the harvest divided by the direct price elasticity of demand.

The formalisation proposed here also shows that the rich benefit from scarcity. Dupuit notably rejects the "*ancien régime* crisis" schema, later popularised by Labrousse (1944). According to the usual model of this crisis, the increase in the price of corn leads to a fall in demand for industrial goods by the poorer classes, forced to spend more on bread—a fact accepted by Dupuit—and brings about a decline in production and in industrial employment,⁶¹ which Dupuit dismisses⁶² with the simple assumption that a shortfall in the harvest will not affect the output of other goods.⁶³ The fall in the price of industrial goods, from which the

⁶⁰Dupuit's analysis, which plots the grain harvest against the demand curve as the sole expression of consumer needs, ignores the phenomenon of speculation, which according to Cherbuliez accounts for the King-Davenant law, i.e. "the disproportion that becomes manifest, especially in the first days of a scarcity, between the real deficit in supply and the high prices that are its consequence. (...) While those who possess grain are prompted, by the thought of a forthcoming increase in price, to hold back their supply, either for their own consumption or with an eye to making a profit, speculators, industrialists who use cereals as raw material, and many ordinary consumers, are prompted by the same expectation to increase their demand (...). The real deficit is therefore only the mediate cause of the high price; it merely awakens and brings into play the motives which are its immediate causes" (1854, p. 559), an explanation which was again adopted by Guyot (1911). Cherbuliez here intersects Condillac's distinction (1776/1980, pp. 3 and 151) between real scarcity (*disette réelle*) and alleged scarcity (*disette d'opinion*) and also follows Condillac (p. 8) in ascribing the effect of King's law to the public's poor evaluation of the real shortfall. For Dupuit, the disproportion between shortfall and price stems from the staple nature of bread consumption, with the real shortfall being the immediate cause of the high price. Cherbuliez, moreover, defines the real shortfall after deducting the fixed amount of grain required for seed (evaluated at 13 million hectolitres by Lavergne, 1865, p. 91), a point overlooked by Dupuit. This fixed deduction, to which economic historians have attributed a key role, is itself sufficient to engender a price-harvest correlation along the lines of King's law (J.-P. Simonin, 1990).

⁶¹ The British economists often emphasised the fact that the rise in the price of bread depressed demand for other foodstuffs, notably meat (Stewart, 1800/1994, vol. IX, p. 103; Lauderdale, 1804/1966, p. 83) or grain-based beverages, as we shall see later.

⁶² On this point he stands apart from most of his contemporaries. On the debates of the time about the nature of the economic crisis of 1846-1847, see Lutfalla (1972, pp. 505-512).

⁶³ Dupuit's concept of economic crisis is worthy of note. In a speech rejecting the monetary origin of crises he says "Every crisis (...) is necessarily the result of a diminution in the output of genuinely useful objects. This diminution makes them more expensive, and this in turn becomes an obstacle to regular saving by individuals, and sometimes even a reason to consume earlier savings. Consequently the industries that relied on these savings find themselves in difficulty, while those who still possess sav-

rich benefit, is accounted for by the reduction in overall spending on non-essentials.⁶⁴ If q^* and p^* represent the quantity and price of industrial goods respectively, and w_1 (a rich person's income) and w_2 are divided up entirely between subsistence and industrial goods while the poorest class, class 3, consumes only subsistence products, then the equilibrium between the value of industrial output and the spending allocated to it in normal years is expressed as:

$$(17) \quad p^* q^* = n_1(w_1 - p\bar{e}_1) + (1 - s_2)w_2 n_2$$

which gives us the determination of industrial prices as a function of output:

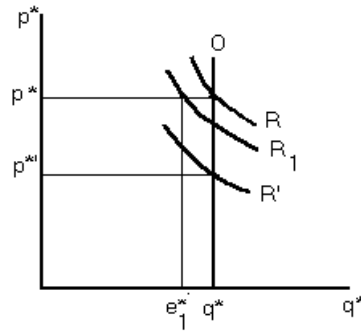
$$(18) \quad p^* = \frac{n_1(w_1 - p\bar{e}_1) + (1 - s_2)w_2 n_2}{q^*},$$

corresponding to the intersection in Graph 3 between the isoexpenditure curve R and the vertical supply curve for industrial goods. Following the poor harvest, class 2 is forced to abstain from buying industrial goods, while the rich spend more on agricultural produce, giving us

$$(19) \quad p^* q^* = n_1(w_1 - p'\bar{e}_1)$$

ings on the market obtain a higher rent for them, since the demand for them is great and the supply meagre" (S.E.P., 1857b, p. 467). But whereas Lavergne saw the poor harvests of 1853-1856 as the origin of the 1857 crisis, for Dupuit the cause lay in France's colonial wars, which drained resources from the production of "useful objects". Briaune (1857, pp. 259-260), to the contrary, held that the surplus of activity caused by the wars had neutralised the effects on industry of the poor harvests.

⁶⁴ The usual critique (D.S. Landes, 1950; Gould, 1962) of Labrousse's reasoning rests on the observation that the increase in farming income, as a result of the higher price of corn, offsets the loss in the purchasing power of bread buyers. The industrial crisis is therefore due to the fact that the consumption capacity of those who gain from the price rise is less than that of those who lose out; an argument already put forward by Briaune (1857, p. 8). In Japan, on the other hand, where the relation between these two consumption capacities was the inverse, the rise in the corn price had an expansionist effect (Gravier, 2001, p. 1778). Dupuit, like Labrousse, also ignores demand for industrial goods among corn producers.



Graph 3

and the price of the industrial goods falls to:

$$(20) \quad p^{*'} = \frac{n_1(w_1 - p'\bar{e}_1)}{q^*} < p^*$$

which corresponds to the intersection between the isoexpenditure (or constant outlay) curve R' (which only concerns the rich) situated above curve R , and the vertical supply curve for industrial goods.⁶⁵

The consumption of industrial goods by the rich is equal to q^* in years of scarcity, while in normal years it is

$$(21) \quad e_1^* = \frac{n_1(w_1 - p\bar{e}_1)}{p^*} = \frac{n_1(w_1 - p\bar{e}_1)q^*}{n_1(w_1 - p\bar{e}_1) + (1 - s_2)w_2n_2} < q^*$$

as can be seen from Graph 3: although the rich spend less on industrial goods in years of scarcity as compared to normal years—which corresponds to a downward displacement of their isoexpenditure curve in these products, from R , to R' —they can consume more of them. Since they do not consume any less in terms of subsistence, their well-being is increased.⁶⁶

⁶⁵ This method of price determination by comparing supply with isoexpenditure curves is different from the demand-curve method, although it arrives at the same result.

⁶⁶ The idea that a rise in the price of corn increased the welfare of the rich while diminishing that of the poor at the start of the 19th century is alluded to without explanation by Marshall (1920/1974, pp. 157-158).

Dupuit rounds off his analysis of the causes and effects of high prices by setting out the conflict of interests between cereal producers and consumers in a closed economy, already discussed by Boisguilbert (1704/1966, p. 848) and Quesnay (1757):⁶⁷"These large variations in the price of corn mean that the interest of the corn producer is totally different from that of the consumer. In years of plenty, the price falls so low that, for the farmer, the proceeds from the harvest are not enough to cover the growing costs and the ground rent; in years of scarcity, the price rises so high that it not only compensates the loss due to the lack of quantity, but constitutes an enormous profit"(1859a, pp. 165-166). After promising to return to the subject later, Dupuit concludes by pointing out the asymmetrical effects of the harvest shortfall:"...my sole aim is to demonstrate that the deficiency of the harvest has very different effects on the various classes of society. The resulting hardship is far from being general: it falls almost entirely on the poor, and there are some classes who do not suffer, while still others make a profit"(p. 166).

2. POLICIES TO COUNTER THE EFFECTS OF SHORTAGES

For Dupuit the measures—or "expedients", as he calls them—commonly taken against the effects of shortages were summed up as follows:

Individual charity: Donations of money, food, etc.

Collective charity: The *sociétés alimentaires*

Municipal charity: Issuing bread to the poor; providing bread at reduced prices; charity workshops

Municipal measures: The *taxe du pain* based on the price of flour; reserves of corn or flour in public granaries or at bakers' shops; a constant and average charge for bread, sustained by a regulatory fund.

⁶⁷For theoretical analyses of Quesnay's account of this opposition, see Delmas & Demals (1994), Steiner (1994) and J.-P. Simonin (1996a & b). Steiner (1998, pp. 83-85) analyses this account within the framework of his study of the formal rationalisation of economics. Another conflict of interests is signalled by Ricardo in his *Essay on the Influence of a Low Price of Corn* (Ricardo, 1815), this time pitting landowners against every other social category (including farmers). Shortly before Dupuit's article, the conflict between grain producers and grain consumers was described with a numerical example by Molinari (1851, pp. 122-123).

Governmental measures: An imposed maximum price of corn; prohibiting the use of corn other than for food; special incentives for agriculture; preventing corn from leaving the country in times of scarcity; regulating the import and export of corn according to its price—the sliding scale; always allowing corn to enter and leave freely" (p. 166).

Before examining these measures in detail, Dupuit posits a fundamental principle for all closed economies: "...all the measures envisaged to combat food shortages can only result in a displacement of the privations they occasion, without diminishing the sum of these privations. It is not within the power of the most able individual nor of the most powerful State to add one grain of corn to the harvest. All that can be done is to take from him who has in order to give to him who has not, in other words, to change the distribution of consumption" (p. 167).⁶⁸ As none of the measures proposed is aimed at the massive redistribution of wealth from rich to poor that would be necessary due to the inelasticity of cereal demand, it is not difficult to see that they would be unable to redress the situation. It seems a fair supposition, then, that the respective roles of the widespread harvest failure and the asymmetry of its impact are as follows: it is not the harvest failure, but the asymmetry of its impact, that triggers famine, but it is the harvest failure that—in "the regime of liberty in which society lives" where consumption is not "regulated by force", i.e. where it is not possible to redress the fundamental asymmetry between rich and poor—renders the various countermeasures inoperable. The fact that Dupuit does not envisage rectifying the shortage with such a redistribution strategy is easy to understand: to attain its goal the redistribution would have to be on such a large scale that it would disrupt the natural workings of society, based on the untrammelled interplay of supply and demand.⁶⁹

Dupuit's position here conflicts with the findings of Malthus who, while generally hostile to poor relief measures, conceded that "their operation in the present scarcity has been advantageous to the country. The principal benefit which they have produced, is exactly that which is most bitterly complained of: the high price of all the necessaries of life" (1800/1970, p. 19). The dearth of 1799 is thought to have pushed up the numbers of people

⁶⁸ Dupuit does not however use Cherbuliez' argument (1854, pp. 558-559) that government measures not only cannot remedy a shortage, but actually make it worse by leading consumers and producers to exaggerate the real importance of the harvest shortfall and to adopt speculative behaviours that accentuate the rise in subsistence prices. The omission is unsurprising in as much as Dupuit overlooked the role of such behaviour as a factor in price increases.

⁶⁹ On this point, see François Vatin's contribution.

forced to reduce their consumption of cereals from 2 or 3 million to 5 or 6 million (out of a population of 10 million). This conclusion is echoed by Tooke, not only with regard to the British poor laws but also on the public provision of food in Paris:"The final effect of a rise in price so much beyond the defect of the crops, (...) is to limit the consumption and to apportion the privations resulting from the scarcity over a larger part of the population; thus diminishing the severity of pressure upon the lowest class, and preventing or tending to prevent any part of it from perishing" (1838/1972, p. 14). We are faced with a paradox: Dupuit insists on the inequality of income distribution as an explanatory factor for the effects of shortages, but rejects public intervention on the grounds of the global nature of subsistence failure; Malthus insists on general subsistence failure as an explanation for shortages (while pointing out that the poor will be worst afflicted), and yet concedes that aid can help to spread the effects of the shortage more evenly.⁷⁰⁷¹

Dupuit's position is also out of kilter with the policies recommended by the liberal economists during the siege of Paris (Molinari, 1870 ; S.E.P., 1870a & b). Siegfried notably divides the population of Paris into three categories, analogous to those defined by Dupuit,"people who are totally bereft, people whose resources are limited, and finally those who have the means to live comfortably"(1870, p. 341). The first were to be fed for free in public canteens, the second were to be granted access to subsidised canteens, while the third, buying their supplies on the market,

⁷⁰ This opposition can also be understood in terms of the different direct price elasticity values among the rich and the poor implicit in the respective models. Sen's modelling of Malthus' ideas implies zero elasticity for the assisted poor and unitary elasticity for the rich (J.-P. Simonin, 1999a), while Dupuit's analysis entails near-zero elasticity for both categories.

⁷¹ Rossi's contention, mentioned earlier, that inequality of income distribution gives rise to a surplus of corn that can be called on in times of scarcity can be reconciled with Malthus' analysis: the effect of the rise in the price of corn due to poor relief will be to divert the surplus from its usual applications, which must be price-elastic, towards feeding the poor. This is an impossibility in Dupuit's analysis, which rules out other uses than for human food. Such a transfer would, in principle, be identical to transferring corn from alcohol production to subsistence, which we look at later; the "modern" model presented in Annex 3 illustrates both analyses. Rossi, however, expected the surplus to be transferred by private charity and not by the price rise caused by poor relief. Mannequin's wish, meanwhile (1868, pp. 380-381), was that the rich would exercise voluntary abstinence in times of scarcity.

would have their consumption limited by the rise in prices.⁷² As in Malthus' analysis of poor relief, and unlike in Dupuit's positions, the burden of the shortage would be borne by the richer classes.

In examining these measures, Dupuit does not miss an opportunity to remind us of the superiority of private enterprise over public undertakings and of his faith in the free operation of the market. As this attitude was shared by the most of the economists of the day, these judgements are to be found in most studies of subsistence crises (Cherbuliez, 1854; Molinari, 1854).⁷³

The limits of private charity are clearly spelt out: it will merely help certain sections of the poor to the detriment of others, who will be deprived of the volume of cereals given away, with no guarantee that the recipients of aid are those in the greatest distress, and it will raise the price of cereals (pp. 167-168).⁷⁴ The effect of collective charity is even worse: "it is no longer individuals that are aided, but categories, and woe to those who fall outside them" (p. 168).⁷⁵

However, Dupuit reserves most of his criticism in this area for the "*sociétés alimentaires*". These organisations were set up with "the aim

⁷² This proposal from Siegfried fits Dupuit's model of price discrimination (1844, 1849a). Legoyt (1871, p. 342) pointed out that these different customer segments, so to speak, were in practice spontaneously differentiated on the basis of appearance, notably clothing, which echoes a proposal by Dupuit (1849a, p. 220) to impose differential tolls on the same criterion.

⁷³ This explains why the positions adopted by Dupuit in this article, being widely accepted by his liberal colleagues in the S.E.P., were not met with the objections that greeted most of his contributions.

⁷⁴ Cherbuliez, on the other hand, felt that, confronted with the distress of workers afflicted by scarcity and industrial crisis "private charity sees (...) before it a task worthy of its mission, a task that it alone can fully undertake, that it alone can accomplish without sacrificing the future to the present, and without finally doing more harm than good" (1854, p. 561). Charity in the 19th century manifested itself, among other ways, in the "economical canteens and ovens" described by Siegfried (1870).

⁷⁵ Some of the advocates of Sen's approach accord with Dupuit's criticisms: "It has been argued above that famines generally do not involve food shortages. It would be wrong to suppose, however, that governments can acquire enough food for purposes of relief through purchases from the market or that relief can be provided in the form of cash payments. Governments' attempts to purchase food from the market in the pre-famine or famine periods will increase the relative price of food and thus risk worsening the situation. Relief in the form of cash payments will also increase the relative price of food and is most likely to redistribute food among the poor" (Ghose, 1987, p. 290).

of providing the poor with foodstuffs at the wholesale price, exonerating them from paying the profits that retailers make from their sale" (p. 168). Dupuit seizes this opportunity to launch into spirited defence of the role of intermediaries, using arguments, based on cost-efficient buying and selling, analogous to those of Turgot (1766/1997, pp. 197-199) or Condillac (1776/1980) and which were common in the literature of the day (cf. Molinari, 1853, pp. 318-320; Bastiat 1847/1862b, pp. 396-398, 1850/1860a, pp. 356-363, etc.). He concludes that intermediaries can only exist by providing a genuinely useful service to the consumer (pp. 169-170).⁷⁶ Moreover, an intermediary will be a more effective manager than one appointed by a *société alimentaire* (pp. 170-171). But above all "...the capital error of this system is the assumption that one can reduce prices without increasing quantity, and that one can increase demand without increasing prices. So, having eliminated the fruiterer, you are now going to deliver the peach, that you paid 10 centimes for at the wholesale market, to the consumer at cost price. But the consumer, who used to pay 20 centimes, will ask you for two peaches at 10 centimes each, and his neighbour, who didn't eat peaches because they cost 20 centimes, will ask you for one now that they cost but ten. How are you going to satisfy these new demands? (...) political economy has its own inflexible laws and will find its own way (...) to restore the equilibrium between production and consumption, and when tomorrow, in order to satisfy all of these appetites that you have stirred up by lowering the price, you ask the wholesaler for three peaches instead of one, without fail he will ask you for the extra 10 centimes that were previously taken by the local fruiterer. (...) One cannot reduce the price of a commodity unless one increases the quantity. Otherwise one is simply sharing out the producers' profits in a different way" (p. 171).⁷⁷

⁷⁶ This argument was presented in the same terms by Ambroise Clément (1859, pp. 28-29), who also felt that 'cutting out the middle-man' would impair competition. Later, Le Hardy de Beaulieu specified that "the service rendered by the intermediary to those who employ them is twofold: it consists both in work saved and in risks taken" (1871, p. 161), an idea which he applied to the grain trade, amongst other things (pp. 168-171).

⁷⁷ Dupuit's reasoning is identical to that employed by Pareto (1897/1964, pp. 126-127) to illustrate the consequences of abolishing land rent. In his general case against the *sociétés alimentaires* Dupuit puts forward the argument that price cuts are impossible at constant output, whereas in an earlier debate he accused these cooperative associations of failing to encourage reduced bread consumption after poor harvests, and of displacing the burden of the shortfall onto other categories (S.E.P., 1855c, p. 469). The latter argument is clearly incompatible with the first: if the cooperatives cannot diminish the price of a commodity, then they cannot curb the rise in the price of corn in times of

Dupuit's reasoning leads to a result that is familiar from the theory of the incidence of taxation or margins on commodities: the agents whose supply or demand is least elastic will bear the brunt of any extra margin or tax on a commodity. Where supply, as here, is totally inelastic, the margin will be borne entirely by those who provide the commodity, and abolishing the intermediaries will not have changed the price paid by the consumer.⁷⁸

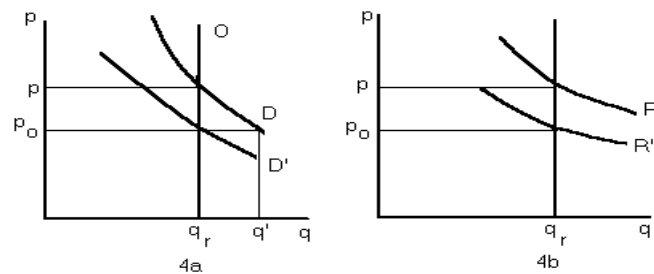
Graph 4a provides an illustration in terms of market equilibrium. When the harvest q_r is offered on the market, the consumer demand curve D implies an equilibrium price p . If the intermediaries take a margin at rate m , $1 > m > 0$, the price paid to the producers, who alone bear the brunt of the margin, is p_0 such that $p = p_0(1+m)$, as determined by the intermediary demand curve D' . As Dupuit points out, if this margin is

scarcity. This incompatibility was also noticed by Mannequin who, in writing about cooperative bakeries makes no explicit reference, unlike Dupuit, to trading margins: "Their delusion lies in that they cannot see that in times of scarcity (*cherté*) the price of bread, being subordinate to the price of corn, depends far less on the costs of production than on the law of equilibrium that universally governs prices. In times of scarcity, the production costs of corn are not noticeably increased; its price, however, may increase threefold or even fourfold. How can that be explained without a law independent of the costs of production?" (1868, p. 377).

⁷⁸ This reasoning is reproduced later by Dupuit (1861c, p. 114) when writing about the incidence of taxation. Taking the example of a possible reduction in the tax on wine, he considers that since the supply of wine is, at least in the short term, fixed, the reduction in tax will not filter through to the consumer, as the tax is borne entirely by the producers. In the medium term, however, wine producers will increase production and the price of wine will fall, which is only normal: once supply is elastic, part of taxation is borne by the demand side. And so, without actually using the term, Dupuit shows that he perfectly understood the implications of the elasticity of supply and demand. In another debate, by contrast, Dupuit (S.E.P., 1862 a, pp. 463-464) maintains that stamp duty is borne by the buyer of the property, a point picked up on by Léon Walras, who insinuates that the error is attributable to Dupuit's unhappy experience as a buyer! (idem, p. 471). The problem of incidence seems not to have been universally understood at the time. Block, for example, on the incidence of customs duties, wrote: "Duties on commodities without equivalents [in the importing country] are purely fiscal. In most cases, the total amount of such tax is added to the price. This addition always occurs when production is not unlimited: demand then exceeds supply and the consumer bears the cost of the tax. When, on the contrary, the production of the taxed commodity is unlimited, the importer is sometimes obliged to bear part of the tax" (Block, 1861, p. 349). Block's assertions, contrary to Dupuit's findings, are clearly erroneous.

suppressed, the price p_0 will lead to a positive net demand $q' - q_r$ which, by a "Walrasian" adjustment, in turn leads back to price p .⁷⁹

Dupuit's argument mixes together two distinct problems with a shared characteristic, namely the suppression of the trading margin: on the one hand, the replacement of the food trade by "*sociétés alimentaires*", on the other, the outright suppression of retail trade, which Ekelund and Hébert describes as the affirmation that "forced vertical integration might lower economic efficiency and public utility" (1999b, p. 316).⁸⁰



Graph 4

⁷⁹ This result is also produced by the model set out in the first section. Given a margin rate of m the price-harvest relationship, as defined by equation (4) and ignoring the fixed consumption rate of the rich, is expressed as

$$p = p_0(1 + m) = \frac{w_2 n_2}{q - n_1 \bar{e}_1}$$

corresponding to curve R in Graph 4b, which associates price p with harvest q_r . The price received by the corn producer is therefore

$$p_0 = \frac{w_2 n_2}{(1 + m)(q - n_1 \bar{e}_1)} < p$$

corresponding to curve R' . The new margin does not alter the price paid by the consumer, which is still defined by equation (4), but it does diminish the price received by the producer.

⁸⁰ I do not feel, however, that I can follow these authors when they maintain that Dupuit's argument provides a solid basis for the Chicago School's contention that such practices as sales tax, exclusivity contracts and the territorial division of the market maximise utility (idem, pp. 317 and 424).

Municipal charity⁸¹ suffers from the same defect as individual charity and collective charity: it merely modifies the distribution of the cereal shortage among the poor (p. 172). Dupuit takes the opportunity to attack the "charity workshops, to which unemployed workers were convened" (p. 173) having himself been placed in charge of such an initiative back in Angers: "The belief is that with the wages they earn in these workshops, the workers will be able to stave off the ill consequences of high subsistence prices. This illusion is founded on two economic errors (...). It overlooks the fact that 1) bread is only expensive because it is scarce, and the charity workshop will not make it any more abundant;⁸² 2) that communal work paid for in taxes is merely a way of displacing demand for labour, and it is impossible for the State or the town hall to actually create work" (p. 173).

On the first point, this is another case of mere redistribution of cereal consumption among the poor (p. 173). On the second, Dupuit points out that the workshops' activity was inefficient, that the work they did was of doubtful utility, and that it was financed to the detriment of private saving (i.e. investment) or consumption (pp. 173-176).⁸³

The other measures, examined in the following issue of the *Journal des économistes*, were aimed at generally rectifying shortfalls in the harvest.⁸⁴ Dupuit starts by examining the municipal measures: the *taxe du pain*; corn

⁸¹ Horace Say (1847, pp. 347-348) described the abuse of the system that took place in Paris when bread vouchers were issued to the poor during the crisis of 1846-1847. The system had been brought in to replace the *taxe du pain*, and compensation thereof, adopted during earlier scarcities. The cost was so high that the compensation system was reinstated during the crisis of 1853.

⁸² Legoyt was of a different opinion: "...the distribution of abundant wages, in 1854, by the widespread development of public works, to a certain extent assuaged the murderous influence of high prices" (1858, p. 361). This fact, combined with better organisation of public assistance, may have limited the death toll to 60,000 as against 107,000 in 1847, when the price had reached an identical high.

⁸³ Dupuit does not mention the effect of diverting labour from other activities, a point insisted upon by Dupin (1848, p. 387) in his analysis of the failure of public works during the Irish famine. This failure, as well as that of the workshops of 1848, led liberal economists, during the siege of Paris, to recommend the distribution of food (in a form that could not be sold on) rather than financial aid (Molinari, 1870, S.E.P., 1870 a & b, Siegfried, 1870).

⁸⁴ Most of these measures are criticised, with arguments very similar to Dupuit's, in an article by Ambroise Clément (1859) published at almost the same time and which welcomes Dupuit's work in a footnote (p. 35). Mannequin (1866, 1868) makes much the same points, also showing that, conversely, no public measure can prevent the price of corn from falling during a glut (1866, pp. 386-388).

or flour reserves; a regulatory fund to stabilise the price of bread. Dupuit accuses the *taxe du pain*,⁸⁵ i.e. the determination of the bread price by the authorities, of "rewarding poor quality" (p. 346), of becoming "inaccurate and unjust" (p. 346), and of removing the incentive to competition (p. 347).

Rather more discussion is accorded to the "reserves of corn or flour in public granaries or at bakers' shops".⁸⁶ Dupuit starts by justifying the role of the speculator⁸⁷ in terms reminiscent of Adam Smith (1776/1904, I.10.49): "If, the day after the harvest, all the harvested corn were brought to market, the consequence would be a depreciation that would ruin the producer, and within the first few months a greater part of the harvest would be consumed than its magnitude would allow, if it is to last the entire year. In the natural way of things, however, this dual inconvenience is avoided, as the farmer, wary of low prices, only brings his corn to market in proportion to his need for money, and when his need causes him to bring too great a quantity to market, the speculator temporarily removes it in order to bring it back when the price is higher, that is, when corn has again become more scarce. This intermediary, by regularising consumption, renders an immense service to society (...). Doubtless, the corn speculator is not motivated by the interest of society, but is

⁸⁵ The right of mayors to set the price of bread was enacted into law in July 1791 and upheld by the decree of 1862 that liberalised the bakery trade. The price of a kilo of bread in Paris was assessed as follows: 11 francs was added to the price of a sack of flour (weighing 157 kg.) and the total was divided by the number of kilos of bread that could be obtained from one sack (i.e. 204). For example, if the price of a sack of flour was 91 francs, then the price of a kilo of bread was 50 centimes (Modeste, 1856, p. 52). This tax, and other bakery regulations, drew widespread criticism (J. Garnier, 1854a & b; Modeste, 1856; Ambroise Clément, 1859; Borie, 1862; Michelant, 1862; Boiteau, 1863; S.E.P., 1867a; J. Clément, 1869).

⁸⁶ At the time this referred to compulsory reserves that Parisian bakers had to deposit in the municipal storehouses. A decree issued in November 1858 had set the size of the reserves to between one and three months' bakery supplies. For Ambroise Clément (1859, pp. 32-33), in addition to constituting reserves against shortages, the decree was aimed at reviving the price of corn, which had fallen very low. The reserves were not used during the crisis of 1861-1862, a fact which Borie hailed as a success (1862, p. 364); the harvest shortfall—estimated at 16 million hectolitres for an annual consumption of 85 million—was made up for by imports. To stabilise the price of corn, Briaune (1857) suggested generalising the system to the whole of France (p. 212) and including the milling industry (pp. 213-215); these measures were to be funded by levying a duty on bread, and backed up with granary subsidies for farmers.

⁸⁷ The economic chronicle of the *Journal des économistes* (vol. 36, n° 147, July 1853, pp. 157-158) mentions an order issued against "hoarders" (*accapareurs*) in the département of Aude.

not the same true of any other industry? (...) the admirable thing about the institution of freedom of work, is precisely that it is to each man's advantage to do, in his own personal interest, that which is most in the general interest, because the more society needs a service, the more society is willing to pay for it"(1859a, p. 347).⁸⁸

Dupuit now contrasts the bureaucratic management of public granaries with that of speculators:⁸⁹"The speculator (...) only buys corn when it is cheap, that is, over-abundant, and sells it when it is expensive, that is, when it is scarce; (...) he adopts the most economical means for its conservation; (...) The quantity of corn stored in the public granary could equally have been stored in the farmer's granary or in the speculator's granary. The question is who—the State, or private interest—can store and conserve the corn at the lower cost?"(p. 348).⁹⁰The bureaucratic management of the public grana-

⁸⁸ This argument is practically identical to those put forward by Young (1794/1860, vol. II, p. 342). All of these authors, following Smith, overlook the possibility of speculative bubbles on the market, as Salim Rashid has pointed out (1980, pp. 496-497). J.-B. Say (1840, vol. 2, p. 185; 1841/1972, p. 205) is perhaps one of the few to draw attention to the limits of speculation, while, in the extreme case, Molinari (1870) defends the role of the speculator even in a situation as exceptional as the siege of Paris. This defence of speculation was again heard during the crisis of 1911-1912, with regard to the workings of the futures markets (S.E.P., 1912). It should be said that Say (1840, vol. 2, pp. 179-187) had his doubts about the effectiveness both of regulation and of free trade in combating shortages, suggesting instead a system of state-subsidised private granaries. This system, used as a backup to the statutory grain stores, was considered by Briaune (1857) to be the only means to ward off subsistence crises. Briaune not only contested the effectiveness of free trade (on the basis that the volumes imported and exported were too low), but also considered that trade cannot carry a surplus over from one year to the next as "when it speculates, it does so from one day to the next" (p. 103).

⁸⁹ The public grain warehouses known as the *greniers d'abondance* had already been systematically criticised by Turgot (1770/1997, pp. 343-354). Unlike Dupuit, Turgot (and also J.-B. Say, 1841/1972, pp. 205-207; A. Clément, 1859, p. 34 and Borie, 1862, pp. 361-365) stressed the conflict between the public granaries policy and the transportation of grain from good-harvest to poor-harvest areas by the free operation of the market. The comparison between public granaries and speculators is also found in Stewart (c.1800/1994, vol. IX, p. 62).

⁹⁰ Assessments of storage costs by Dussard (1853, pp. 177-178) showed that the costs were considerable, and that storage could not be profitable unless the amplitude of price fluctuations remained substantial. For Briaune (1857) the main obstacle to storage by farmers was not cost. He emphasised the lack of financial resources (p. 206), the imbalance of power with trade (p. 206-207) and the "free rider" mentality, which he analysed with remarkable insight (pp. 208-209). Contrary to Briaune, Mannequin (1866) questioned the reality of year-to-year grain storage at that time.

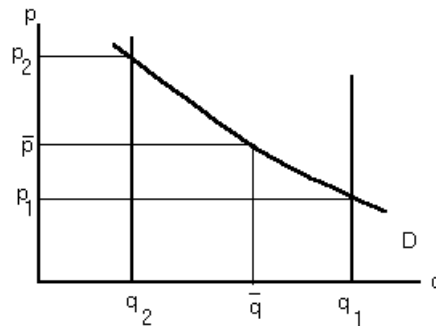
ries is compounded by the fact that the very existence of the granaries will discourage all trade and transport of corn (pp. 348-349).

Finally Dupuit criticises the idea of a "constant and average charge for bread, sustained by a regulatory fund", meaning the implementation of a fixed price for bread:⁹¹ "If it were possible to maintain a constant price, then consumption would also be constant, as there would be no reason to eat less bread one year than the next; however, the consumption of a commodity of variable output cannot be constant..."⁹²

In a year of plenty, when the natural price of bread would be 30 centimes per kilogram, as consumption would be limited by the average [set] price of, say, 45 centimes, an enormous surplus of corn, finding few outlets in industry or exports, would bring the [real] price down to an excessively low level, resulting, certainly, in a great profit for the fund, but in total ruin for the farmer. Thus in years of plenty one would have, on the one hand, people going without bread—whatever the price, it would still be too high for many people—and on the other, people not knowing what to do with their corn. In years of shortage however, consumption, being regulated by the average price, would be inclined to exceed production, and the price of corn would rise to such a level as to make this result impossible; consequently the fund would be emptied and we would be forced to return to the current system of paying for bread at the price dictated by supply and demand" (pp. 349-350). This line of reasoning is illustrated in Graph 5. For an average price of \bar{p} consumption would be constant at \bar{q} , giving a surplus when the harvest is q_1 and a shortage when the harvest is q_2 .

⁹¹ On this subject, Dupuit writes that "many good minds have been beguiled by this idea and are still hesitant, even after the experiment that was attempted" (p. 349). This is presumably a reference to the *Caisse de la Boulangerie de Paris* set up in 1853 by Haussmann, the new Prefect of the Seine. The Caisse—despite the aforementioned attacks on the *taxe du pain* and criticism from other quarters, including J. Garnier (1853) and Pommier (1854)—remained in operation, with differing regulations, up until the fall of the Empire. Its purpose was to finance a stable bread price by paying bakers the difference between the fixed price and the real price of bread (or deducting the difference, when the price was low). It must be said that, despite some fraudulent practices, the Caisse managed to maintain general financial equilibrium in the medium term, and saw Paris through the food crisis of 1853-1856 without popular unrest (Horie, 1984) (for Briaune, however, 1857, p. 260, the absence of subsistence riots was due to the Crimean war). This "unexpected success" (Léon Say, 1867, p. 435) seems to suggest that the Caisse did not entirely deserve the criticisms of the liberal economists.

⁹² This point is discussed in Mannequin's articles (1866, 1868).



Graph 5

Dupuit begins his analysis of governmental measures by swiftly dismissing the idea of a statutory ceiling on corn prices: "The maximum price system is based the same sophism as the average price: it takes no account of the relationship between price and consumption. Any artificial reduction in price leads to a corresponding increase in consumption, and worsens the shortage instead of assuaging it" (p. 351).

From his examination of all of these measures, he concludes that "to combat scarcity in a truly effective manner, one must increase the quantity of corn made available to the consumer" (p. 351) and terminates with a survey of policies that seem to be designed with this objective in mind. The first measure he looks at is the "prohibition on using corn other than for human sustenance". Dupuit reiterates that cereals have few other uses than as food, and that the administration discourages or prohibits these uses depending on the situation,⁹³ whereas they should in fact be encouraged: "... in years of plenty, all industries not engaged in the feeding of humanity, especially those whose products are easily preserved, would use a great deal of corn and would maintain its price (...). After poor harvests, these industries would reduce their output: as the value of their products would not follow the rise in corn, there would be less incentive for them to produce. Their products, being easily preserved and designed to satisfy less pressing needs than hunger,

⁹³ During the crisis of 1853-1855 the distilling of alcohol from cereals was banned by a decree, issued on 26 October 1854. Briaune plays down the problem for France "where, thanks to the culture of the vine, the production of grain alcohols is anyway limited and, when corn becomes expensive, almost disappears altogether" (1857, p. 144).

would undergo far smaller price variations than corn. In an average year, the situation might be as follows:

Consumption of corn	for human sustenance	80 measures	
---	for other uses	20	---
	Total	100	---

If output were to decrease by one tenth, which, as things stand, would perhaps double the price of bread, the new distribution might be very similar to this:

	for human sustenance	76
	for other uses	14
	Total	90

Consumption of corn for human sustenance would lose but one twentieth. The proportion might even be more advantageous, and would certainly be so if the other uses habitually took up a greater fraction of the harvest: a quarter, a third, or even a half. It is beyond doubt that the industries not engaged in the feeding of humanity would then bear, almost alone, all the disadvantages of the shortage, disadvantages which would be less keenly felt insofar as the other products would have the advantage of keeping for longer. The price of bread would then vary no more than that of sugar" (p. 352).⁹⁴

This line of reasoning is very close to that of Torrens (1808) for whom the most effective means for preventing the occurrence of famine was to make alcoholic beverages from corn:⁹⁵"a year of deficient crop may come without producing famine; the corn which was raised to be consumed in the stilleries an breweries will flow in the bakers' shop and supply the wants of the people. The deficient crop will raise the price of bread, of corn-spirit, and of beer, but it will not raise the price of these commodities in the same propor-

⁹⁴ The emergence of alternative uses for corn in low-price periods is mentioned by Boisguilbert (1704/1966, pp. 849 and 851). The stabilising effect of such uses on the consumption of corn for food is noted by Steuart (1767), cited in Stewart (c.1800/1994, vol. IX, pp. 78-79).

⁹⁵ Sugar would appear to be a poor comparison to choose: the figures presented by Block (1861, p. 367) for the period 1846-1850 show that sugar consumption was highly sensitive to "the volume of business", by which he meant income, which could not be the case for corn. Oddly enough, Lauderdale used sugar rather than corn to demonstrate the effects of variation in the supply of goods for which demand is inelastic (1804, pp. 59-72).

⁹⁶ For Torrens this practice was preferable to free trade, as there was no guarantee that a country could make up for its shortfall in corn through imports (an argument also espoused by Mannequin, 1866, pp. 382-383). The only effect of free trade would be to ensure that no country suffered from the shortage more than any other (Torrens, p. 65).

tion; for, when the supply of any two articles is diminished, that which is most necessary will experience the greatest rise. The sensations of hunger being more powerful than the sensations which prompt us to use strong drink, the people, in a time of scarcity, will cease to consume strong drink in order that they may obtain a sufficient supply of food. For example, if each man in the community, after obtaining the necessary supply of habitation and clothing, has, on the average, ten pounds to lay out on food and five pounds to expend on corn-spirit and beer, then it is evident that a deficient crop, which obliges him to give twelve pounds to for his food, will leave him but three pounds to expend on drink. Thus every diminution in the supply of corn must produce a diminution in the demand for corn-spirit and for beer. But as the demand for these articles is diminished, they will cease to be prepared; when corn brings a higher price in the form of bread than in the form of intoxicating liquors, it will flow from the stilleries and breweries into the bakers' shop" (Torrens, 1808, pp. 67-68).⁹⁷ Dupuit, like Torrens, held that rises in the price of corn had a greater impact on the price of bread than on the price of strong drink, and that corn usage was allocated between the two end products on the basis of their relative increase in price.

We can assess the effect of attenuating price variation, as suggested by Dupuit, by applying his figures to the model proposed in the first section. The subsistence supply in equations (1) and (9) would now be $q - q_a$ instead of q , with q_a being the quantity of corn used for ends other than flour and bread. The term $\frac{q'}{q}$ in equations (5), (8) and (15) would

⁹⁷ In modern terms we would say that Torrens was describing an (uncompensated) cross-price effect in which corn alcohol or beer were gross complements of bread: because of the low direct price elasticity of demand for bread, higher bread prices lead to higher spending on bread, which implies a fall in spending on, and demand for, alcohol. The mechanism is identical to that of the Ancien Régime crisis, but in this case there is no industrial crisis because the sacrifices the poor make for bread affect alcoholic drinks exclusively, and not industrial goods. This transfer of spending accentuates the upward pressure on the bread price, but is offset by the transfer of corn supply from the brewery to the bakery. Conversely, if demand for alcohol is price-elastic, higher alcohol prices will lead to lower spending on alcohol, and consequently higher spending on other goods, including bread, which then becomes a gross substitute for beer or spirits. This exposition seems more complete than the one proposed by Endres (1987, p. 626), who considers that Lauderdale and Torrens both assume a zero revenue effect for bread and a positive one for alcohol. In fact Torrens' reasoning is based on a hierarchy of needs, with individuals first satisfying their more immediate needs, leaving other needs to compete for whatever wealth is left over, as we see from the passage where the money set aside for bread and alcohol is determined only once the need for a roof over one's head has been satisfied.

be replaced by $\frac{q'-q_a}{q-q_a} = \frac{q'(1-x')}{q(1-x)}$, where x and x' are the share of alternative corn usage in normal years and in poor years respectively. On the basis of Dupuit's figures, this means replacing 0.9 by 0.95. And so, in the model that makes the sole assumption of fixed consumption by the rich, equation (5) would become

$$(5') \quad \frac{p'}{p} = \frac{1-y_1}{\frac{q'(1-x')}{q(1-x)} - y_1}$$

and a 10% decrease in the harvest would cause a price rise of 11.11% instead of 25%. In this case, alternative corn usages prevent King's law from coming into play since $\frac{p'}{p} = \frac{q}{q'} = 1.1111$, a result that implies the

condition $\frac{1-x'}{1-x} = 1 - y_1 \left(1 - \frac{q}{q'}\right)$, which is verified here. In the two other

models, by contrast—which, unlike the previous one, correspond to Dupuit's initial figures—the change in subsistence supply would lead to a price rise of 77.6% instead of 100%: alternative corn usages reduce variations in the price of corn, although the figures put forward by Dupuit are insufficient to annul King's law.⁹⁸ It thus emerges that Dupuit's reasoning is only borne out by the model from the first section that does not actually fit his figures; it is not borne out by the models that do fit the figures.⁹⁹

Dupuit's next target is the "special and direct encouragements given to agriculture". He observes that "the tendency of all government actions is to push for greater agricultural output" (p. 354) by means of preferential transport tariffs, bonuses, subsidies, tax benefits etc., all of which he condemns: "I do not think that these efforts have the slightest favourable influence on food crises, since such crises are due (...) not to the habitual insufficiency of harvests, but to their irregularity. If these mechanisms were fully as

⁹⁸ If we stay within the model from the first section, the mechanism described by Torrens can restrict but not entirely annul King's law. While the spending of the non-excluded poor is diverted from beer and spirits to bread, the overall share of their spending devoted to bread remains unchanged, which means that equation (9) is replaced by equation (6), giving a smaller relative variation in the price of corn, although still larger than that of the actual harvest.

⁹⁹ A more modern approach to Dupuit's example can be found in Annex 3.

effective as is claimed, then by increasing agricultural output by, say, one tenth, they would of necessity increase the population by the same proportion, and nothing would be changed to make the problem any less difficult to solve"(p. 354).¹⁰⁰¹⁰¹ And anyway"...agriculture is not the only means for a land to obtain corn, as its inhabitants make up for its shortcomings in that respect by exchanging other products of the soil or manufactured goods. There are very numerous populations that live in relative abundance though they rarely cultivate the thankless soil on which they live. For these peoples, the surest way of obtaining corn is to make watches, to spin cotton or to weave fabrics"(p. 354) and it would be an error for these countries to subsidise agriculture to the detriment of other industries. This tribute to international specialisation is followed by an overarching denunciation of subsidy in all its forms: "the State can give nothing to an industry without taking it from another, and as the State is duty bound to encourage every industry, it follows that it not only encourages none, but in fact it puts them all in a worse position than if it had left them well alone" (p. 355).

The article ends with a long dissertation on the freedom of import and export, or the degrees thereof. Dupuit repeats that the corn harvest is variable by definition but "the greater the expanse of land, the smaller the variation. (...) as a result, scarcities are, strictly speaking, always a local problem, and if the means of transport and lines of communication were so developed that the costs of carrying such a heavy and cumbersome material as corn were

¹⁰⁰ Likewise Briau felt that "no agricultural progress can preserve a nation from the periodic inequality of harvests, and wherever industry produces 'another man for every loaf of bread' the periodic recurrence of high prices is inevitable" (1857, p. 141).

¹⁰¹ Dupuit was at odds, in this respect, with many of his contemporaries who saw agricultural growth as a way of eradicating famine. This ignored the respective evolution of corn production and population in France (Fontenay, S.E.P., 1853, p. 449). Wolowski (S.E.P., 1865a), Magne (1865), Lavergne (S.E.P., 1866, p. 479) and Cerfberr (1866) attributed the low price of corn in France from 1884 to 1886 to overproduction due to strong growth in corn output at a time when the population was almost stationary, although Delaunay (1850, pp. 373-375), Blaise (1883) and F. Bernard (1884) noted that while corn production was growing faster than the population, corn consumption per head was growing faster still, leading to a regular increase in import volumes. To those who saw demographic growth as a solution to the slump in agricultural prices, Dupuit replied with an ironic vision of agricultural progress: "It would be a daunting task indeed for our young households if, given an increase in production of 30% as the result of the artificial fertilisation of cereals, they had to make up for the corresponding shortfall in the population; the miracles of spontaneous generation would be more than welcome" (S.E.P., 1866, p. 489). This gibe is a long way from the principle of population espoused in his articles of 1859 and 1865. Growth in output did not prevent this period of low prices being followed by a price spike in 1867-1868.

rendered next to nil, then people need almost never suffer from scarcity.¹⁰² Unfortunately this is not the case: a perfect levelling can never be attained, neither in quantity nor in price. There must be enough difference between the price of corn in the country where it is sought and that in the country to which it is brought to cover the transport costs and the profits of all who practice such a trade" (p. 356),¹⁰³ and hence "...everything that favours or facilitates the transport of corn from one country to another tends inevitably to smooth away the effects of inequality in harvests, and consequently the causes and hardships of scarcity" (p. 357).¹⁰⁴

Freedom of exchange is resisted by certain social categories because it would alter the distribution of wealth. Farmers would initially see their proceeds diminish, but this reduction would be reflected in land rents: "But this diminution is no more than a change in the distribution of wealth, not a loss in the strict sense (...) the landowner's loss is the consumer's gain, no more¹⁰⁵ (...) this difference in price has neither created nor destroyed

¹⁰² The same view is found in Adam Smith (1776, IV.5.78) and in Ricardo (1815, keyword 'dearths').

¹⁰³ Dupuit even observes: "...that not only is the price of corn not the same the length and breadth of France, but there are often quite large differences between markets not far apart. Sometimes even, despite price differences that would more than suffice to cover the cost of transport, speculators refrain from any commercial operation between the two markets, knowing perfectly well that supplying a few bushels from one market to meet the demand for a few bushels on the other would suffice to level out the prices, with the result that the quantity that could profitably be transported would be too small to cover the overhead costs inherent in any undertaking" (pp. 356-357). Juglar attributed the differences in domestic prices, often greater than the mean difference between France and other countries, to the fact "that the quantity of corn demanded by the market is not variable, as it is for other commodities; one only makes as much corn as can be consumed (...). If then one removes, from an internal market, the corn that was meant to supply it, and takes it to a more advantageous market, then prices immediately rise, and private interest commands that such trade cease..." (1853, p. 154). This kind of reasoning could easily be used against international trade in subsistence resources.

¹⁰⁴ Apart from the critique of the effects of the sliding scale, none of the subsequent arguments were recycled in *La liberté commerciale*.

¹⁰⁵ Here we have the argument used by the campaigners against the English Corn Laws. Jeffrey Williamson's (1990) study of the effects of the Corn Laws, which shows that they were in large part responsible for the growing disparities of income in early 19th-century England, confirms Dupuit's conclusions. In two later debates (S.E.P., 1865a, 1866) Dupuit reaffirms that the low price of corn (a desirable thing, in his view), whether it results from free trade or from agricultural progress, is borne exclusively by landowners. In the second debate he compares the landowners' losses with those that would be sustained by the health professions if medical advances were to eradicate

wealth. The nation, in this regard, has lost nothing and gained nothing; but it has made a beneficial exchange of less useful products for sorely needed corn" (p. 357).

Freedom of import, moreover, has the effect of protecting the poorer classes against scarcity by redistributing wealth in their favour: "...the sufferings of these classes are considerably diminished, for while the poor are better fed, they are at the same time better housed and better dressed. But the rich classes—who would have consumed the indigenous products that the country has been obliged to trade for imported corn, or the imported products that would otherwise have been obtained in exchange—are adversely affected, forced to accept privations that they would have been spared if the foreign corn had not been allowed in. These, then, are the consequences of the importation: the imported corn, initially paid for in specie, leads to a monetary crisis, that is, the depreciation of every kind of commodity; this depreciation in turn stimulates exports (...) and sooner or later the balance is re-established, meaning that the country, coming into possession of the same quantity of gold and silver that it formerly held, has ultimately paid for the imported corn with commodities. Free trade in grain therefore alleviates the sufferings of the poor classes in those countries where the grain is imported, and imposes upon the rich classes certain privations that they would not have had to endure under the system of isolation" (p. 358). For Dupuit, then, redistribution in favour of the poor works not only to the detriment of land rents, but to the detriment of the rich as a whole. This result relies on the monetary process of re-establishing the balance of trade, to which Dupuit refers in *La liberté commerciale* (1861a, pp. 55-62) to illustrate that, in international trade, products are exchanged for products: in this case, corn for indigenous products.

It is important to note that, for Dupuit in the 1859 article, the free import of grain simultaneously combats the dual causes of famine: both the harvest shortage, and the poverty that underlies the asymmetry of its impact. Looking at the issue the other way round, from Ghose's perspective, the prohibition of trade could be seen both as a factor in mass poverty, through its effect on income distribution, and as a factor in famine, as it prevents local shortages from being made good. The question arises, however, as to whether Dupuit's reasoning is not in contradiction with some of his earlier arguments. He rejected agricultural subsidies on the grounds that the resulting increase in agricultural production would be

disease: "Should we, in order to protect them, stage a debate to decide whether to hold on to our old diseases?" (p. 489).

absorbed by an equivalent increase in population; yet an increase in the quantity of subsistence through imports would have the same effect in the long term, especially as Dupuit points out that the poor would be better fed. This would eventually lead to an increase in the population, and the problem of poverty would again rear its ugly head. This oversight seems all the more curious when one reads Dupuit's own words, in another free trade tract: "For as long as England prohibited cereal imports, her population was limited by the quantity of subsistence that her soil could provide; but when she opened up her markets, the limit on her population was pushed back by the total quantity of subsistence that she could obtain by means of her other products (...) so that farm land rents, which had at first declined under the influence of foreign corn imports, revived again under the influence of the increased population" (1860, p. 517). Likewise in the 1865 article he writes: "If in Belgium and England population growth is somewhat less slow [than in France], this should not be attributed to agriculture making more rapid advances in those countries, but rather to industrial progress, which enables them to exchange a greater number of products for subsistence goods" (1865a, p. 23).¹⁰⁶

The critical point is then, after all, the one he makes at the outset, namely that free trade reduces variation in the quantities of subsistence available to the country, and thereby variation in its price. This is indeed the only point that he went on to develop in *La liberté commerciale*. Dupuit also writes, in another chapter of that book, that while free trade is the only remedy against scarcity, it will not put an end to poverty: "Poverty is far more the consequence of individual and personal failings than of economic institutions. I will readily admit that in a great country such as France, if there were none but honest, industrious, intelligent and provident men, there would be no poverty, even with a more prohibitive regime than the one that we had. The eradication of poverty is therefore more a moral question than an economic one. (...) As for that poverty that originates in the vices of the individual, political economy can do nothing. To abolish it would require an assault on

¹⁰⁶ It might be suggested that, under conditions of free trade, Dupuit's objections about measures designed to increase the purchasing power of the poor would cease to apply, as the resulting increase in demand would be met by imports. Indeed, in a debate that took place after Dupuit's death, Clamageran declared that the price rises caused by poor relief would result in increased cereal imports, thereby re-establishing the equilibrium between supply and demand (S.E.P., 1867b, pp. 304-305). Briaune went further still, considering that imports, since they could not bring down the price of grain, made it necessary to undertake "unproductive or untimely labour projects, in order to raise wages to the level of commodity prices; with special assistance for families who cannot earn their food by their own labour" (1857, p. 258).

individual freedom, which is so much more precious than the freedom of trade"(1861a, p. 144). And so freedom of exchange, which in the article of 1859 provided a course of action against the twin causes of scarcity—insufficient harvests, and the asymmetry of their impact, due to poverty—can now, in the book of 1861, only remedy the first.

If we set aside all claims other than the effect of free trade on variations in quantity and price, we are left with a reiteration of the arguments put forward by Quesnay one hundred years earlier. The reference to Quesnay becomes inescapable when, at the end of his article, Dupuit develops a line of analysis that seems largely inspired by the tables in Quesnay's article *Grains* (1757). The analysis is presented in support of Dupuit's rejection of the "sliding scale", a system of customs duties that was adjusted in accordance with the size of the harvest¹⁰⁷ and which, he asserted, led to the following results:

"Abundant harvest: exit permitted, entry prohibited.

Average harvest: entry and exit prohibited.

Insufficient harvest: entry permitted, exit prohibited" (p. 359).

Such a system, in his view, openly licences the behaviour of hunger rioters appealing to what has been called "the moral economy".¹⁰⁸ It would above all be harmful because international trade in grain cannot be established without stable and constant relationships (pp. 359-361). To those who claim that the abolition of the sliding scale would lead to a collapse in the price of corn and the abandonment of agriculture, he replies:"We have examined the fate of the farmer in the system of national isolation, be it natural or artificial; we saw that he was not affected by the abundance of harvests in the same way as the rest of the population; that the abundance that assured the welfare of the latter became a cause of poverty and ruin for the farmer, while scarcity in a certain measure procured him great profits. This diversity of interests is most unfortunate. (...) Not only does free trade in grains (...) alleviate the suffering caused by scarcity, it (...) removes this antagonism between the interests of the producer and those of the consumer. It clearly acts to rein in the limits of the price of corn, making it roughly constant,

¹⁰⁷ First developed in Britain, this system—introduced into France by a series of laws from 1814 to 1833 and repealed in 1861 (A. Bernard, 1868)—was supposed to maintain the price of a hectolitre of wheat at 20 fr, however, this was rarely achieved (Delaunay, 1859). It spawned many articles, enquiries and debates, in one of which Dupuit took part, using free trade arguments akin to those in his article (S.E.P., 1859).

¹⁰⁸ This argument was developed in the form of a sketch by Molinari (1854c and 1855a).

since with imports and exports respectively bringing in or taking away a greater or lesser amount of corn, depending on the abundance of the harvest, supply and demand remain generally stable. As a result the profits of the nation's corn producers come out roughly proportional to the quantity they harvested, and their prosperity never stands in contrast to public misery (...).

The advantage of a stable corn price is, admittedly, counterbalanced by greater variation in the profits of agriculture. Under the isolation system, the price rises quickly when the harvest diminishes, and the farmer is thereby compensated for the lack of quantity, just as in years of plenty a large quantity to some degree compensates for plummeting prices.

Some figures may help us to understand this economic outcome:

Let us suppose that the price of corn currently oscillates between 15 and 35 fr.

And that for landowners the harvest varies between 200 and 100 measures.

Their profits vary between 3 000 and 3 500 fr.

The variance is only 500 fr.

With free trade in cereals the price will oscillate only between 20 and 25 fr.¹⁰⁹

While the harvest still varies between 200 and 100 measures.

Profits now vary between 4000 and 2500 francs.

With a variance of 1500 francs

Thus, under isolation, profit corresponds to scarcity, while under free trade, it corresponds to abundance; the variance, however, is three times greater, although the average profit is the same.

This variation is without doubt problematic (...) but (...) harvests are variable, corn cannot be kept, and no economic measures can sweep away all of the implications of this for both consumers and producers. The consumer, however, cannot wait (...) whereas the producer can set aside the profits of one year to cover the losses of the next. One should therefore have no hesitation" (pp. 361-362).

The similarity between this example and the tables of Quesnay, Dupont de Nemours or Turgot is striking. A detailed comparison can be found in Annex 4; suffice it to say here that although Quesnay and Dupuit both seek to demonstrate that free trade in grain can reconcile the

¹⁰⁹ Dupuit did not choose his figures at random: he assumes a price minimum of 20 francs, which was the goal of the sliding scale and the price deemed at the time to represent the break-even point (Molinari, 1854a, p. 321). The figure of 20 francs per hectolitre, described by des Essars as "sacramental" (S.S.P, 1897, p. 72), was still being used as a basis for customs duty calculations in 1894, although F. Bernard (1897) showed that it was well above the cost price.

previously conflicting interests of farmers and consumers, they clash over the effects of free trade on the price of corn: Quesnay sets out to show that trade would improve the farmers' situation by increasing the price of corn without damaging the interests of the consumers, while Dupuit aims to prove that it will improve the consumers' situation by lowering the price of corn without damaging the interests of the farmers.¹¹⁰ In each case, however, the convergence of interests results from the fact that free trade has transformed the situation from one where prices vary proportionally more than the harvest to one where prices vary proportionally less than the harvest.¹¹¹¹¹²

Dupuit does not seem totally convinced by his own numerical example, which might explain why it was left out of *La liberté commerciale*; he immediately puts the question: "But what would ultimately become of agriculture if it were thus abandoned, without protection, to the vagaries of free trade and crop yields?"¹¹³ (...) With these greater variations in agricultural prof-

¹¹⁰ The debate on the sliding scale of corn duties (S.E.P., 1859) shows that Dupuit was one of the few who thought that free trade would bring down the price of corn in France. The other participants in the debate, implicitly rallying to Quesnay's position, thought that the price of corn would rise. The authors cited earlier who attributed the low prices of 1864-1866 to agricultural overproduction insisted on the fact that the low prices were not due to the abolition of the sliding scale, since France had a positive trade balance in corn.

¹¹¹ Dupuit's concern to explain the reasoning behind this reconciliation contrasts with the inane optimism of Wolowski, who volunteered, in a debate in which Dupuit also took part, that "With free trade, everyone profits equitably from the riches of the soil and the free gifts of Providence; no-one is sacrificed, neither the producer, nor the consumer; liberty is the inseparable companion of justice" (S.E.P., 1866, p. 495). Earlier, Faucher had written that "free trade is among the designs of Providence" (Académie des Sciences Morales et Politiques, 1850, p. 300).

¹¹² This argument was recycled by Guyot (1911, p. 22) with regard to the crisis of 1911 (for a popular protectionist refutation of that particular argument, see Anonymous 1912/2002). In Dupuit's day, these conclusions were contested by Briaune (1857), although he had concurred with them in 1845. For one thing, he observed that fluctuations in the corn price in Britain were greater after free trade than they had been before (p. 190), but this tells us nothing in the absence of statistics about quantity. For another, he suggested, on the basis of French price statistics, that given constant consumption, farmers and consumers alike would gain more from a system of producer-managed corn reserves than from free trade. This runs contrary to Quesnay's affirmation but is in line with the findings of the modern theory of storage (Makki, Miranda and Tweeten, 1996).

¹¹³ The question was an important one: a central argument of free trade opponents was the danger of laying waste the nation's agriculture. The liberal J. Simon (1880, p. 461)

its, what would become of the average profit? In a word, would the farmer be richer or poorer?" (p. 363). He answers his own question by citing the experience of other countries (notably the repeal of the Corn Laws in Britain). For Dupuit, however, the key analogy is the situation in France resulting from internal free trade, which nobody would seek to abolish. And in the extreme case of cultivation having to be abandoned in certain regions,¹¹⁴ "...that would prove one thing only: that the regime of protection had forced the inhabitants of certain provinces to eke from the land, through dogged labour, commodities they could more easily have obtained by making other products and exchanging them (...).

There is therefore no cause for concern about the effect that free trade in grain would have on agriculture or industry in the country where it was proclaimed; whatever the effect, it would necessarily increase the volume of products that the country could consume, while reducing the quantity of labour required to obtain them" (pp. 364-365).¹¹⁵

Dupuit rounds off his article with a liberal economist's profession of faith: "Having examined all the means and all the expedients thought up by governments and individuals alike to assuage the ill effects of food shortages, we have arrived at the conclusion that the only effective measure is that great

conveys this argument by means of the now familiar fortress metaphor: "When our fields have been turned into deserts, we will no longer, as today, run the unlikely risk of suffering famine in the event of scarcity; we will instead depend constantly and irremediably on others. (...) A nation cannot just blithely place itself in the position of a fortress that is supplied with everything, except food."

¹¹⁴ Briaune (1857, pp. 194-196) thought that internal free trade had led to a the concentration of corn farming in regions of France that were subject to the same climate conditions—a situation that made it harder to make up for harvest shortfalls—and feared that free trade could have the same result.

¹¹⁵ At no point does Dupuit imagine that free trade in grain could lead to the loss of entitlement for an entire country, a fear which lay behind popular riots against exports. Just such a loss is envisaged by J.-B. Say: "one may have neighbours, such as the English, for whom the production of corn, as a result of taxes, is so expensive that its price constantly exceeds that of the same commodity on our own markets. Consequently, after a poor season, when England allows in corn imports, although the price of corn will be high in France, it will be still higher in England; and individuals will find it in their interest to export subsistence crops that are already too scarce here in France" (1840, vol. 2, p. 180). This argument, subsequently developed by Briaune (1857, pp. 193-194), overlooks the fact that in this case there must be other, cheaper, sources of supply than France, but in the same order of ideas one can point to the flour shortage in Argentina in March 2002, following massive corn exports driven by the depreciation of the peso against the dollar.

principle: *Laissez faire ! Laissez passer !*¹¹⁶ For the odd thing about political economy, it must be said, is this: that it is not even necessary to know its most elementary principles in order to resolve its most difficult problems. The corn question, the sugar question, the iron question, the meat question, the bread question, etc., etc., all of these are resolved in the same way and can be resolved in no other way. The task of the economist in these questions is not to seek out a solution—which is to be found in the four sacramental words just quoted—but rather to refute, one by one, the errors spawned by the inventive imaginations of the protectionists, and to dispel the illusions which delay the advent of the true solution. That is the aim of this study" (p. 365).¹¹⁷

Chapter 21 of *La liberté commerciale*, by contrast, culminates on a more neutral note: "...as shortages are caused by inequality in local harvests, the only effective remedy that can be proposed lies in a system designed to make good the shortfalls found in some areas with the surpluses of production found in others"(1861a, p. 167).¹¹⁸¹¹⁹

¹¹⁶ This was the dominant position in Britain in the 19th century, indeed from Smith onwards, and goes a long way towards explaining successive British governments' policy of non-intervention in Indian famines (Rashid, 1980, pp. 500-502; S.E.P., 1867b, pp. 298-299).

¹¹⁷ This ultra-liberal conclusion qualifies Dupuit for membership of the group of French liberal economists derided by Léon Walras when he wrote: "Most of them have four words: *laissez - faire, laissez - passer*, the simple utterance of which represents in their eyes the whole of science, pure and applied. As you can see, theirs is an easily learned science, one you could quickly teach to a parrot, in the space of a morning, with the help of a few sugarlumps. You only need to press them a little, and their ambition soon becomes clear: to elevate the principle of free competition into a sort of infallible religious dogma" (1876/1987, p. 302). Walras omits to mention that he himself once subscribed to the same dogma (L. Walras, 1860, p. 390). The hard-line liberalism found in the conclusions of Dupuit, Cherbuliez or Molinari contrasts with the moderate conclusion to J.-B. Say's *Traité*: "To return to the corn-trade, I must protest against the indiscriminate and universal application of the arguments I have adduced to show the benefits of liberty. Nothing is more dangerous in practice, than an obstinate, unbending adherence to system, particularly in its application to the wants and errors of mankind" (1819/1972, p. 212; 1855, I.XVII.158). Say's position here is close to that adopted by the members of the Société d'Economie Politique in 1867.

¹¹⁸ Dupuit's article contradicts Yves Charbit's assertion that for the French liberal economists "opening the borders was never evoked as a means for resolving subsistence crises" (1981, p. 20), which he attributes to the fact that "France, unlike Britain, was not dependent on the outside world for its grain supply" (p. 19-20). This argument echoes the confusion denounced by Dupuit at the start of his article: subsistence crises are not linked to the level of grain output, but to variations in output. Britain had to import grain, but had not experienced famine since the 17th century. France was almost self-sufficient at the start of the 19th century, but experienced subsistence crises, and

3. THE RELATIONSHIP BETWEEN POPULATION AND SUBSISTENCE PRODUCTION

Dupuit's article of 1865, with its assertions that "newcomers, not finding the necessary subsistence, are pitilessly kept down by misery" (1865a, p. 12) and "nowhere, indeed, has the population ever outstripped its subsistence: everywhere, death has kept good order" (p. 25), can be read as an illustration and defence of the "nature's feast" allegory, whereas in 1859 he had seemed reticent towards that formula. Much of the article consists of a statistical study—analysed in another contribution to this volume—demonstrating that, for the various *départements* of France, a higher birth rate corresponds to a lower mean length of life. From this study, and from a comparison of population trends in a number of countries, Dupuit concludes that population growth is driven by increases in the means of subsistence, produced nationally or imported, and that the average lifespan varies inversely to the nation's fertility. This inverse relationship stems from the fact that an unsustainably high fertility relative to the available subsistence leads to a degradation in living conditions and thence to shorter life expectancy: "The cause of the average length of life is therefore not physiological but economic. Clearly, when the immense majority of deaths occur in childhood, in adolescence, in the prime of life, what these untimely victims lack is not the natural vital impulse, but what economists

eventually self-sufficiency disappeared, along with the crises. Articles by Molinari and Cherbuliez (1854) (who, though not French, rank as honorary French liberals), and by du Puynode (1847), J. Simon (1880), Guyot (1911) and numerous passages from Bastiat's writings also weigh against Charbit's statement. Briaune, who described the partisans of free trade in grain as "the rabble that always follows the prevailing school" (1857, p. 268), wrote that "free trade in grain (...) makes itself out to be the antidote to scarcity" (p. 182).

¹¹⁹ The opponents of free trade in grain always highlighted the difficulty and cost of transporting the required quantities. The corn deficit in France in 1854, for example, was estimated at the time by the authorities as equivalent to 4,000 shiploads; Horii (1984, p. 375) even puts the figure at twice that amount. Another commonly adduced argument was that of political upheaval: in 1854 corn imports rose by only 14.7% compared with 1853, whereas they had doubled between 1846 and 1847 (Horii, pp. 375-376), largely because the Crimean war had cut off France's main source of supply in southern Russia (incidentally leading to the development of corn farming in Algeria) (Saint Julien, 1861, p. 123-124), but also because of the rise in freight prices. Imports did however make up for the harvest shortfall of 1861, rendering unnecessary the regulatory measures that had been put in place, such as the *Caisse de la Boulangerie* and the bakers' reserves (Borie, 1862).

call subsistence; by which is meant everything that is necessary for survival. In our civilised societies, no one dies a violent death from hunger (...). But people do die from the prolonged insufficiency, or poor quality, of subsistence, which comprises not only food, but housing and clothing; people die from excessive labour for their age or sex" (p. 6).

The notion of subsistence is broader here than in the 1859 article: it is no longer assimilated exclusively to food and specifically to corn. The emphasis, moreover, is no longer on the risk of shortage or famine but on chronic malnutrition, which has become a more significant factor than subsistence crises in reducing life expectancy.¹²⁰ Dupuit nonetheless warns that we should not "believe that the limit imposed upon population by subsistence is one and invariable" (p. 26) and dusts down the ship-cum-beleaguered garrison allegory, for which he evidently harboured a special fondness: "On a ship, or in a besieged town, when supplies start to run low, one issues the crew or inhabitants with rations that are often well below the ordinary ration. This results not in violent death, but in a general weakening that shortens the life of the weakest organisations [sic]" (p. 26). He goes on: "It is therefore a mistake to assume that a given quantity of subsistence corresponds to a set population. With a certain population figure, each inhabitant can live without hardship, adequately fed, clothed, housed and sheltered from the elements; with a larger figure, and thus a smaller ration of subsistence, hardship will take its toll on health and will shorten the average life; finally, as the population grows ever larger, so poverty will increase in proportion, until its ravages reach the limit of the fertility of the species, at which point the population will become stationary" (p. 26).¹²¹ Dupuit concludes "For a country that

¹²⁰ There is an instructive comparison here with Robert Fogel's work (1992, 1994) showing that the decline in the Europe's death rate in the 18th and 19th centuries is attributable more to the reduction in chronic malnutrition than to the disappearance of mortality peaks following poor harvests.

¹²¹ Note Dupuit's position on the causes of poverty. Here, poverty results above all from overpopulation. He later wrote, in reply to Baudrillart "that [the author] did not say that population was the *one and only* cause of poverty; he recognises that there are others, that bad laws, bad taxes and bad governments doubtless all take their share of the blame, but overpopulation is the principal cause" (S.E.P., 1862e, p. 477). In *La liberté commerciale*, as we saw, he plays down the role of institutions; poverty is the result of individual behaviours (including reproductive behaviour). In another debate (S.E.P., 1863, pp. 346-347) he maintains that no improvement in society can alleviate poverty unless demographic growth is brought under control. At the same date, reviewing a book by Molinari, Dupuit writes "those who refuse to accept Malthus and the effects of individual provision are obliged to blame poverty on the vices of society, to demand that it be reformed in accordance with some preconceived system, and, swept along by

provides a certain quantity of subsistence, there is therefore one limit which the population must not pass, if it is to enjoy the full span of life allotted to its kind, and another limit which it cannot pass, as its fertility would then no longer suffice to replace those who die before their time. All the populations on earth maintain themselves between these two limits"(p. 27).¹²² And the exact position of a country between these two limits depends not on economic progress, but on the size of its birth rate.

This degradation in living conditions, caused by the population outgrowing its subsistence, is suffered by the poor and not by the rich, just as, in the 1859 article, the reduction in per capita subsistence following a poor harvest affected the poor and not the rich, who if anything benefited by it. In this case, the reduction in per capita subsistence as the result of population growth affects only the poor, while the rich again benefit, due to increased inequality of income:"If one cares to examine the consequences of the economic laws that govern the distribution of wealth, one finds that (...) overpopulation increases the inequality of provision, adding to the surplus of the rich and subtracting from the essentials of the poor. When the population is too numerous, capital is scarce; it is much sought after, and charges dearly for its services. Labour, however, is plentiful, and its price falls as a result of supply. (...)¹²³In those countries where, to the contrary, there is insufficient population, workers are paid high wages,¹²⁴ and land is sold or rented cheaply, in a word, production is shared out more equally. Nothing, therefore, could be more aristocratic than overpopulation, and nothing more democratic than underpopulation" (p. 29).

Suddenly, and with no apparent logic, Dupuit changes tack:"What do the workers constantly demand? Two contradictory things: shorter working

logic, they end up falling into socialism" (1863a, p. 115). By contrast, Proudhon in 1846 and Achille Guillard in 1855, who both opposed Malthus' ideas, refused to attribute poverty to overpopulation.

¹²² This argument bears comparison with one of Fogel's findings: "Rather than one level of subsistence, there are numerous levels at which a population and a food supply can be in equilibrium (...). However, some levels will have smaller people and higher "normal" (non-crisis) mortality than others" (1994, p. 377).

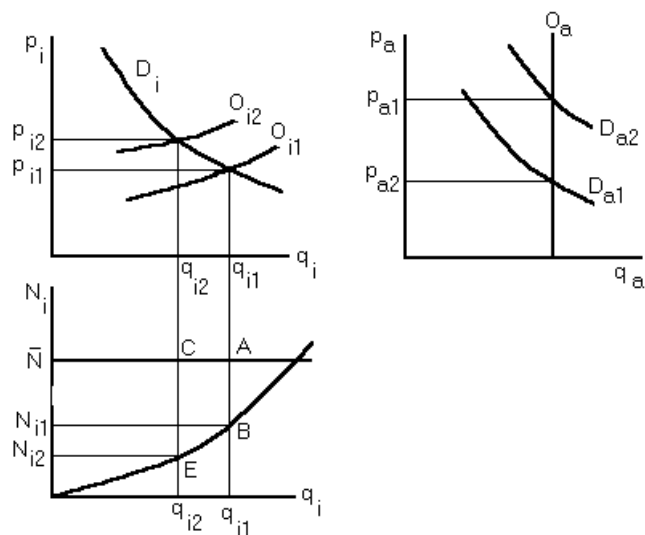
¹²³ It is at this point that Dupuit inserts the passage quoted at the beginning of this article, arguing that higher subsistence prices increase labour supply and depress wages. Without going into the theoretical validity of this argument, it is clear that the two analyses do not operate at the same level.

¹²⁴Dupuit's argument runs contrary to H. Passy's contention (S.E.P., 1863, pp. 336-337) that a decline in population could, by reducing the market for industry and by depriving industry of labour, lead to a fall in wages.

hours and higher wages. How can one obtain more with less production? Clearly this is impossible. If we accept for a moment that working hours are reduced in all the workshops, that the children are turned away and packed off to school, and their mothers sent home to cook the family meal and mend the clothes, which is highly desirable in every regard, then overall output will diminish by the equivalent of their labour, and inevitably, if the population remains the same, workers' wages will diminish by an even greater proportion"(p. 29).

For a clearer understanding of what Dupuit meant by lower wages, this fine example of reactionary rhetoric, founded on what Hirschman (1988) termed the "perversity" and "jeopardy" theses, can be read alongside a contribution by Dupuit to a debate, reproduced in the same issue of the *Journal des économistes*, on workers' rights to strike and to form coalitions. For Dupuit, any increase in wage rates as a result of collective action necessarily entails a reduction in the number of working days. Starting from the basis of a wage of 5 francs a day for 200 actual working days out of a possible 300—i.e. Fr 1,000 a year—he argues that increasing the rate to Fr 6 a day will cut the number of working days to 160, a loss of 40 working days and 40 francs in annual earnings: "thus, although the workers obtain a higher wage rate, it would be a mistake to conclude that they obtain higher wages. Indeed how could they, without increasing production? Take a household that consumes 200 kilos of meat and 2 hectolitres of wine; now, thanks to an agreement concluded between certain bosses and certain workers, that same household can consume 300 kilos of meat and 3 hectolitres of wine, and yet the output of meat and of wine is no greater than it was before. What happens is that everything goes up in price, and the worker obtains no more with his new wages than he did with the old. The manufacturer, faced with higher wages, will increase the price of his commodity; to believe otherwise is delusion (...). The only result is a decline in the consumption of the object manufactured, leading firstly to a reduction in the demand for labour, and subsequently to unemployment for a number of workers, or more accurately an increase in the number of days of unemployment"¹²⁵(S.E.P., 1865c, pp. 117-118).

¹²⁵ This reasoning is practically identical to that put forward in 1846 by Proudhon in his *Philosophie de la misère* (1872, vol. 1, pp. 119-120). It was this type of argument that later sparked Zamanski's response (1908, 1911).



Graph 6

This less than coherent line of reasoning is represented in Graph 6, which distinguishes markets for agricultural and industrial goods. The rise in workers' rates of pay (in Dupuit's example they were typesetters) is reflected by the displacement of the subsistence demand curve from D_{a1} to D_{a2} which, as the supply O_a is constant, corresponds to an increase in price from p_{a1} to p_{a2} , bringing the real wage rate back down to its initial level. As a result of the rise in the nominal (money) wage rate the supply of industrial goods is displaced from O_{i1} to O_{i2} which, due to the downward slope of the demand curve for these goods D_i , corresponds to an increase in price from p_{i1} to p_{i2} and a decline in output from q_{i1} to q_{i2} . This decline in turn leads to a drop in labour demand from N_{i1} to N_{i2} , which may be proportionally larger than the increase in the nominal wage rate, whence a diminution in the product wN . The labour supply being \bar{N} , the drop in labour demand results in an increase in unemployment from AB to CE .

Among the measures that come in for criticism, Dupuit is particularly insistent on the subject of child labour. In his view, banning children from the workplace, though in itself a desirable measure, will only succeed in reducing their families to misery: "...these children are no longer at the factory, but neither are they at school, nor at home—how could their

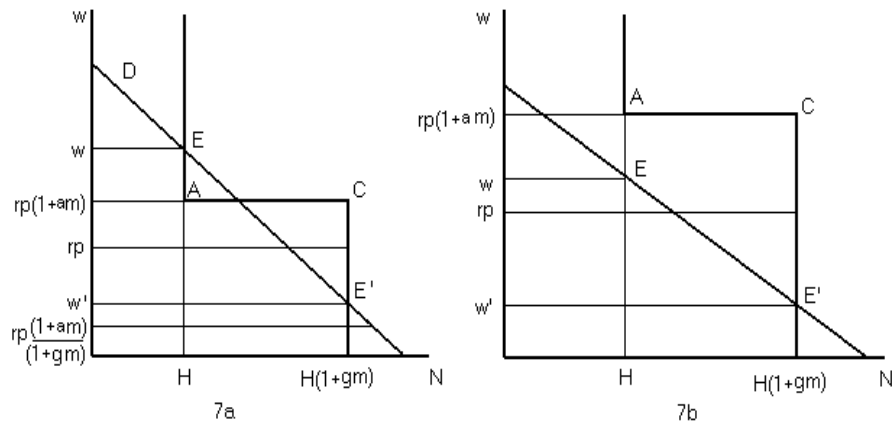
parents possibly find food for them there? (...) they are in the cemetery alongside their father, or perhaps their mother, who were carried away by the excess of work that they took on in order to replace the labour of the child"(p. 30) and he concludes "Society did not like to see the child at the factory, the spectacle disturbed its peace of mind, it required a law to assuage its conscience; but when the child is in the cemetery, why bother with it, since it can be neither seen nor heard?"(p. 30). This position can be examined with the aid of Graph 7.¹²⁶ It is assumed for this purpose that the working class consists of H households each of which represents an adult work unit receiving the nominal wage w . Each household comprises m children. The work of each child is equal to a proportion g of the labour of the adult unit, where $1 > g > 0$, and the corresponding wage is also a proportion g of the adult wage. The subsistence ration required by the adult unit is r , and that required by the child is ar , where $1 > a > 0$. For a subsistence price p , the household's subsistence requirement will cost $rp(1 + am)$. The household can survive without sending the children to work if the adults' wages come out at $w > rp(1 + am)$. But at anything below that level, the children will have to work, and the family will survive if:

$$w(1 + gm) > rp(1 + am) \text{ or } w > rp \frac{(1 + am)}{(1 + gm)}$$

Graph 7a portrays the scenario where the ban on child labour does not have the dire consequences predicted by Dupuit. The labour supply is limited to the H adults, the vertical line intersecting the x -axis at H , if the adult wage is greater than $rp(1 + am)$, but also includes the children, giving the vertical line at $H(1 + gm)$, if the adult wage is below that threshold. If we consider the labour demand curve D , we have two possible points of stable equilibrium: point E , at which the wage w enables the family to survive without child labour, and point E' , at which the wage w' is so low that the children's labour is required. If the labour market stands at the equilibrium point E' where the children have to work, then banning child labour will displace the point of equilibrium to E , which means that it will increase wages to the point where child labour is no longer necessary for the survival of the family. Graph 7b, however, is in line with Dupuit's conclusions: at E the labour of the adults alone is not sufficient to ensure the survival of the family, only the equilibrium

¹²⁶ The graph in question is inspired by, although it differs from, Kaushik Basu's representation (1999, 2000) of the family's decision on sending its children to work.

point E' can do that. And yet there is no a priori reason to prefer this hypothesis, which was soon disproved by the facts.



Graph 7

The last part of the article sets out the reasons why emigration is no solution to the problem of overpopulation. At first sight "emigrating or dying is clearly much the same thing for those who are left behind (...) those whom poverty has carried away might just as well be considered to have departed for the new world" (p. 31).¹²⁷ Indeed, "from the viewpoint of the welfare of those who remain, what emigration could procure such beneficial results as those obtained by death? The grim reaper takes away the weak, the children; in a word, the unproductive. Emigration generally takes only the adults, i.e. the producers" (p. 31) especially as those bound for the new world, rather than the next, can take their capital with them (p. 32).

Dupuit concludes his article with this blunt statement: "The fertility of the population is a cause of misery that no economic measure can evince" (p. 36).

¹²⁷ An equally macabre opinion was expressed by du Puynode who, believing that emigrants stood little chance of survival, wrote: "it is without doubt one way to restore the level [of population]; but in what does it differ, apart from prolonging the suffering, and adding to the anguish, from that other far simpler method: dying in one's own bed? Our philanthropist friends are all too reminiscent of certain physicians who, to be rid of their patients, send them off to die in some remote place" (du Puynode, 1855, p. 76).

CONCLUSION

At the end of this overview it seems fair to assert that, amidst a generally rather unoriginal line of reasoning, Dupuit's 1859 article puts forward an original theory on the causes of subsistence crises. Although still locked into an approach that sees the issue in terms of food availability, Dupuit recognises that it is not the poor harvest in itself which causes a shortage or famine, but the asymmetry of its impact due to inequality of income; in this he foreshadows part of Sen's approach. The poor harvest does, however, render inoperative any measures aimed at alleviating shortages in a closed economy where the distribution of income is not open to debate. The only way to avoid subsistence crises is to open up the grain market to cross-border trade, thereby reducing disparities of income among factors of production and, above all, eliminating extreme variation in supply.

It is instructive at this point to compare Dupuit's conclusions with those of Adam Smith and Malthus. For Smith "a dearth never has arisen (...) from any other cause but a real scarcity, (...) a famine has never arisen from any other cause but the violence of government attempting, by improper means, to remedy the inconveniences of a dearth" (1776/1904, IV.5.44). In other words, dearth results from poor harvests, while famine is brought about by public policies. For Dupuit also, dearth results from poor harvests, but famine results from inequality of income, while public policies are at best ineffective, and at worst exacerbate the situation. For Malthus, as for Tooke, it is public policies (poor relief) that are responsible for dearth, although they can assuage the effects of dearth on the poor, i.e. by staving off famine.

In his explanation of subsistence crises, as we saw, Dupuit gives voice to feelings that would seem to identify him with the "moral economy", but when it comes to policy, he is firmly in the "formal rationalisation" camp, rejecting any measures that could be tainted by the "moral economy". We need to remember that the analytical tools that Dupuit—like all the English and French-language liberal economists of the time—used for the purposes of rationalisation were developed by 18th-century economists, notably Smith and Turgot. This is hardly surprising in as much as it was in the 18th century that the idea of opening up subsistence markets to free trade took shape as a theory. The same comment can be made about the numerical data Dupuit presents in his first article. They belong to the tradition of 17th and 18th-century essays

in which figures are intended to reflect the real economy but are in fact entirely constructed to support a rational argument (J.-P. Simonin, 1996a). This approach, common throughout *La liberté commerciale*, is in keeping with Dupuit's refusal to use economic facts to justify or refute theories, a position attested by his methodological stance, quoted at the beginning of this article, and by his contributions to debates on free trade: "This brings the discussion into the sphere of facts, which is poor ground for political economy; not because the facts contradict it, but because they are hard to see, to observe, to interpret. It is through reasoning that free trade must be defended"(S.E.P., 1860a, p. 308).

"One should not assume, from the fact that farm land rents increased in England after the repeal of the Corn Laws, that the increase was caused by the repeal. What evidence do we have that, without Robert Peel's reform, land rents would not have risen in even greater proportion? (...) This fact in itself proves nothing; for the experiment to be conclusive, England would have to be divided into two equal parts, and each of them subjected to a different regime"(S.E.P., 1860a, pp. 309-310).

"...the causes that affect prices are very numerous and very complex, and the influence of any one of them can be paralysed and cancelled out by the others, without entitling us to question its existence (...). Far from seeking to draw advantage from facts that seem to contradict the theory, in order to reassure our opponents as to its consequences, we must instead explain that these facts are but momentary, and that other quite different facts are certain to arise before long"(S.E.P., 1855b, p. 465).¹²⁸

For Dupuit, as these excerpts show, observable economic facts are the result of interaction between a great many causes: it would be illusory to seek to explain them by any one cause. Only pure reasoning allowed the *ceteris paribus* clause to be invoked, at a time when the techniques of "counterfactual analysis" had not yet been invented. Thus, the rise in land rent in Britain was due not only to the repeal of the Corn Laws, but also to growth in the population and in its living standards, to progress in agriculture, etc. Dupuit's attitude to facts might account for the absence in his work of any mention of the crises of 1847 and 1855: he presents only the figures evaluating the 1855 corn harvest in comparison to population size (p. 162). The singularity of his attitude is underlined

¹²⁸ This position is reaffirmed in *La liberté commerciale* (1861, pp. 72, 137-138, 215), where Dupuit notably evokes the image of a high tide, with its impact held in check by an offshore breeze (p. 138).

when one compares Dupuit's article with those of Molinari, Cherbuliez: "Cherbuliez and Block, or to Briaune's very different, and highly original, book (1857). All of them reproduce Davenant's table—which Dupuit ignores—and present figures for the high-price periods of 1847 or 1853-1855.

There is a contrast between the two articles, of 1859 and 1865, on this point. While the first purports to be a series of rigorous theoretical arguments, at times supported by purpose-built numerical examples, the second is above all an empirical study of the relationship between birth and death rates, aimed at validating the principle of population on the basis of observed facts. It might be thought that this second approach flouts the methodological positions described above.¹²⁹ In fact it is explained by the fact that, for Dupuit, demographic growth is a primary variable: its influence predominates over all other factors, which cannot impede it: "Malthus' doctrine is confirmed by the statistics of all times and all peoples" (S.E.P., 1862e, p. 474); "The population question therefore dominates all others in political economy" (Dupuit, 1865a, p. 28).¹³⁰

Finally, it is legitimate to ask just how relevant Dupuit's analyses were to the reality of his day. He wrote these articles at a time when subsistence crises were ceasing to be a critical problem in the countries of Europe;¹³¹ indeed Dupuit acknowledges that the problem had been con-

¹²⁹ If so, Dupuit would be a sitting target for the kind of criticism that du Puynode levelled at Bastiat after the latter had justified his principle that "*the means of existence increase more rapidly than population*" by "the facts, since everywhere we find the range of man's satisfactions widening" (Bastiat, 1850, 16.98). Du Puynode objected that by relying "on the facts, for his principal argument, he forgets that just a few pages earlier he declared that 'such a line of reasoning cannot be advanced seriously' " (1855, p. 73).

¹³⁰ This statement echoes Guillard's approach: "This doubt [about the principle of population] must be resolved by statistics; it is to statistics that we must submit this important problem. The whole of economic science hangs on its solution" (1853, p. 185). Of course, the anti-Malthusians (F. Passy, H. Passy, Baudrillard, Wolowski, etc.) likewise based their rejection of the population principle on facts (S.E.P., 1862e, 1863).

¹³¹ Karl Persson (1999, pp. 152-153) observes that hunger riots began to peter out in Europe from about 1850, which he attributes to the combined effect of bread taking up a smaller share of the ordinary household budget and reduced instability in the price of corn due to improved exchanges. Some rioting did break out in the Poitou region of France in 1855 (Duveau, 1946, p. 330). Duveau (p. 331) pays particular attention to the scarcities of 1861 and 1867-68, but the price of corn during those crises peaked at levels well below those of 1855-56. The last French hunger riots date back to the dearth of 1911-1912 (Guyot, 1911; Zamanski, 1911), in what later—and certainly later than the

siderably alleviated thanks to improved lines of communication.¹³² Why then did Dupuit devote such a lengthy article—reformulating a well-established liberal doctrine that dated back to the previous century—to a problem which, although the scarcity of 1853-1856 was still fresh in people's minds, would seem to have lost much of its gravity? In fact while the article was a contribution to the campaign for free trade, which is why it was re-used in *La liberté commerciale*, it was also intended as a response to French government regulation: bread coupons, statutory pricing, the *Caisse de la boulangerie* bread fund and compulsory grain stocks for bakers. And so the "dernier souffle"¹³³ of grain market regulation, and the persistence of popular prejudice in its support, was met by a final salvo from Dupuit and the other French liberal economists in favour of free trade in grain.¹³⁴

Shortly after Dupuit's death, the focus shifted to other countries. In 1867 the Société d'Economie Politique devoted a debate to Britain's policy (founded on Adam Smith's precepts) of non-intervention in the Orissa famine of 1865-1866, ignoring the dearth that occurred that very year in France. While some of the participants continued to reject public intervention (at least for European states), most of them accepted the idea in the case of a catastrophic famine (as long as the normal operation of the market was not hampered), and the letter from Block, with which the debate concludes, has the makings of a response to the position set out by Dupuit at start of his 1859 article: "when famine has taken hold, when starvation, with all its attendant horrors, rules the land, it is there that

date suggested by Persson—came to be called the "butter revolution". There was also unrest in Belgium, Germany and Austria during the same period.

¹³² As early as 1850, Faucher (*Académie des Sciences Morales et Politiques*, 1850, p. 299), referring to an article by Dupin on the dearth of 1847, stated that there were no more shortages in France, thanks to improved communications and free trade.

¹³³ Persson (1999, p. 138) adopts the French idiom to describe the "last gasp" of the *Caisse de la boulangerie*. This contention is open to question, as in 1867 the *Journal des économistes* reported in its economic chronicle: "Shortages are unfortunately widespread in Europe, and everywhere government is operating through edicts and decrees" (1867, vol. 8, n°23, March, p. 317) and in 1869 a number of towns tried to reinstate the *taxe du pain* (J. Clément, 1869). Still later, Guyot (1911), Zamanski (1911) and an S.E.P. debate (S.E.P., 1912) describe the regulatory measures inspired by the shortage of 1911, while the protectionist system was in full sway (for a protectionist, and populist, analysis of that crisis, see Anonymous(1912/2002).

¹³⁴ Louis Smith (1861, p. 191) and du Puynode (1861, p. 460) can also be heard lamenting the persistence of these prejudices two years after Dupuit's article.

THE COMPETENCE OF POLITICAL ECONOMY ENDS,¹³⁵ and that of politics and morality begins. Consequently the governor of Bengal, by turning to political economy to decide whether he should save the starving, has acted like a doctor consulting the procedural code to determine what medicine to give his patient. Is medical science responsible for that doctor's error?"(S.E.P., 1867b, p. 314).¹³⁶

ANNEX 1

MATHEMATICAL FORMULATION OF DUPUIT'S TEXT AND THE FORMALISATION OF KING'S LAW BY W. WHEWELL

The formalisation of Dupuit's text defining the effects of a poor harvest on the various categories of consumer leads to results that invite comparison with one of the formalisations of King's law proposed by William Whewell (1850, pp. 2-8).

The earlier equations (4), (7) and (14), expressing the relationship between the price of corn and the quantity harvested for a given level of spending on corn by the non-rich classes, follow the general form

$$(A-1) \quad p = \frac{a}{q-b} \quad a > 0, b > 0 \text{ or } < 0 \quad \text{or} \quad q = b + \frac{a}{p}$$

implying a linear relationship between total corn expenditure and the price of corn, $pq = bp + a$, in which King's law is verified for $b > 0$.¹³⁷ This is the case here, where $b = n_1 \bar{e}_1 > 0$ represents the quantity of corn consumed by the rich and a represents total expenditure on corn by the other classes. This price-harvest relationship can be characterised by the different elasticities used in plotting the demand curve.

¹³⁵Block's capitals.

¹³⁶And yet in 1877 an article by a certain "J.C." (1877), expressed the view—once again with regard to a famine in India—that the government should abstain from any intervention liable to skew market mechanisms.

¹³⁷This curve is a special case of the one proposed by W. Jevons (1888, IV.121) to describe the relationship between the price of corn and the harvest,

$p = \frac{a}{(q-b)^n}$, only with $n = 1$ here, whereas Jevons posited $n = 2$.

The point elasticity of demand relative to price for equation (A-1) is written:

$$(A-2) \quad e = -\left(1 - \frac{b}{q}\right) = \frac{-a}{a+bp}$$

For non-infinitesimal changes, the arc elasticity ranges between two coordinate points (q, p) and (q', p') . Using the definitions of Dalton (1920) and Lerner (1933) we obtain:

$$\hat{e}_D = \frac{(q'-q)/q}{(p'-p)/p} \quad ; \quad \hat{e}'_D = \frac{(q'-q)/q'}{(p'-p)/p'} \quad ; \quad \hat{e}_L = \frac{(q'-q)/q}{(p'-p)/p} \quad ; \quad \hat{e}'_L = \frac{(q'-q)/q'}{(p'-p)/p'} \quad ^{138}$$

The point elasticity at either end of an arc is equal to the Lerner arc elasticity for the quantity at the corresponding point:

$$(A-3) \quad \hat{e}_D = -\left(\frac{q'-b}{q}\right) \quad ; \quad \hat{e}'_D = -\left(\frac{q'-b}{q'}\right) \quad ; \quad \hat{e}_L = -\left(1 - \frac{b}{q}\right) = e \quad ; \quad \hat{e}'_L = -\left(1 - \frac{b}{q'}\right) = e' \quad ^{139}$$

These definitions can be supplemented by the relationship between the elasticity of total expenditure pq relative to price and the direct price elasticity of demand. The point elasticity of the total expenditure relative to price is linked to the point elasticity of demand e by the relationship $e_{RT/p} = 1 + e$. The arc elasticities of the total expenditure relative to price, calculated from the start or end points of the arc, are linked to the Lerner arc elasticities by the equations:

$$\hat{e}_{RT/p} = \frac{(p_2q_2 - p_1q_1)/p_1q_1}{(p_2 - p_1)/p_1} = 1 + \hat{e}_L \quad ; \quad \hat{e}'_{RT/p} = \frac{(p_2q_2 - p_1q_1)/p_2q_2}{(p_2 - p_1)/p_2} = 1 + \hat{e}'_L$$

For equation (A-1) the arc and point elasticities of the total expenditure relative to price are identical:

$$\hat{e}_{RT/p} = 1 + \hat{e}_L = 1 + e = e_{RT/p} \quad ; \quad \hat{e}'_{RT/p} = 1 + \hat{e}'_L = 1 + e' = e'_{RT/p}$$

¹³⁸ These formulas and their results confirm that :

$$\hat{e}_L \hat{e}'_L = \hat{e}_D \hat{e}'_D, \quad \frac{p'}{p} = \frac{\hat{e}_L}{\hat{e}_D} = \frac{\hat{e}'_D}{\hat{e}'_L}, \quad \frac{q'}{q} = \frac{\hat{e}_L}{\hat{e}_D} = \frac{\hat{e}'_D}{\hat{e}'_L}$$

¹³⁹ From the general definitions of e and \hat{e}_L , it emerges that $e = \hat{e}_L$ if $\frac{dq}{dp} = \frac{(q'-q)}{(p'-p)} \cdot \frac{p'}{p}$, which is indeed the case for the function specified here, where both

terms equal $-\frac{a}{p^2}$.

This property can be used conversely to define equation (A-1). The arc and point elasticities of the total expenditure relative to price are effectively equal if

$$\frac{dpq}{dp} = \frac{p'q' - pq}{p' - p}$$

implying a linear relationship of the type $pq = bp + a$ and consequently equation (A-1).

These show that the formulas proposed by Whewell (1850, pp. 2-8) in his mathematical analysis of the relationship between harvests and corn prices:¹⁴⁰

$$(A-4) \quad p' = p(1+x), \quad p'q' = pq(1+mx) \quad 1 \geq m, \quad q' = q \left(\frac{1+mx}{1+x} \right)$$

can only be established for a relationship such as (A-1). This establishes a direct correspondence between equation (5) and these formulas. Some basic calculations (P.J. Henderson, 1973) illustrate the meaning of Whewell's symbols:

$$(A-5) \quad x = \frac{p' - p}{p} \quad ; \quad m = \frac{(p'q' - pq)/pq}{(p' - p)/p} = \hat{e}_{RT/p} \quad 141142$$

Since $\hat{e}_{RT/p} = 1 + \hat{e}_L$, we obtain $m = 1 + \hat{e}_L$: Whewell's coefficient m is equal to 1 plus the Lerner arc elasticity. It is equal to 1 plus the Marshall point elasticity when the latter is equal to the Lerner arc elasticity, which is true only for relationships of the type (A-1). In this case

$$(A-6) \quad \frac{p'}{p} = \frac{q-b}{q'-b} = \frac{1-\frac{b}{q}}{\frac{q'-b}{q}} = \frac{\hat{e}_L}{\hat{e}_D}$$

whereas Whewell's formulas lead to

¹⁴⁰ While these formulas are linked to Whewell's work on King's law, they do not aim to account for Davenant's table, which Whewell described with the aid of a third degree polynomial.

¹⁴¹ Henderson posits that m is both the arc elasticity $\hat{e}_{RT/p}$ and the point elasticity e_{RT} . This equivalence cannot be assumed a priori except for functions of the type (A-1).

¹⁴² This meaning of m led Henderson to reject, wrongly, McGregor's reading (1942, p. 316) that $m = 1 + e$ where e is the Marshall point elasticity, although he later came round to that view himself (Henderson, 1985), with no explanation.

$$(A-7) \quad \frac{p'}{p} = \frac{1-m}{\frac{q'}{q}-m}.$$

If we posit $m = \frac{b}{q} = \frac{bp}{bp+a}$ we arrive back at $m = 1 + \hat{e}_L = 1 + e$, where e is the point elasticity. It is easily verified that m is also equal to the point elasticity and the arc elasticity of the total expenditure relative to price:

$$(A-8) \quad e_{RT/p} = \hat{e}_{RT/p} = \frac{b}{q_1} = m.$$

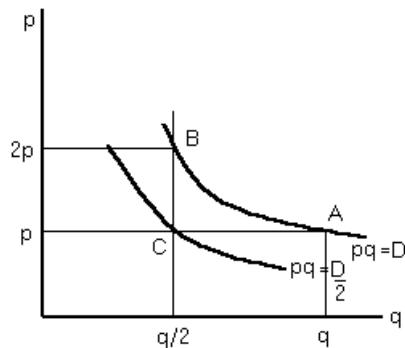
Comparing these results with the formalisation obtained from Dupuit's text, we find that equation (5), derived from equation (4), is formally identical to equations (A-6) and (A-7), implying that $y_1 = \frac{b}{q} = m$. A certain relationship therefore emerges between Whewell's mathematical formulas and the modes of economic reasoning in force at the time. The formulas can nonetheless be adapted to other approaches: as Annex 4 shows, they are compatible with one of Quesnay's tables. The principle underlying this table differs from the logic of Dupuit's demonstration, however, as it rests on the assumption that annual overall corn consumption is constant regardless of price, which implies a quite different representation of equilibrium in the corn market (J.-P. Simonin, 2003a).

The variations in corn price represented by equations (8), (15) and (16)—associated with variations in the amount spent on corn by classes other than the rich—no longer correspond to movements along a price-harvest curve, as found in Whewell's model, but to movements from one curve to another, and can therefore not be directly associated with his formulas. This can be visualised with the aid of Graph 8, which plots three price-harvest curves. Curve D_a corresponds to an abundant harvest, where even the poorest can buy corn (equation (14)); curve D_n corresponds to a normal harvest, where the poorest are excluded from the corn market (equation (7)); curve D_d corresponds to a deficient harvest, where the intermediate class devotes its entire income to buying corn (equation (4)). The points representing the effective prices and harvests are: A in abundance, B in normal conditions and C in scarcity. The resulting curve ABC is therefore broken, just as Lenoir and Mannequin supposed: it is therefore possible for King's law to be contravened on segment AB while being respected on segment BC.

ANNEX 2
MALTHUS AND KING'S LAW IN THE ABSENCE
OF POOR RELIEF

In order to prove that poor relief was the cause of higher corn prices, in accordance with King's law, Malthus used lines of reasoning based on two different assumptions: in the Essay of 1803, it was the reduction in every individual's consumption; in the pamphlet of 1800, the exclusion of the poor.

His claim in the Essay that, in presence of "A deficiency of one half of a crop, if the people could immediately consent to consume only one half of what they did before, would produce little or no effect on the price of corn" (1826, III.V.9), is incorrect. The shortfall in the harvest will result in a proportionally identical rise in the price of corn if and only if spending on corn remains constant. For a one-half decrease in the harvest not to affect the price, spending on corn must also diminish by half. These results are illustrated in Graph 9.



Graph 9

In a normal harvest year, spending on corn is $D = pq$. In a poor year it is $D' = p'q'$. If $D = D'$, $pq = p'q'$ and $\frac{p'}{p} = \frac{q}{q'}$, the price rise is proportionally identical to the shortfall in the harvest. The price is multiplied by 2 if the harvest is divided by 2 (the movement from A to B in the graph). To obtain $p' = p$, it would be necessary that

$$p' = \frac{D'}{q'} = p = \frac{D}{q} \text{ and therefore } \frac{D'}{D} = \frac{q'}{q}$$

implying a fall in expenditure proportionally identical to the shortfall in the harvest, corresponding to a movement from A to C in the graph.

Poor relief results in increased spending on bread, $D'' > D$, and movement towards the top of the isoexpenditure curves, hence $\frac{p''}{p} > \frac{q}{q'}$, a result that conforms to the King-Davenant law. For example, for $D'' = 2D$ and $q = 2q'$, $p'' = 4p$.

In the pamphlet, Malthus sets out by describing the determination of the price of corn during a scarcity: "Let us suppose a commodity in great request by fifty people, but of which, from some failure in its production, there is only sufficient to supply forty. If the fortieth man from the top have two shillings which he can spend in this commodity, and the thirty nine above him, more, in various proportions, and the ten below, all less, the actual price of the article (...) will be two shillings" (Malthus, 1800/1970, pp. 8-9). He then supposes that the 40 richest consumers can continue to spend 2 shillings, as can the 10 poorest after receiving 1 shilling in aid (which assumes that all of the poor started out with 1 shilling: the initial, pre-scarcity, price). In this case, ten individuals will have to be excluded by lottery, a mechanism which, he suggests, is no better than the "sordid distinction of money" (p. 9). These figures show that in this case the exclusion of the poor does not inhibit King's law. What we have, in effect, is:

$$\frac{p'}{p} = \frac{2}{1} = 2 > \frac{q}{q'} = \frac{50}{40} = 1.25.$$

Nothing surprising here, as the exclusion of the poor reduces expenditure by 10 shillings while the 40 richest consumers increase their spending by 40 shillings: a net increase of 30 shillings in overall expenditure. Using the symbols defined in the text of Dupuit's article, $n = 50$, $n_3 = 10$, $w_2 = 2$ and $w_3 = 1$, we obtain the quasi-elasticity of consumption relative to price:

$$\frac{\frac{q'}{q}}{\frac{p'}{p}} = \frac{-n_3 w_3}{n(w_2 - w_3)} = -0.2$$

which does indeed correspond to a price rise 5 times greater than the decrease in supply, as defined by Malthus in his example. For price and harvest to vary in equal proportion, the excluded poor would have to be able, at the outset, to afford a price of 1.6 shillings (1 shilling and

7.2 pence). Their exclusion by the 2-shilling price level would then reduce expenditure by 16 shillings, while the others would have to spend 16 shillings more, which corresponds to

$$\frac{p'}{p} = \frac{2}{1.6} = 1.25 = \frac{q}{q'} = \frac{50}{40}.$$

If the poor had initially been able to afford between 1.6 and 2 shillings, the price rise would have proportionally smaller than the shortfall in the harvest.

ANNEX 3

THE STABILISING EFFECT OF ALTERNATIVE USES OF CORN—AN ELASTICITY-BASED APPROACH

Dupuit's reasoning, and the example he gives regarding alternative uses of corn, can be evaluated using a more modern formalisation¹⁴³ than the one presented in the main text.

Let x be the share represented by alternative uses in the overall demand for corn, e the direct price elasticity of overall corn demand, e_c the direct price elasticity of corn demand for bread and e_a the direct price elasticity of corn demand for alternative uses,¹⁴⁴ where $|e_a| > |e_c|$. The elasticity of overall demand for corn is defined as

$$e = (1-x)e_c + xe_a = e_c + x(e_a - e_c)$$

whence $|e| > |e_c|$: overall corn demand is more elastic than corn demand for food alone. The relationship between the relative variations in the price of corn \bar{p} and the harvest \bar{q} is expressed thus:

$$\dot{p} = \frac{\dot{q}}{e} = \frac{\dot{q}}{e_c + x(e_a - e_c)}.$$

¹⁴³ See J.-P. Simonin (1996a) for various applications of this type of formalisation.

¹⁴⁴ These elasticities are linked to the elasticities of demand for bread, and for other uses, following the concept of derived demand for production factors and notably the second Marshall-Hicks rule: "The demand for anything is likely to be more elastic, the more elastic is the demand for any further thing which it contributes to produce" (Hicks, 1932, p. 242). The formula for this relationship is given by Ferguson (1969, p. 237). As the demand for corn-based products other than bread is relatively elastic compared to the demand for bread, the demand for corn for these alternative uses will be more elastic than the demand for corn to make bread.

The relationship between the relative variation in the final consumption of corn \bar{c} and the relative variation in the harvest is therefore:

$$\dot{c} = e_c \dot{p} = \frac{e_c}{e} \dot{q} = \frac{e_c \dot{q}}{e_c + x(e_a - e_c)} .$$

If x is null, i.e. if there are no alternative uses, then $e = e_c$, the entire drop in production is borne by the final consumption and the price rise is as high as the direct price elasticity of final consumption will allow, $\dot{p} = \frac{\dot{q}}{e_c}$ and $\dot{c} = \dot{q}$. If however x is non-null, the price rise is reduced relative to this maximum level and the relative decrease in consumption becomes lower than that of production. Clearly \bar{p} and \bar{c} tend towards zero as x tends to infinity. Since x is between zero and one, it is impossible for alternative uses of corn to absorb harvest fluctuations "almost alone" as Dupuit claimed. He therefore considerably overstated the stabilising effect of such alternative uses. It is also worth asking under what conditions this strategy would reverse the effect of the King-Davenant law, as Dupuit's last phrase seems to suggest. This would be the case if $|\bar{p}| < |\bar{q}|$, i.e. if

$$x > \frac{1 - |e_c|}{|e_a| - |e_c|} .$$

Since x is between zero and one, this condition can only be met if $|e_a| > 1$. Variation in the price of corn can only become proportionally smaller than variation in the harvest if the direct price elasticity of the alternative uses of corn is greater than 1 in absolute value. These conditions cannot be applied to the figures proposed by Dupuit, which correspond to non-infinitesimal variations in the harvest and in consumption.

ANNEX 4

QUESNAY AND TURGOT'S TABLES AND DUPUIT'S FIGURES

Are the figures that Dupuit uses in his exposition of the effects of free trade on corn prices closer to those of Quesnay (1757/1958, p. 462)

or of Turgot (Turgot/Vigreux, 1947, p. 198)?¹⁴⁵ Table 3 sets out the price/harvest relationships inferred by each of these two authors under conditions where external trade in grain is prohibited.

Table 3

Years	Harvest per arpent in setiers ¹⁴⁶	Price / setier (Quesnay)	Total revenue (Quesnay)	Price / setier (Turgot)	Total revenue (Turgot)
Abundant	7	10 liv.	70 liv.	15 liv.	105 liv.
Good	6	12	72	20	120
Average	5	15	75	25	125
Poor	4	20	80	30	120
Bad	3	30	90	35	105
Mean year	5	17.4 (17 livres 8 sous)	77.4 (77 livres 8 sous)	25	115

Turgot's figures correspond to the equations:

$$p = -5q + 50, \quad pq = -5q^2 + 50q, \quad \frac{dpq}{dq} = -10q + 50.$$

The total revenue varies inversely to the harvest for harvests greater than 5 *setiers* per *arpent*, and in parallel to the harvest for harvests below 5. The King-Davenant law, which states that the variation in price is proportionally greater than the variation in the harvest, is valid only for harvests greater than 5, whereas in Quesnay's table the law applies across the range of harvests. The equations corresponding to Quesnay's figures are as follows (Delmas & Demals, 1994; Steiner, 1994; Simonin, 1996a & b):

$$p = \frac{60}{q-1}, \quad pq = \frac{60q}{q-1}, \quad \frac{dpq}{dq} = \frac{-60}{(q-1)^2} < 0 \quad ^{147}$$

¹⁴⁵ For a less detailed study of this question, but one which looks at the wider influence of these tables on 19th-century French economic thought, see J.-P. Simonin (2003b).

¹⁴⁶ Pre-revolutionary measures: *arpent* (surface area), approx. 1 acre; *setier* (volume), approx. a dozen bushels or 156 litres; the *livre* (money) was divided into 20 *sous*—Translator.

¹⁴⁷ These and the previous equations cannot be derived from a straightforward demand curve, but represent price-harvest relationships that reflect the various equilibria in the grain market by factoring in the storage behaviours of the market players (Simonin, 1996b). Note the formal similarity between equation (4) and the expression of price as a function of harvest.

implying that variation in the grain price is always proportionally greater than in the harvest. By positing $q = 5$ (the harvest for a normal year) we obtain from these equations an expression identical to the one derived from Whewell's formulas in Annex 1:

$$\frac{p'}{p} = \frac{1 - \frac{1}{q}}{\frac{q'}{q} - \frac{1}{q}} = \frac{1 - 0.2}{\frac{q'}{q} - 0.2}$$

a result that reproduces all of Quesnay's figures.

Dupuit only gives the extreme values for harvests and prices. In the absence of trade, when the harvest decreases by 200 to 100 measures, the price of corn increases by 15 to 35 francs: a 50% drop in the harvest leads to a price rise of 133%,¹⁴⁸ broadly corresponding to the King-Davenant law, which underlies Dupuit's whole argument. The fact that Dupuit transposes Turgot's price figures (15 and 35) from livres into francs hints that his example corresponds to Turgot's table. If so, his figures would yield the following equations:

$$p = -0.2q + 55, \quad pq = -0.2q^2 + 55q, \quad \frac{dpq}{dq} = -0.4q + 55$$

which indicate that the King-Davenant law would only hold for harvests greater than 137.5 measures and would therefore not apply to shortage situations, which contradicts Dupuit's general argument. Applying Quesnay's table to Dupuit's figures gives us the equations:

$$p = \frac{2625}{q-25}, \quad pq = \frac{2625q}{q-25}, \quad \frac{dpq}{dq} = \frac{-65625}{(q-25)^2} < 0$$
¹⁴⁹

implying a variation in the price of corn that is always proportionally larger than the variation in the harvest, which corresponds to Dupuit's argument. As with Quesnay, these equations lead to an expression identical to the one derived from Whewell, positing $q = 150$ as a normal years' harvest:

$$\frac{p'}{p} = \frac{1 - \frac{25}{q}}{\frac{q'}{q} - \frac{25}{q}} = \frac{1 - 0.1667}{\frac{q'}{q} - 0.1667}$$

¹⁴⁸ Note that these figures are not consistent with the ones Dupuit uses elsewhere in his article, notably when he says that a 10% decrease in the harvest would double the price of bread.

¹⁴⁹ In Annex 1 this formula, and the one established by Steiner for Quesnay's table, are compared with the formula derived from Whewell's formalisation.

Applying these various formulas to Dupuit's figures gives us Table 4, showing that the overall situation of farmers would be more favourable under Turgot's price-harvest relationship than under Quesnay's.

Under conditions of free trade, Quesnay and Turgot's tables both indicate that King's law ceases to apply, as the variation in price is proportionally smaller than in the harvest for the range of harvests in question. The equations obtained for Turgot's table are now:

$$p = -2q + 34, \quad pq = -2q^2 + 34q, \quad \frac{dpq}{dq} = -4q + 34$$

and for Quesnay's table :

$$p = -q + 24, \quad pq = -q^2 + 24q, \quad \frac{dpq}{dq} = -2q + 24$$

The differences between the two authors here lie solely in the figures used (Quesnay, *Grains*, p.474 ; P. Vigreux, 1947, p. 200), which are represented in Table 5.

Table 4

Years	Harvest in measures	Price (Quesnay's relationship)	Total revenue (Quesnay's relationship)	Price (Turgot's relationship)	Total revenue (Turgot's relationship)
Abundant	200	15 fr.	3 000 fr.	15 fr.	3 000 fr.
Good	175	17.5	3 062.5	20	3 500
Average	150	21	3 150	25	3 750
Poor	125	26.25	3 281.25	30	3 750
Bad	100	35	3 500	35	3 500
Mean year	150	22.95	3 198.75	25	3 500

Table 5

Years	Harvest (Quesnay)	Price (Quesnay)	Revenue (Quesnay)	Harvest (Turgot)	Price (Turgot)	Revenue (Turgot)
Abundant	8	16 liv.	128 liv.	7	20 liv.	140 liv.
Good	7	17	119	6	22	132
Average	6	18	108	5	24	120
Poor	5	19	95	4	26	104
Bad	4	20	80	3	28	84
Mean year	6	18	106	5	24	116

Table 6

Years	Harvest in measures	Price per measure	Total revenue
Abundant	200	20	4 000
Good	175	21.25	3 718.75
Average	150	22.5	3 375
Poor	125	23.75	2 968.75
Bad	100	25	2 500
Mean year	150	22.5	3 312.5

Dupuit's figures correspond to essentially similar equations:

$$p = -0.05q + 30, \quad pq = -0.05q^2 + 30q, \quad \frac{dpq}{dq} = -0.1q + 30$$

which lead to the rejection of the King-Davenant law for harvests of under 300 measures. These figures are presented in Table 6.

Like Turgot, but unlike Quesnay, Dupuit assumes that free trade does not increase the size of the harvest and that it brings down the average price of corn, to the benefit of the consumer. But if we apply a relationship like Quesnay's to Dupuit's first figures, the drop is not from 25 to 22.5 francs, but only from 22.95 to 22.5 francs, a minimal decrease. In extreme situations, by contrast, Quesnay and Dupuit both associate a halving of the harvest with a price rise of 25%, whereas for Turgot the increase is 40%. For all three authors, the variation in the grain producers' revenue is greater under free trade than under prohibition. However, in the figures that Dupuit actually presents, the average total revenue for the farmers is not affected by free trade, whereas in the reconstructions proposed here, it diminishes with Turgot's price-harvest relationship and increases with Quesnay's.

Ultimately, the figures used by Dupuit suggest that he borrowed from the tables of both Quesnay and Turgot, but that only Quesnay's tables are fully in line with his reasoning.

II. Dupuit's economic analysis

8. Dupuit's theory of international specialisation: formalisation and critical evaluation

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Despite his omission from Joël Ravix' (1991) panorama of the various debates on free trade and protectionism in 19th-century France, Jules Dupuit was one of the most ardent advocates of free trade.¹ Beyond the debates at the Société d'Economie Politique, transcribed in the *Journal des économistes*, he expressed most of his ideas on the subject in his book *La liberté commerciale, son principe et ses conséquences*, published in 1861. Among other developments, it contains an original analysis of international specialisation. This article sets out to formalise that analysis in order to evaluate it and expose its limits. The first part presents Dupuit's analysis of international specialisation and contrasts his conclusions with the findings of Cournot (1838, 1863) and List (1841). The second part outlines a model of equilibrium for a two-good economy inspired by Findlay's approach (1974) but which, owing to the characteristics of Dupuit's thought, differs from Findlay's model and also from that of Pasinetti (1960). The third part looks at various instances of international specialisation in the light of this model, and demonstrates the extent to which most of Dupuit's conclusions are erroneous.

1. DUPUIT'S THEORY OF INTERNATIONAL SPECIALISATION

Dupuit's theory of international trade rests largely on the same theoretical foundations as the approaches of the other liberal authors of the day, such as Joseph Garnier, Courcelle-Seneuil and Rossi (Ravix, 1991, pp. 487-494): Adam Smith's absolute advantage, J.-B. Say's law of markets and, in Rossi's case, Ricardo's differential rent (although he ignores Ricardo on comparative advantage).²

¹For an overview of all of Dupuit's positions on free trade, see J.-P. Simonin (2001).

²He differs in this respect from Cherbuliez (1862, tome 1, pp. 375-391) and Cournot (1863/1981, pp. 217-224), who develops an analysis of "international barter" directly

At the start of his book Dupuit posits that mankind's unlimited needs and wants can only be satisfied through work and effort. "Of all the means employed to obtain more products with less effort, one of the most powerful is, incontrovertibly, the division of labour" (1861a, p. 15). But "this division of labour is only possible insofar as it is followed by the exchange of products" (p. 17). On the international and domestic levels alike, products are exchanged exclusively for other products (p. 55). This exchange is based on the principle of absolute advantage: "With free trade, it is evident that every man will go looking for the product wherever it can be obtained the most cheaply, and where, consequently, it will require the least labour to manufacture" (p. 63). On this basis, one would be hard put to demonstrate how a nation with a disadvantage in all types of production had anything to gain from international trade.

As for the determinants of international specialisation, Dupuit contrasts the characteristics of agriculture and industry (or mining). His analysis of agriculture draws (though without citing any references) on Ricardo's theory of differential rent. Rent he defines as "the surplus of the value of the earth's produce over the costs of farming" (p. 69) and "if we consider (...) ever more fertile tracts of land (...) the main difference between them will lie in the ever higher rents they yield" (p. 68), which is why farmers working soils of differing fertility can still coexist where there is a single market price (pp. 69-70). This characteristic is in evidence internationally as well as nationally, and Dupuit adduces a numerical example to show that even if the free import of corn brings down the price of corn, this will not cause farmers to abandon growing corn but will merely have the effect of lowering land rents, i.e. redistributing wealth from the landowner towards the consumer:

"When a farmer wants to calculate the costs of growing corn (...) he proceeds thus:

Crop costs, wages, fertiliser, etc.	Fr800
Rent paid to owner for lease of land	Fr 1,200
Total for 100 hectolitres produced	Fr 2,000

inspired by J.S. Mill and, through Mill, of Ricardo's famous example. Cournot recognises, citing Mill, that "it is not the difference between the absolute costs of production that determines the exchange, it is the difference between the comparative costs" (p. 223). For a better understanding of why Dupuit apparently overlooked the theory of comparative cost or advantage, we should bear in mind that even Gide and Rist (1944/2000) considered it to be little more than an unnecessary overcomplication of Adam Smith's writings (p. 109) or an "academic dilution" (pp. 728-729).

Cost per hectolitre Fr 20³

Having established these figures, he declares that he cannot withstand competition from foreign corn arriving on the market at 15 francs. And yet this is a fundamental error; for, if the average price of corn were reduced to 15 francs, the farmer, making only 1500 francs from the sale of his 100 hectolitres, and still having 800 francs of farming costs, could and would now only pay 700 francs for the farmland instead of 1200. He would now establish the production cost of corn as follows:

Crop costs, wages, fertiliser, etc.	Fr 800
Rent paid to owner	Fr 700
Total for 100 hectolitres produced	Fr 1,500
Cost per hectolitre	Fr 15

The introduction of foreign corn would therefore have no other result than to bring down the price the land rent from 1200 to 700 francs. There is no reason whatever why the farmer should not continue to produce corn. The only change is in the fate of the landowner, but his loss is the consumer's gain. It is no more than a change in the distribution of wealth, and it would be a grave error to consider it a loss for the nation"(pp. 70-71). Clearly, Dupuit's example is only relevant to land with a given yield: it cannot account for the effects of corn imports on land of varying fertility. Agriculture on poorer soils could well cease as a result of competition from foreign corn. That would happen in this very example if the price per hectolitre were to fall below 8 francs, and if so, the imports would indeed affect corn production as well as land rents.

Elsewhere Dupuit notes that due to the diminishing fertility of land "one of the characteristic features of cereal production is that production costs rise rapidly as the quantity to be produced increases"(p. 76). These diminishing returns of agriculture contrast with the situation of industry: "If you ask the owner of an iron-mill or a coal-mine to double, treble, even quadruple his annual production on condition that that price per ton remained unchanged, he will gladly accept the deal, and might even agree to a reduction in price"(p. 76). From this characteristic of fixed costs or yields one can deduce that in the case of "two neighbouring coal mines, one of which can offer a ton for 10 francs, while the other can at best accept 15 (...) it is clear that the owner of first would force his neighbour to abandon his undertak-

³The 20-franc price mark was held to be the remunerative price at the time (Molinari, 1854a, p. 321) and served as the reference point for the sliding scale policy.

ing"(pp. 69-70).⁴Another result is that for this type of product "production is presently limited only by consumer demand"(p. 78). Dupuit extends the scope from domestic to international competition with the following example:"Suppose that, in a certain country, a ton of pig-iron—given sufficient competition so that the return on invested capital is nothing out of the ordinary—costs 20 francs; then the introduction of foreign pig-iron at 15 francs might render indigenous pig-iron production impossible.

The production cost for 100 tons would be determined thus:

Purchase, carriage of ore and fuel, labour, etc.; costs proportional to quantity produced: Fr 1200.

Interest on capital outlay for the establishment of furnaces, factories; general costs independent of quantity produced: Fr 800.

Total for 100 tons: Fr 2000, i.e. Fr 20 per ton.

As the acceptance of foreign pig-iron would bring the price down to 15 francs a ton, only 300 francs would remain for the interest on the capital investment, less than 2%, assuming that the 800 francs represented 5%. This situation would allow the factory to continue working for a while, it being preferable to gain 2% from an investment than nothing at all; but as the material wears out, it will not be replaced (...) and eventually the factory will be forced to close"(pp. 78-79).⁵

Having described the effects of foreign competition on local agriculture, Dupuit goes on to describe the emergence of international specialisation: "If a country continuously receives cereals, it must of necessity export other products, by virtue of the principle set out above, namely *that products are only ever exchanged for other products*. In this country, the products other than cereals are therefore cheaper than in other countries, particularly the one from which its corn comes, since, by the same principle, the country that exports cereals receives other products in exchange. Now to compare the situation of farmers cultivating land of equal fertility in the two countries; (...) the situation is far better in the country that receives the cereals than in the country that exports them. Where the cereals are imported, the farmer sells more dearly that which he does not consume and buys more cheaply that which he does not produce. The country receiving the cereals will always therefore be better cultivated than the one that exports them: it can afford to grow crops on land of

⁴Dupuit's conclusion here contradicts Dunoyer's assertion (1847, pp. 239-243) that industrial enterprises can coexist within the same country despite different costs.

⁵A comparable study on the different effects of competition on industry and on agriculture had already been published by Arrivabene (1847, pp. 334-335).

lower quality than the exporting country" (pp. 74-75). This curious conclusion is assessed in Part 3.

Dupuit moves on to consider how a country at a disadvantage with regard to all products would cope with specialization: "Imagine then a country which not only has poor soil, but which has such great difficulty finding within that soil the fuel or metals required to manufacture its tools and machines that it is more advantageous for that country to seek them from distant lands"(p. 75). In a context of free trade "the farmer, to obtain the ton of coal, the machinery, the fabrics that he needs, will prefer to give 100 hectolitres of corn to a foreign producer than 150 to a domestic one (...). The more fertile country will accept this corn, because it has need of it to sustain the workers in its mines and manufactures; if it had to grow the corn from its own soil, it would have to spend more on its own cultivated or uncultivated land than would the importing country"⁶(p. 76). This passage seems ambiguous: at the start of his example Dupuit seems to be paving the way for a theory of comparative advantage—in as much as the universally disadvantaged country can still export its agricultural produce, for which it seems to have some comparative advantage—but his conclusion shows that he is still very much within the absolute advantage model, as the agricultural production "costs" are lower in the corn exporting country than in the importing country. One possible explanation for this might be that, although the disadvantaged country is generally less fertile than its counterpart, its best land is nonetheless more fertile than the second-grade land in the other country. It would therefore be in the interest of the latter to import grain rather than cultivate such land. This supposes, however, that the disadvantaged country is in a position to export the produce of its best land, which implies a very low population to allow for a surplus of exportable food—a hypothesis that Dupuit does not make.

This reading seems to be ruled out by a paragraph in which Dupuit insists on his own analytical framework: "When one sees foreign iron or coal arriving in France, one is right to assume that the production of these materials requires less labour in their country of origin. But when one sees corn arriving from the Crimea, and assumes that this is due to that country's greater fertility, one is mistaken. If the price of corn is lower there than in France or England, this is because the Crimea needs products that its workers are unfitted or unable to produce as cheaply as in the foreign country, even though the latter demands a great deal of corn in exchange for few such products, and

⁶Dupuit, like Rossi and Cournot, occasionally uses the word "import" where we would now say "export" and vice versa, the exact meaning being clear from the context.

because the farmer is obliged to accede to these demands due to the remoteness and commercial difficulties of his country.⁷ Were the Crimea less fertile than she is, her corn would not fetch a higher price there; the price would, however, rise if her trading conditions were to ease, or the costs of transport become less onerous"⁸ (pp. 77-78). This reasoning is easy to express mathematically, thanks to the precept that products are exchanged for products. For the cereal importing country, the value of its industrial goods exports is equal to the value of its corn purchases:

$$p_v E_v = (p'_c + m_c) E_c$$

where p_v is the price of the industrial goods, p'_c is the price of the cereals in the country of origin, m_c the unit cost for the transport of cereals, E_v the quantity of industrial goods exchanged and E_c the quantity of cereals exchanged. The price of cereals is determined by the equation

$$p'_c = p_v \frac{E_v}{E_c} - m_c$$

The higher the transport margin, the lower the price of cereals in the exporting country. Any gain in fertility in this country will, moreover, lead to an increase in cereal production which in turn, for a given subsistence requirement, will cause an identical increase in corn exports E_c . As products are exchanged for products, this increase in exports entails an increase in industrial goods imports, such that the price of cereals remains unchanged. However valid or invalid this reasoning may be, it demonstrates that the disadvantaged country exports its corn surplus in order to obtain industrial goods, even if it has to grow it on land less fertile than in the country of destination, and that the price of the exported corn is set at a level that will be acceptable in the importing country.

⁷This phrase is redolent of part of List's argument (1841/1909, II.XIII.24) against full-scale national specialisation in agriculture, and seems to contradict Dupuit's optimistic conclusions about the advantage that the disadvantaged country could gain from specialisation.

⁸Two articles by Molinari (1861) and Saint-Julien (1861), published in the same year as "*La liberté commerciale*", show that the price of Russian corn at the point of harvest was almost the lowest in the world, but that due to transport costs within Russia, compounded by financial and bureaucratic costs, the price of Russian corn at the ports of origin was little different from that of American corn, while Russian corn was actually more expensive than American corn at the ports of destination.

This analysis is confirmed by Dupuit's conclusion: "the export of cereals obeys a quite different set of laws to the followed by most other goods; their movement from one country to another is caused not by the greater or lesser fertility of the different countries' soils, but by the difference in the facility with which they can produce other forms of wealth. Whatever the fertility of the soil, cereals are always proposed freely and spontaneously in exchange for goods that would be more expensive to produce at home than to bring in from abroad" (p. 80). From this one can conclude that specialisation is ultimately decided on the sole basis of differences in absolute industrial costs between countries.

Just how original Dupuit's analysis was becomes evident when one compares it with Rossi's. The latter, abundantly cited by Dupuit throughout *La liberté commerciale*, also contrasts industry and agriculture, but only with regard to the effects of setting up a protectionist system: while trade barriers will procure only a temporary profit for the industrialist, as the inflow of capital into the protected sector will soon bring profits down to the ordinary level,⁹ the increase in land rent will persist for as long as agriculture is protected (Rossi, 1843/1884, vol. 3, pp. 290-291).

To round off this brief outline of the determinants of specialisation we turn to the chapter in which Dupuit seeks to prove that "it is always the country least well endowed by nature that gains the most from free trade" (p. 89).¹⁰ Going back to his example of the rich country and the disadvantaged country¹¹ he posits a situation of free trade in which the latter imports all of its industrial goods from the former in exchange for cereals. But in addition to these products, he introduces into each country two sectors of non-exchangeable goods and services: the artisans (what he calls "the local professions") and the intellectual professions. He assumes that the disadvantaged country has a population of 26 million: 20 million in agriculture, 3 million in the local professions

⁹Rossi's reasoning on this point follows that of Ricardo, who describes the effects of an industrialist discovering a new market (Ricardo, 1815, keyword 'ordinary level').

¹⁰Ricardo (1821, 7.17n) argued in terms of comparative advantage to demonstrate that a universally disadvantaged country gains from trade. According to Gide and Rist it was thought at the time that "the greater gain was for the poorer, less naturally endowed or industrially advanced country, being the one, by definition, for which it would have been more difficult, if not utterly impossible, to manufacture the imported products directly" (1944/2000, p. 405).

¹¹For Dupuit, the rich country is a northern nation and the disadvantaged country a southern one (p. 87).

and 3 million in the intellectual professions. This country exports, to its richer counterpart, enough corn to feed 4 million workers, who produce the industrial goods imported by the poorer country. The country's 20 million-strong farming population therefore feeds a total non-agricultural population of 10 million (p. 90). Dupuit now supposes that, following trade prohibitions, the poorer country has to manufacture its own industrial goods, and that to produce the quantities previously imported now requires the labour of 8 million workers, instead of 4 in the richer country. As farming can only sustain 10 million non-agricultural workers, there is only room for another 4 million workers. The consumption of non-agricultural products can now only be 10/14ths of what it was under free trade, a drop of almost 30% (p. 91). The distribution by sector of the 26 million inhabitants adapts accordingly: 17 million farmers, 2 million in the "local professions", 1 million in the intellectual professions and 6 million in manufacturing and mining (p. 92). Dupuit offers his rationale for this new breakdown: "Where before we had 20 million farmers, we now have 17 millions. Why? As we explained above, agriculture always expands until it reaches land that merely covers the costs of cultivation; and thus (...) the farmer, finding himself in still worse conditions for the sale of his produce, will be forced to give up part of his crop land for pasture, and to reduce his labour on the rest. The excess of his production over his consumption will no longer bring him enough at market to pay for his clothes, tools, carts and machines"(p. 92).¹² These 17 million farmers can only sustain the 26 million people already living in the country:"But, if it took 20 million farmers to feed a non-agricultural population of 10 millions, then 17 millions will certainly not feed more than 9; the three other classes of the population will therefore consist not of 10 millions, but of only 9 millions"(p. 93) and the largest reduction "will of necessity be in the intellectual professions (...), among those who are not necessary to the survival of the individual"(p. 93). It is this diminution in the intellectual professions which, for Dupuit, represents "society's real and capital loss" (p. 94) as a result of protectionism.¹³ This

¹²Dupuit admits that this figure is arbitrary. The values for the agricultural production function parameters that lead to Dupuit's figures are presented later in this article.

¹³Dupuit continues: "The kind of degradation which part of the population must endure, in renouncing intellectual labour for manual labour, is nothing less than a return to barbarianism, to the condition of the savage" (p. 94). Free trade is not "a mere question of coal and cotton, (...) it is above all a question of letters, of science, of art, in a word, of civilisation. The struggle of free trade against prohibition is the struggle of intellectual labour against manual labour" (pp. 94-95).

passage is also important for the argument that, under conditions of autarky, agricultural employment and production are determined by the quantity of food that needs to be provided for the population, which limits the possibilities of employment in other sectors.

On this same point, Cournot reached the opposite conclusion when he pondered whether Mill and Ricardo's "formula for international barter", based on comparative advantage, was "(...) no more than an ingenious device to insert artificially, into certain commercial data, a symmetry which is not there, and to hide, from themselves and from others, the consequences of this lack of symmetry" (1863/1981, p. 300). Taking the example of the exchange of cloth for linen, i.e. one industrial product for another, he proposed that, if the cloth exporting nation "can but succeed in manufacturing linen for its own use, without affecting in any way its production of cloth, and if it therefore turns away the foreign linen, it will conserve enough means to buy in from overseas—in return for its cloth—cereals to feed its growing population, fine wines to slake the sensual palates of its wealthy gourmets, objects of art and curiosity to be exhibited with pride; (...) while the other nation (...) may well see its working population dwindle, and its wealthier classes consigned to hardship, debt and poverty. Whereas if, fearing such consequences, it allows cloth to enter only on condition that its own linen is granted entry, more or less guaranteeing that it can pay for its cloth purchases in linen, it in effect restores the symmetry assumed in the theory of international barter, by reason of the great analogy between the conditions of economic production of the two commodities"¹⁴(*idem*, p. 300). Without going into the formal validity of his reasoning,¹⁵ Cournot seems to have suddenly incorporated into the

¹⁴While Dupuit set himself the challenge of proving that a disadvantaged country gains from trade according to the theory of absolute costs, Cournot set out to show that it loses according to the theory of relative costs. Cournot's findings conflict with those of Mill, who held that it was the poorest countries that gained the most from trade: "the countries which carry on their foreign trade on the most advantageous terms, are those whose commodities are most in demand by foreign countries, and which have themselves the least demand for foreign commodities. From which, among other consequences, it follows, that the richest countries, *caeteris paribus*, gain the least by a given amount of foreign commerce: since, having a greater demand for commodities generally, they are likely to have a greater demand for foreign commodities, and thus modify the terms of interchange to their own disadvantage" (Mill, 1909, III.18.59, cited in Gide and Rist, 1944/2000, p. 407-408, note 3).

¹⁵Cournot doesn't explain why it is in the interest of the cloth producing country to replace its linen imports with agricultural imports, which do not figure in his analysis of "international barter". Nor, unlike Dupuit, does he explain how the economic condi-

theory of comparative advantage the conclusions of Friedrich List (1841) on the dangers of agricultural specialisation—conclusions which make for an interesting comparison with Dupuit's.

List's argument is based on the idea that agriculture can benefit from the division of labour.¹⁶ "A nation which possesses merely agriculture, and merely the most indispensable industries," (1841/1909, II.XIII.13) lacks a division of labour not only between agriculture and industry, but even within agriculture itself, due to the shortage of markets that results from the absence of manufacturing revenue:¹⁷ "A part of the productive power which the agricultural nation thus loses, will fall to the lot of that nation which exchanges its manufactured goods for agricultural products. This will, however, be a positive loss only in case the agricultural nation has already reached that stage of civilisation and political development which is necessary for the establishment of a manufacturing power. If it has not yet attained that stage, and still remains in a barbarous or half-civilised state, if its agricultural power of production has not yet developed itself even from the most primitive condition, (...) by the importation of foreign fabrics and the exportation of raw products its prosperity nevertheless increases considerably from year to year, and its mental and social powers continue to be awakened and increased" (idem). This last point, oddly enough, seems quite close to the ideas developed by Dupuit: the disadvantaged agricultural country gains from trade, which contributes to the development of its intellectual forces.¹⁸ But from here on the two analyses diverge. List continues: "If, however, the agricultural nation has already reached the culminating point of its agricultural development, as far as that can be attained by the influence of foreign commerce, (...) and if, nevertheless, owing to the successful competition of the manufacturing nation in the markets of the agricultural nation, no manufactures can spring up in the latter, in such a case the agricultural productive power of the agricultural nation is exposed to the danger of being crippled." (idem). He defines his terms: "By a crippled state of agriculture we mean that state of things in which, from want of a powerful and steadily developing manufacturing industry, the entire increase

tions of agricultural production differ from those of industrial production, entailing a lack of symmetry in trade.

¹⁶In putting the emphasis on the division of labour in agriculture, List goes against Adam Smith, for whom the division of labour in industry was far more significant (A. Smith, 1976/1904, I.1.4).

¹⁷Such an economy is therefore at a disadvantage agriculturally, as well as industrially, as it cannot benefit from the division of labour in agriculture.

¹⁸The second French edition of List's book, which came out in 1857, may conceivably have served as the source for Dupuit's argument about disadvantaged economies.

of population tends to throw itself on agriculture for employment, consumes all the surplus agricultural production of the country, and as soon as it has considerably increased either has to emigrate or share with the agriculturists already in existence the land immediately at hand, till the landed property of every family has become so small that it produces only the most elementary and necessary portion of that family's requirements of food and raw materials, but no considerable surplus which it might exchange with the manufacturers for the manufactured products which it requires"(II.13.14). The only way to avoid such a situation is to create a national industrial base; agriculture will benefit from its proximity and will thus be sheltered from the vagaries of international trade. As part of this policy, budding industry must be protected—an idea to which Dupuit (1861a, pp. 227-228) was totally opposed.

Dupuit—following a process of reasoning that, according to Ekelund and Hébert (1999a), foreshadows Marshall's thinking on market adjustment mechanisms—concludes that over the long term the price of exported goods is bound to increase (in the case of agricultural products) or remain constant (for industrial products) relative to autarky, whereas the price of imports is always bound to fall (p. 137).^{19,20} If we apply this conclusion to the relations between the rich country and disadvantaged country, then as a consequence of international trade the price of industrial goods should fall in the poor country and remain constant in the rich one, while the price of agricultural products should rise in the poor country and fall in the rich one. If p is the ratio in autarky of industrial prices over agricultural prices in the rich country, p' the corresponding ratio in the disadvantaged country, and p^* the ratio resulting from international trade (ignoring transport costs), we obtain $p' > p^* > p$, which is the traditional outcome of the theory of comparative advantage. For Dupuit, however, this is just a consequence of trade, not a criterion for specialisation.

¹⁹This point is dealt with masterfully in the Ekelund and Hébert article, to which we refer the reader.

²⁰This was not a particularly original conclusion. In the same year, Maurice Block wrote "When a country's imports are newly accepted into another country, the first effect is a price rise in the exporting country. The second is a fall in the importing country, but smaller than expected, both because of the price rise at the point of production and because of the greater spread of the new market" (1861, p. 369). This result had already been expressed and formalised by Cournot: "communication should raise the price of the good on the exporting market, and lower it on the importing market" (1838/1980, p. 93).

We conclude this first section with two contrasting contemporary judgements on Dupuit's analysis of international specialisation. Lamé Fleury, one of Dupuit's friends, wrote: "For his terms of comparison he takes, by an extreme and certainly most ingenious hypothesis, a country offering the most advantageous conditions of production and another with the most disadvantageous of circumstances (...). This demonstration [is] almost mathematical in its rigour and seems to me capable of persuading the most recalcitrant of minds" (1861, p. 121). For Dunoyer, on the other hand, the demonstration that the disadvantaged country gains from trade is the least successful part of the book: "The exposition is long-winded and laborious" (1861, p. 278) and "(...)there is, in this part of his work,²¹ something strained and abstract which makes it rather difficult to grasp" (p. 281), which he puts down to the author's mathematical culture.²²

Although these judgements agree on the mathematical character of Dupuit's analysis, it does not in fact rely on any formalisation. But as Dupuit puts forward precise hypotheses about costs and yields in various different sectors, and about how agricultural production is determined, it is tempting to check the validity of his conclusions using a model based on these very hypotheses. In what follows, we examine his determination of equilibrium in a closed economy and then go on to analyse various situations of international specialisation. The aim of these extrapolations is not so much to formalise Dupuit's reasoning as to assess his conclusions within the framework of a "modern" model of international trade built on the hypotheses he set out in his book.

²¹Dunoyer accuses him of not having "seen with sufficient precision and clarity the law by which wealth propagates throughout the world, from rich and industrious countries to those that are less so" (1861, p. 281), which is not unreminiscent of Ricardo's view that free trade "diffuses general benefit" (1821, 7.11). Dunoyer had earlier presented a more precise explanation for the gains of a disadvantaged country, listing higher prices for a product in the exporting country, the costs of selling overseas, product differentiation, efficiency gains from trade, and the expansion of markets (1847, pp. 244-245).

²²Dunoyer immediately concedes however that "One could not really claim that this turn of mind is particularly evident here, and, however skilful a mathematician he may be, Monsieur Dupuit is nonetheless an economist of great distinction" (1861, p. 281).

2. THE EQUILIBRIUM OF ECONOMIES IN AUTARKY

With a nod to the Ricardian origins of the models proposed by Findlay (1974) and by Pasinetti (1960), we posit a country that produces two goods—cereals and velvet—for which the yields, Y_c and Y_v , respectively, are obtained by the quantities of labour N_c and N_v . Due to diminishing returns from the land, the marginal productivity of labour in cereal production tends to decrease.²³ We adopt the production function used by Bhaduri and Harris (1987) in their study of the dynamics of the Ricardian system:

$$(1) \quad Y_c = aN_c - \frac{bN_c^2}{2} \quad a > 0 \quad b > 0$$

which gives us the marginal and average labour productivity values

$$(2) \quad \frac{dY_c}{dN_c} = a - bN_c; \quad \frac{Y_c}{N_c} = a - \frac{bN_c}{2}$$

The marginal productivity of labour is nil for $N_c = \frac{a}{b}$ which corresponds to the maximum yield $Y_c = \frac{a^2}{2b}$. The average productivity and the yield are nil for $N_c = \frac{2a}{b}$. The land rent is defined as:

$$(3) \quad R = \left(\frac{Y_c}{N_c} - \frac{dY_c}{dN_c} \right) N_c = \frac{bN_c^2}{2}$$

Velvet is produced at constant yield according to the function

$$(4) \quad Y_v = \alpha N_v$$

which gives us marginal and average labour productivity values equal to α .

The price of cereals, the price of velvet, and the wage rate are p_c , p_v , and w respectively. The relative price of velvet compared to cereals is $p = \frac{p_v}{p_c}$. By maximising the sum of the yield values for both goods, while

²³Because of its inherent assumptions, this model cannot address the question of intellectual labour. Nor can it incorporate List's analysis of the division of labour in agriculture.

respecting the condition that the population is divided up between the two industries ($N = N_c + N_v$)—a procedure compatible with Dupuit's general approach—we arrive at an equality between the price ratio and the ratio of marginal labour productivities for each good:

$$(5) \quad p = \frac{a - bN_c}{\alpha}$$

this result can also be obtained by equalising the profit rates of each industry (Findlay, 1974, p. 2):

$$\frac{p_c(Y_c - R - wN_c)}{p_c w N_c} = \frac{p_v \alpha N_v - p_c w N_v}{p_c w N_v} \text{ }^{24}$$

Condition (5) can be used to express agricultural employment in terms of relative prices:

$$(6) \quad N_c = \frac{a}{b} - \frac{\alpha}{b} p$$

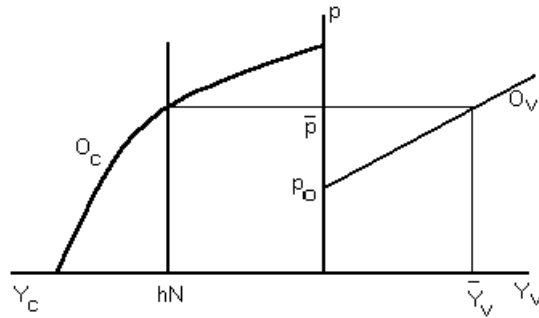
which when factored into equation (1), gives us the supply of cereals in terms of relative prices:

$$(7) \quad Y_c = \frac{a^2}{2b} - \frac{\alpha^2}{2b} \cdot p^2$$

represented by curve O_c in Graph 1. Cereal production is nil for $p = \frac{a}{\alpha}$

and reaches a maximum of $\frac{a^2}{2b}$ when p is nil.

²⁴Without specifying the exact production function for cereals, Findlay uses this condition to deduce the supply curves for both goods, O_c and O_r —see the figure in Annex 1, which solves the model according to Findlay's hypotheses. The annex brings out plotting errors in Findlay's supply and demand curves.



Graph 1

Industrial employment being defined as $N_p = N - N_c$ the supply of velvet can be deduced from equations (4) and (6):

$$(8) \quad Y_v = \frac{\alpha(bN - a)}{b} + \frac{\alpha^2}{b} p$$

The supply curve for velvet (O_v in Graph 1) is a line that rises in proportion to p . Velvet production becomes nil when the relative price of velvet falls to $p = \frac{a - bN}{\alpha} = p_o$ which is equal to the ratio of the marginal productivity of labour in agriculture when the entire population is employed in agriculture over the marginal productivity of labour in industry.

To determine the relative price of the goods we need to bring in a demand factor. Findlay rejects Ricardo's persistent assumption that the demand for cereals is proportional to population²⁵ and adopts Pasinetti's (1960) hypothesis, by which all rents are paid in velvet while wages and profits are paid in corn.²⁶ As this hypothesis is totally foreign to Dupuit's approach, we adopt the hypothesis that demand for cereals is propor-

²⁵For Findlay, Ricardo's approach is inconsistent with its own assumptions since, except under static conditions, corn is required not only to restock the current wage fund but also to increase it through profit accumulation. As the rate of profit is one of the system variables, the approach is invalid.

²⁶The determination of equilibrium in autarky under this hypothesis is described in Annex 1.

tional to population, hN , where $h > 0$.²⁷ This corresponds to the condition which states that agricultural production must be sufficient to sustain the population. Thus, in the example from page 92 of *La liberté commerciale* on population distribution within the disadvantaged country under conditions of autarky, it takes 17 million farmers to produce enough food for a population of 26 millions, leaving only 9 million people available for other activities. Even under conditions of free trade, it takes 20 million farmers to sustain 30 million people. Dupuit's reasoning, set out on the same page, and which we looked at above, appears at first to be in contradiction with this hypothesis: the reduction in cultivation—and thus in agricultural production and population—is, in his analysis, caused by the rise in the relative price of industrial goods that results from autarky. This reasoning, which is perfectly consistent with equations (5) (6) and (7), corresponds simply to a movement along the cereals supply curve in Graph 1 in response to variations in the relative price; it does not answer the question of how that relative price is determined. It cannot be determined within the industrial sector, as non-agricultural employment and production are, for Dupuit, the resultant of agricultural employment and not the other way round (p. 93). By the same token, it cannot be determined by the interplay of supply and demand in each sector. Dupuit's example is simply accounted for by the fact that the loss of external markets forces agricultural production to align with the needs of the country's own population, which is accompanied, as we shall shortly see, by a rise in the relative price of industrial goods.

If we accept this hypothesis, the equality between the supply of cereals and the demand for cereals hN gives us the equilibrium relative price and the equilibrium agricultural employment level

$$(9) \quad \bar{p} = \frac{\sqrt{a^2 - 2bhN}}{\alpha}$$

²⁷The consequence of this hypothesis is that the model loses the dynamic character of Ricardo's analysis which is also found in Findlay and Pasinetti. The relation here is a short-term one, since in the long term, according to Dupuit, the population is limited by the available subsistence. In which case we have $N = \frac{Y_c}{h}$ and the model is once again dynamic, but there is now an indeterminacy that needs to be resolved with a hypothesis along the lines of Pasinetti's. The whole question of Ricardo's dynamics is in any case alien to Dupuit whereas, *pace* Ravix, it is present in Rossi's *Cours*.

$$(10) \quad \bar{N}_c = \frac{a - \sqrt{a^2 - 2bhN}}{b}$$

Note that $\sqrt{a^2 - 2bhN} = a - b\bar{N}_c$, the marginal productivity of agricultural labour in equilibrium. The equilibrium land rent is therefore

$$\bar{R}_c = \frac{a^2 - bhN - a\sqrt{a^2 - 2bhN}}{b}$$

The equilibrium relative price determined on the cereals market leads us to the equilibrium industrial employment and equilibrium production for velvet:

$$(11) \quad \bar{N}_v = \frac{bN - a + \sqrt{a^2 - 2bhN}}{b}$$

$$(12) \quad \bar{Y}_v = \frac{\alpha(bN - a) + \alpha\sqrt{a^2 - 2bhN}}{b}$$

This determination of internal equilibrium is shown in Graph 1.²⁸ Identical results would be obtained for a second country—Dupuit's disadvantaged country—in which the goods were produced according to the production functions

$$Y'_c = a'N'_c - \frac{b'N'^2_c}{2}, \quad Y'_v = \alpha'N'_v$$

The various parameters can be sized so that the model yields the figures in Dupuit's example of the impact on the disadvantaged country of abandoning free trade, which suggests that the model is indeed an appropriate one for representing Dupuit's reasoning. There are a number of possible permutations that allow for coherent values of a' , b' and α' , for example $a' = 866.4$, $b' = 0.00001$ and $\alpha' = 510.9$. In the case of free trade, where 20 million farmers (N_c) sustain 30 million people, this gives a marginal productivity of labour in agriculture of 666.4. In the case of autarky, where 17 million farmers sustain a population of 26 million, the same parameters lead to a marginal productivity of 696.4, higher than in free trade due to the abandonment of poorer land. In this last instance we obtain a relative price of $p' = 1.3928$ by positing $\alpha' = 500$.

²⁸The equilibrium employment and output levels can also be determined directly, without calculating the equilibrium relative price, by positing $Y'_c = hN'$. This method is described in Annex 2.

3. DIFFERENT CASES OF INTERNATIONAL SPECIALISATION

As a result of international trade, the two countries will modify their output in line with the production function parameters and the size of their populations. Dupuit analysed in some depth the case of the universally disadvantaged country that specialises in agriculture due to unaffordable industrial costs. We examine this particular example before looking at the more general case of specialisation in both countries. In each instance we leave to one side the costs of marketing and transport between the two countries, which inform some of Dupuit's conclusions.

3-1 Complete agricultural specialisation in the disadvantaged country

This subsection seeks to formalise Dupuit's example of the relatively infertile and industrially disadvantaged country that specialises totally in agriculture and imports industrial goods. We assume $\alpha' < \alpha$, $a' < a$, and $b' \neq b$. The populations of the two countries are N and $N' < N$. The parameter b is the same in each country. Dupuit supposes that the second country specialises exclusively in agriculture if $\alpha' < \alpha$ or $\frac{\alpha}{\alpha'} > 1$, whereas according to the theory of comparative advantage it will specialise to a greater or lesser degree in agriculture if $\bar{p}' > \bar{p}$, i.e. if the ratio of the marginal labour productivity in agriculture over marginal labour productivity in industry is higher in the second country than in the first:

$$\frac{\sqrt{a'^2 - 2b'hN'}}{\alpha'} > \frac{\sqrt{a^2 - 2bhN}}{\alpha} \text{ or } \frac{\alpha}{\alpha'} > \frac{\sqrt{a^2 - 2bhN}}{\sqrt{a'^2 - 2b'hN'}} > 1$$

If the second country specialises totally in agriculture, then $Y'_c = 0$ and $N'_c = N'$. Its cereal exports E_c to the first country will then be equal to its entire surplus cereal production relative to consumption:

$$E_c = Y'_c - hN' = a'N' - \frac{b'}{2}N'^2 - hN'$$

The agricultural production of the first country will therefore be equal to its own consumption minus the imports from the second country:

$$Y_c = hN - E_c = h(N + N') - a'N' + \frac{b'}{2}N'^2$$

The relative price p^* within the first country, as a result of international trade, is now determined by equation (7), giving

$$p^{*2} = \frac{a^2 - 2bhN}{\alpha^2} + \frac{2b(a'N' - hN') - b'bN'^2}{\alpha^2} = \bar{p}^2 + \frac{2b}{\alpha^2}(Y'_c - hN') > \bar{p}^2$$

On the industrial side, international trade increases the relative price of velvet in the advantaged country relative to the situation of autarky. Employment and production in cereals consequently diminish, while employment and production in velvet increase as a result of trade. The first country therefore gains from trade, but not necessarily the second. The latter clearly loses out if it specialises on the basis of $\alpha' < \alpha$ whereas $\bar{p}' < \bar{p}$ actually pertains, which corresponds to the instance

$$\frac{\sqrt{a^2 - 2bhN}}{\sqrt{a'^2 - 2b'hN'}} > \frac{\alpha}{\alpha'} > 1: \text{ specialisation in cereals, according to Dupuit's}$$

criterion, in this case runs contrary to the comparative advantage criterion, and international trade increases the relative price of velvet in the second country.

If the two criteria converge, i.e. $\alpha' < \alpha, \bar{p}' > \bar{p}$, then complete agricultural specialisation will be beneficial to the second country only if $\bar{p}' > p^*$, in other words if:

$$\bar{p}'^2 > p^{*2} = \bar{p}^2 + \frac{2b(Y'_c - hN')}{\alpha^2} \text{ or } \bar{p}'^2 - \bar{p}^2 > \frac{2bE_c}{\alpha^2}$$

The meaning of the right-hand term of the expression is straightforward. Equation (7) yields:

$$p^2 = \frac{a^2}{\alpha^2} - \frac{2b}{\alpha^2}Y_c$$

whence $\frac{2b}{\alpha^2}$ is the increase in p^2 resulting from an infinitesimal drop in Y_c (due to the rise in the marginal productivity of labour in agriculture), which, when multiplied by a decline in production equal to the volume of cereals imports, gives us the increase in p^2 that results from international trade. If this increase is greater than the difference between the squares of the relative prices in autarky, then the relative price resulting from trade will be greater than the relative price in autarky in the disadvantaged country, and the latter will lose out. It follows that if its agricultural output was relatively high compared to its subsistence needs, then

its cereals exports could be so large that they would end up raising the relative price of velvet compared to autarky.²⁹ Then we would have a situation of "impoverishing specialisation", analogous in its effects to the notion of impoverishing growth. Such a situation is clearly impossible in comparative advantage theory, as the second country would have no motive to abandon industrial production. It would only do so if $p^* \leq p'_0 = \frac{a'-b'N'}{\alpha'} < \bar{p}'$ i.e. if international trade were to bring the relative price in the second country down so far, compared to autarky, that industrial production ceased to be viable. The relative price p^* would then be determined as in Graph 2.

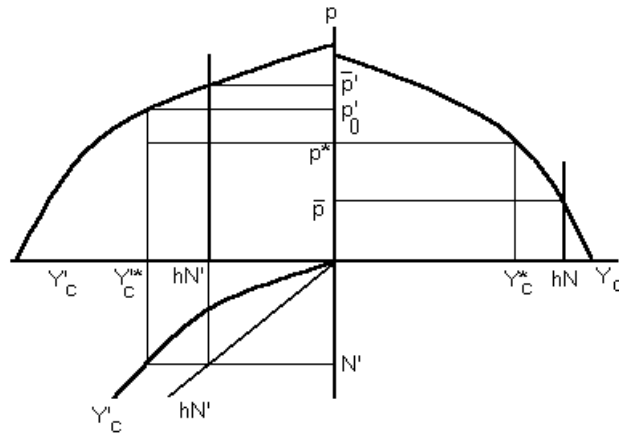
Quadrant 2 shows that the disadvantaged country in autarky has an agricultural output hN' for the relative price \bar{p}' . This quantity (hN') is associated with the population N' in quadrant 3. If the country specialises in agriculture, this population will produce the quantity Y'_{c^*} and cereals exports will be equal to $Y'_{c^*} - hN'$. The output Y'_{c^*} is correlated [or associated] with the relative price p'_0 at which industrial production ceases to be viable.

Quadrant 1 represents the situation of the first country. In autarky, its cereals output, equal to hN , is associated with the relative price \bar{p} . Cereals imports from the other country reduce its output to Y^*_c , avec $hN - Y^*_c = Y'^*_{c^*} - hN'$. This new output value is correlated with the relative price p^* such that $\bar{p}' > p'_0 \geq p^* > \bar{p} > p_o$.

It emerges that cereals transactions are determined by the size of the available output after consumption in the disadvantaged country and that these transactions in turn determine the relative price p^* in the first country. In the graph, this price is lower than p'_0 —the price at which the disadvantaged country starts to specialise in cereals. We can see for ourselves that, conversely, the graph bears out Dupuit's analysis (pp. 92-93) of the effects of the shift to autarky in the disadvantaged country: agricultural output diminishes from $Y'^*_{c^*}$ to hN' as the population to be fed declines from 30 to 26 million; the corresponding movement on the

²⁹This would have the opposite effect to that postulated by Mill, as referred to in an earlier footnote.

disadvantaged country's cereals supply curve indicates an increase in the relative price of industrial goods.



Graph 2

It is debatable whether, in this situation, trade leads to an increase in the total output of each good. This question was brought up by Cournot (1838/1980, pp. 92-93; 1863/1981, p. 201) who showed, albeit using a different example of partial equilibrium, that "communication between markets" could lead to a reduction in the total output of a good. Here, the question only applies to industrial goods, as the total agricultural output of the two countries is unmodified by trade and remains equal to $b(N + N')$. The total output of industrial goods is increased following the disadvantaged country's complete specialisation in agriculture if $Y_v^* > Y_v + Y_v'$. Given equation (10), this will only happen if:

$$\frac{\alpha^2}{b}(p^* - \bar{p}) + \frac{\alpha'^2}{b'}(p_0' - \bar{p}') > 0$$

i.e. if:

$$\frac{\alpha^2}{b}(p^* - \bar{p}) > \frac{\alpha'^2}{b'}(\bar{p}' - p_0')$$

This means that the increase in industrial output in the richer country caused by a rise in the relative price must be greater than the fall in industrial output in the disadvantaged country caused by a drop in the relative price; this condition may not necessarily be fulfilled. If not, then

the quantity of corn exported from the poor country will be too small to sustain enough workers in the rich country to offset the poorer country's lost industrial output. The complete agricultural specialisation of the disadvantaged country, advocated by Dupuit, therefore leads to a decline in that country's well-being; its corn exports would not suffice to obtain the quantity of industrial goods that it itself manufactured before specialising. This can be demonstrated with a numerical example. We start out by positing

$a' = 866.4$; $a = 1,000$; $b = b' = 0.00001$; $b = 510.9$; $\alpha = 800$; $\alpha' = 500$
 $N = 40$ million inhabitants and $N' = 26$ million inhabitants (all active).

With each country in autarky we obtain the following results (in millions of units, except for the relative prices):

$Y'_c = hN' = 13,283.4$; $\bar{p}' = 1.3928$; $N'_c = 17$; $N'_v = 9$; $Y'_v = 4,500$;
 $p'_0 = 1.2128$;

$Y_c = hN = 40,436$; $\bar{p} = 0.9612$; $N_c = 23.1$; $N_v = 16.9$; $Y_v = 13,520$;
 $Y_v + Y'_v = 18,020$.

With the poorer country totally specialized in agriculture, we get

$Y_c^* = 15,766.4$; $hN' = 13,283.4$; $E_c = 2,483$; $Y_c^* = 17,953$; $p^* = 1.0008 < p'_0$;

$N_c^* = 19.936$; $N_v^* = 20.064$; $Y_v^* = 16,051 < Y_v + Y'_v$.

The overall industrial output diminishes as a result of the disadvantaged country's complete agricultural specialisation, and the quantity of industrial goods that the latter can obtain through imports is only $\frac{E_c}{p^*}$ or 2,481 million units, less than its own industrial output in autarky.

The same result can arise even if the overall industrial output of the two countries is increased by specialisation. Thus for $\alpha = 700$ we obtain the following results:

$p^* = 1.206 < p'_0 = 1.2128$; $Y_v = 11,830$; $N_c^* = 15.58$; $N_v^* = 24.42$;

$Y_v + Y'_v = 16,330 < Y_v^* = 17,094$.

Although the overall industrial output is increased by the disadvantaged country's complete agricultural specialisation, the latter, exporting the same quantity of cereals as in the previous example, can now only

afford 2,059 million units of industrial goods—even less than in that example.

This analysis of the disadvantaged country's option of complete agricultural specialisation brings out the weaknesses in Dupuit's argument. It is not in that country's interest to specialise on the sole basis of the difference in industrial costs, as it would run the risk of specializing in a way contrary to the principle of comparative advantage—a case of impoverishing specialisation. It will only specialise completely if the international relative price level is so low as to render all industrial production impossible on its own territory. Dupuit's criterion of specialisation on the basis of absolute industrial costs does not therefore support his own conclusions on movement in the prices of goods as a result of trade. It also emerges that while complete specialisation may appear justified on the basis of comparative advantage, it can lead to a fall in overall industrial output. Furthermore, in the numerical examples above, the disadvantaged country cannot offset the loss of its own industrial output through imports. Dupuit's optimism about the benefits that a disadvantaged country could gain from complete specialisation in agriculture appears therefore to be misplaced; the results obtained are more in line with Cournot's fears about the consequences of a lack of symmetry in trade, even though he expressed those fears in a different analytical framework to the one developed here. The question remains as to whether one finds the same results in the case of incomplete specialisation.

3-2 Incomplete specialisation in each country

For Dupuit, it was inevitable that one of the countries would specialise completely in agriculture from the moment that its industrial costs were higher than that of the other country; this view contrasts with that of Cournot, for whom complete specialisation applied to "particular and extreme cases" (1863/1981, p. 206). The model proposed here invalidates Dupuit's conclusion.

In the general case of two countries with differing technologies and population sizes, international trade implies

$$\frac{a - bN_c}{\alpha} = p^* = \frac{a' - b'N'_c}{\alpha'}$$

Whence:

$$N_c = \frac{a - \alpha p^*}{b}, \quad N'_c = \frac{a' - \alpha' p^*}{b'}$$

By incorporating these equations into the agricultural production functions and the equilibrium of supply and demand for cereals between the two countries, we get the international relative price:

$$(13) \quad p^* = \sqrt{\frac{a^2 b' + a'^2 b - 2 h b b' (N + N')}{\alpha^2 b' + \alpha'^2 b}}$$

This relative price will only lead to the second country's complete specialisation in agriculture if it is less than or equal to $p'_0 = \frac{a' - b' N'}{\alpha'}$, which would take us back to the previous example. If this is not the case, then each country will go down the route of incomplete specialisation. As we saw earlier, the second country will then specialise in cereals and the first in velvet if $\bar{p}' > p^* > \bar{p}$, i.e. on the basis of comparative advantage (or comparative costs).

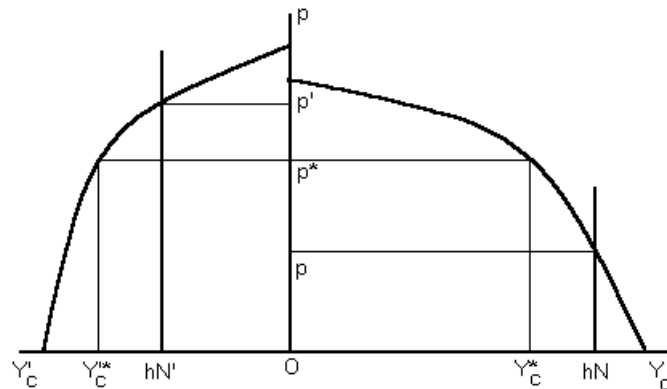
The determination of p^* is illustrated by Graph 3: in equilibrium, the two countries' total demand for corn is equal to their total output, and therefore segment $hN'hN$ is equal to segment $Y_c^* Y_c$, with corn exports (segment $Y_c^* hN'$) equal to imports (segment $Y_c^* hN$).

In this situation, the undesirable effects for the disadvantaged country, as described in the complete agricultural specialisation scenario, are not encountered in the case of incomplete specialisation. If we posit $\alpha = 600$ and keep the initial values of the other parameters, then the equilibrium values in autarky for the disadvantaged country and the division of labour in the richer country remain unchanged, and the other results are as follows:

$$\begin{aligned} p &= 1.2816; Y_v = 10,140; Y_v + Y'_v = 14,640; p^* = 1.3283; N_c^* = 20.225; \\ Y_c^* &= 15,477.7; E_c = 2,194.3; N_v^* = 5.775; Y_v^* = 2,887.5; N_c^* = 20.3; N_v^* &= 19.7; \\ Y_c^* &= 18,241.16; Y_v^* = 11,815; Y_v^* + Y_v^* = 14,706.5 > 14,640; E_v = 1,652; \\ E_v + Y_v^* &= 4,539.5 > 4,500. \end{aligned}$$

As a result of trade, the disadvantaged country benefits from a lower relative price for industrial goods and enjoys a greater quantity of

industrial goods than under autarky. The incomplete specialisation of this country therefore avoids the negative effects of complete specialisation in agriculture.



Graph 3

Having established this general case, we can now take a closer look at two special cases which will enable us to assess certain claims made by Dupuit: firstly, the scenario where both countries have identical technologies in both sectors but have different population sizes, and secondly where the only difference lies in the production costs for velvet.

Analysis of the first situation—in which both countries have equally fertile land and identical industrial costs, but different population sizes—once again invalidates Dupuit's conclusion, in which specialisation depends on the relationship between the absolute costs of industrial goods. If the two countries' technologies and land quality are identical, then $a = a', b = b', \alpha = \alpha'$, and the only difference lies in the level of agricultural productivity corresponding to the different population sizes N and N' . In this situation, international trade entails

$$\frac{a - bN_c}{\alpha} = p^* = \frac{a - bN'_c}{\alpha}$$

whence

$$N_c^* = N'_c^* = \frac{a - \sqrt{a^2 - bh(N + N')}}{b}, \quad Y_c^* = Y'_c^* = \frac{h(N + N')}{2}$$

and

$$Y_c^* - hN = \frac{h(N' - N)}{2}, \quad Y_c'^* - hN' = \frac{h(N - N')}{2}$$

We assume $N > N'$ i.e. that the population of the first country is larger than that of the second, which implies that under autarky the marginal productivity of agricultural labour would be lower in the first country than in the second, whence $\bar{p}' > \bar{p}$. Trade will then take the form of cereals exports from the second country to the first, with a volume of $\frac{h(N - N')}{2}$. After applying equation (13), the international relative price of velvet compared to cereals comes out as

$$p^* = \frac{\sqrt{a^2 - bh(N + N')}}{\alpha}$$

which confirms $\bar{p}' > p^* > \bar{p}$: both countries gain from trade. Cereals imports from the first country are compensated by velvet exports E_v , such that

$$E_v = \frac{h(N - N')}{2p^*} = \frac{\alpha h(N - N')}{2\sqrt{a^2 - bh(N + N')}}}$$

and the output of velvet from each country is respectively, according to equation (8):

$$Y_v^* = \frac{\alpha(bN - a) + \alpha\sqrt{a^2 - bh(N + N')}}{b}$$

$$Y_v'^* = \frac{\alpha(bN' - a) + \alpha\sqrt{a^2 - bh(N + N')}}{b}$$

The output of the first (velvet-exporting) country is greater than that of the second country. But both countries produce both types of good, which corresponds to a situation of incomplete specialisation, represented by Graph 4. Unlike the previous graph, Graph 4 places the cereals supply curves—which are the same for each country because the production functions are identical—in the same quadrant. Each country's output under autarky is determined by its food needs bN and bN' (with $p < p'$ since $N > N'$). In a trade situation, each country produces the average of the autarky outputs for the relative price p^* . The less populous country exports a quantity of cereals AB , equal to BC , the quantity imported by the more populous country.

The other special case is the situation mentioned by Dupuit where the two countries have land of the same fertility, i.e. $a = a'$ and $b = b'$, but different industrial outputs [plutôt productivity], $\alpha > \alpha'$. To avoid any bias arising from the fertility levels of marginal cultivated land we assume an identical population size of $N = N'$. The international relative price for velvet compared to cereals is therefore

$$p^* = \sqrt{\frac{2(a^2 - 2bhN)}{\alpha^2 + \alpha'^2}}$$

with $\bar{p}' > p^* > p'$ if $\alpha > \alpha'$. From this we deduce the cereals output for each country:

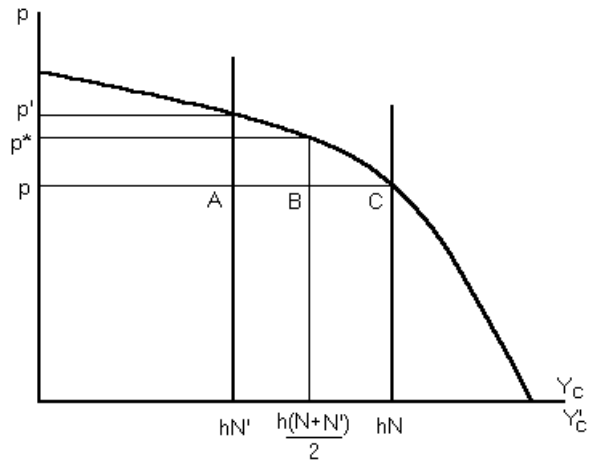
$$Y_c^* = \frac{a^2(\alpha'^2 - \alpha^2) + 4\alpha^2bhN}{2b(\alpha^2 + \alpha'^2)} \quad Y_c'^* = \frac{a^2(\alpha^2 - \alpha'^2) + 4\alpha'^2bhN}{2b(\alpha^2 + \alpha'^2)}$$

with $Y_c'^* > Y_c^*$ if $a^2 - 2bhN > 0$, i.e. if the relative prices in autarky and in international trade are positive. Cereals exports from the second country to the first are:

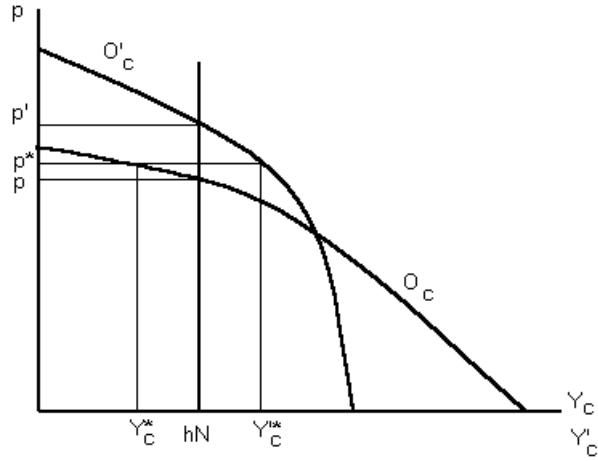
$$Y_c'^* - hN = \frac{(a^2 - 2bhN)(\alpha^2 - \alpha'^2)}{2b(\alpha^2 + \alpha'^2)}$$

which when divided by p^* gives us the volume of velvet imports by the second country:

$$\frac{(\alpha^2 - \alpha'^2)\sqrt{a^2 - 2bhN}}{2b\sqrt{2(\alpha^2 + \alpha'^2)}}$$



Graph 4



Graph 5

In this situation, depicted in Graph 5, the agricultural output of the cereal importing country is lower than that of the exporting country, implying lower agricultural employment and lower land rents. As the land quality is assumed to be the same in either country, the last unit of

cultivated land in the importing country will therefore be of higher quality than the last unit of cultivated land in the exporting country, which contradicts Dupuit's conclusion, discussed in the first section.

As in the previous graph, the cereals supply curves for both countries have been plotted in the same quadrant. Their respective forms are due to the fact $\alpha > \alpha'$. In autarky the two outputs of cereals are equal to hN as the two populations are assumed to be identical in size. This output corresponds to a lower relative price in the industrially advantaged country, $p < p'$. This difference in relative price is consistent with Dupuit's analysis. But, because the cereals output is the same in either country, the quality of the last unit of cultivated land is also the same. Dupuit's conclusion—that in the country with the lower relative price, the last unit of cultivated land is of poorer quality than the last unit of cultivated land in the other country—would be valid only if the population were larger in the first country. In any case, with international trade, the cereal importing country will have a lower cereals output than the exporter, and its last unit of cultivated land will be of higher quality than its counterpart in the other country.

CONCLUSION

Dupuit's theory of international specialisation appears to be a simple extension of his theory of competition within a single country. In international trade, as in a closed economy, the manufacturer with the lowest costs can eliminate a competitor, whereas agricultural producers can co-exist on land of differing fertility. Dupuit is here firmly in the French tradition, running from J.-B. Say to Courcelle-Seneuil, which, unlike Ricardo, holds that domestic and international trade are governed by the same principles (Ravix, 1991, p. 487). When this line of reasoning is combined with the law stating that products are exchanged for products, it leads to specialisation situations defined without reference to comparative advantage. The simple formalisation proposed in this article demonstrates that this approach is deficient, and that most of Dupuit's conclusions on the subject are erroneous.

ANNEX 1: FINDLAY'S MODEL IN AUTARKY

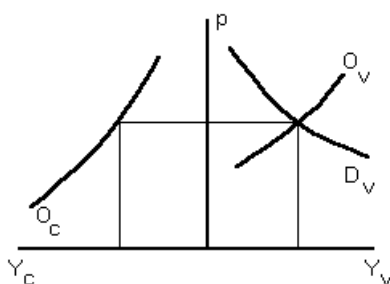
Findlay does not use a precise form of agricultural production function. He plots the supply curves for cereals and velvet (O_c and O_v in Graph 6) *a priori*. Adopting Pasinetti's hypothesis to the effect that all rent is paid in velvet while wages and profits are paid in corn, he plots the demand curve for velvet (D_v in Graph 6) on which the relative price p and the output of velvet are determined by the equality of supply and demand for velvet. This relative price in turn determines cereal output.

Referring back to Graph 1, we can see that these supply curves have been misplotted. The same goes for the demand curve for velvet. Land rents being defined by equation (3), demand for velvet is expressed as

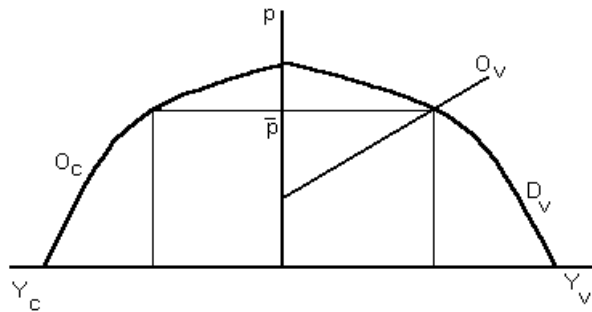
$$D_v = \frac{a^2 - 2acp + \alpha^2 p^2}{2b}, \quad \frac{\partial D_v}{\partial p} = \frac{\alpha^2 p - a\alpha}{b} < 0, \quad \frac{\partial^2 D_v}{\partial p^2} = \frac{\alpha^2}{b} > 0$$

which corresponds to curve D_v shown in Graph 7 with the supply curves of both goods. Note that $D_v = 0$ for $p = \frac{a}{\alpha}$. The equilibrium relative price, different to the one derived from equation (9), is determined by the intersection between the supply and demand curves for velvet. The corresponding equation is

$$\bar{p} = \frac{a + \alpha - \sqrt{\alpha^2 + 2abN}}{\alpha}$$



Graph 6



Graph 7

ANNEX 2: AN ALTERNATIVE MODEL FOR DETERMINING EQUILIBRIUM IN AUTARKY

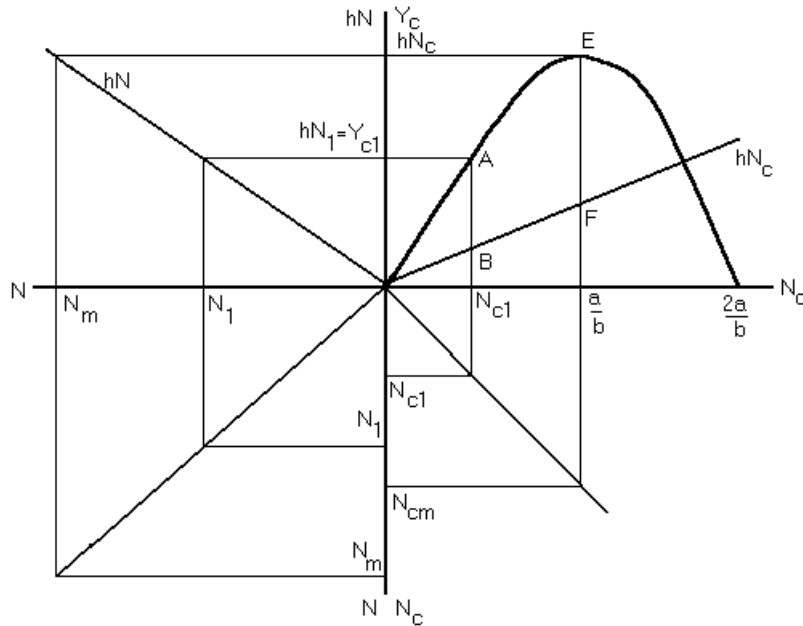
The equilibrium employment and production levels in autarky can be obtained directly, without calculating the equilibrium relative price, by positing $Y_c = hN$. This determination is illustrated in Graph 8.

Quadrant 2 shows that a population N_i implies a subsistence output Y_{cf} . This output is obtained in quadrant 1 with the agricultural employment level N_{cf} . The difference between the reflections of N_i and N_{cf} in the negative part of the y-axis gives us the industrial employment level. The quantity of subsistence required to sustain the industrial labour force is equal to segment AB in quadrant 1, representing the surplus of agricultural production over the quantity of subsistence consumed by the agricultural labour force. The maximum agricultural output $\frac{a^2}{2b}$ would be attained at point E for an agricultural employment level of $N_{cm} = \frac{a}{b}$ (which implies $p = 0$) and would sustain the maximum population $N_m = \frac{a^2}{2bh}$. The industrial employment level $N_v = \frac{a^2 - 2ha}{2bh}$ would again be obtained by difference and would be sustained by the surplus EF .

This is not the situation in which industrial employment is at a maximum. This would be true for a point lying between A and E , where

the surplus $Y_c - hN_c$ was at a maximum, i.e. the point where $h = \frac{dY_c}{dN_c} = a - bN_c$.

This has the solutions



Graph 8

$$N_c = \frac{a-h}{b} < \frac{a}{b}, \quad Y_c = \frac{a^2-h^2}{2b} < \frac{a^2}{2b}, \quad N = \frac{a^2-h^2}{2bh} < \frac{a^2}{2bh}$$

$$N_{vm} = \frac{(a-h)^2}{2bh} > \frac{a^2-2ha}{2bh}, \quad p = \frac{h}{\alpha}$$

However, if curve hN_c intersected the agricultural production curve to the left of point E (which is not the case in Graph 8), then, in the case of demographic growth, industrial production would peak before finally disappearing at the point of intersection where the whole population would be employed in agriculture. This would have the solutions

$$N = N_c = \frac{2(a-h)}{b}, \quad Y_c = \frac{2h(a-h)}{b}, \quad p = p_o = \frac{2h-a}{\alpha}$$

9. Fertility and life expectancy: the analyses of Dupuit, Legoyt and Bertillon¹

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In the first half of the 19th century, France underwent a remarkable demographic change characterised by a decline in fertility and an increase in the mean length of life, or life expectancy at birth.² From the numerous studies inspired by this development, those of Dupuit and of Alfred Legoyt—head of the national statistics office, the *Statistique Générale de la France* (S.G.F.), during the Second Empire—stand out. Dupuit wrote only one article on the subject, entitled *Des causes qui influent sur la longueur de la vie moyenne des populations* (1865a),³ while Legoyt published a whole series of articles in the *Journal des économistes* (Legoyt, 1846, 1847, 1857a & b, 1858, 1860, 1863, 1864, 1867), some of which were reprinted in the *Journal de la Société de statistique de Paris*, touching mainly on the population census and on the S.G.F.'s successive studies of population movement.

The two authors take the same position on the economic significance of life expectancy and share the same statistical analysis of its rela-

¹The authors are grateful to Philippe Le Gall and François Vatin for their comments.

²Or, seen from another perspective, by a simultaneous decline in both birth rates and mortality rates.

³The ideas that Dupuit developed in this article were, however, ones that he had already voiced during two debates at the Société d'Economie Politique on the population question (S.E.P., 1862e, pp. 472-475; 1863) and in letters to the editor of the *Journal des économistes* (Dupuit, 1863b, c and d). The population question was a recurrent debating point at the Société d'Economie Politique and Dupuit, who defended Ricardo's theory of land rent and Malthus' population principle, clashed strongly with anti-Malthusians such as Baudrillart, Fontenay, F. Passy, H. Passy and Wolowski. Indeed Baudrillart accused Dupuit, and also J. Garnier, of suggesting that "one is not really an economist unless one is a Malthusian" (1863a, p. 251). The 1865 article appears, in this light, to have been a restatement of principle destined, in Dupuit's mind at least, to reassert the validity of the Malthusian view. The same process seems to have been at work with regard to his theories on property rights and free trade: his article and book of 1861 grew out of debates in which Dupuit's positions were hotly contested.

tionship with fertility, as measured by birth rates. Their explanations for this relationship differ, however. Dupuit, citing Malthus' *Principle of Population*, accounts for life expectancy by the level of fertility, whereas Legoyt, while acknowledging the connection, ascribes the change in both variables to recent improvements in standards of living in France. Dupuit also appears unaware of a hypothesis already put forward by Quetelet (1835)—and later by Guillard (1853), before being taken up by J. Bertillon (1904, 1911)—according to which the fall in the birth rate can be explained by the decline in mortality. By testing these various theories against demographic data from the second half of the 19th century, we shed light on changing demographic behaviours over the period and gain a clearer understanding of the pertinence of each approach.⁴

1. THE RELATIONSHIP BETWEEN LIFE EXPECTANCY AND FERTILITY

Dupuit and Legoyt attribute the same economic significance to life expectancy. Commenting on the shortness of the mean length of life (37 years) in France at the time relative to the potential human lifespan, Dupuit suggests that life expectancy is determined mainly by economic rather than physiological factors, and blames its brevity on the lack of subsistence among the general population. He comes to the conclusion that "the mean length of life is the most accurate expression of a population's standard of living" (1865a, p. 6) or again, that "the mean length of life can be looked upon as the true thermometer of a population's well-being" (p. 7). But in doing so he is only reiterating Legoyt's idea when he wrote that "the mortality of a people is perhaps the most accurate measure of the degree of well-being that it enjoys" (1858, p. 371).⁵

⁴Certain aspects of Dupuit's article are not discussed here, but in J.-P. Simonin's piece on subsistence crises.

⁵The idea was already an old one: Théodore Fix (1844, p. 20) held that the increase in the mean length of life in France was evidence of the "attenuation of misery". Two years later, Proudhon countered with the suggestion that the increase might only concern the privileged sections of the population, with no actual improvement for the mass of the people (1872, vol. 1, p. 157) and that, rather than "how old the dead are", what really matters is the length of time lived without illness (*id.*, vol. 2, p. 341). Both of these points were acknowledged, less explicitly, by Achille Guillard (1855) who attributed the use of life expectancy as a "demographic measurement of well-being" (p. 107)

Dupuit and Legoyt also adopt the same position on the measurement of life expectancy.⁶ Both insist on the fact that, for a stationary population, the mean length of life is equal either to the population divided by the annual number of births (or indeed deaths) or to the mean age at death⁷ (S.S.P., 1862, pp. 35-36; Dupuit, 1865a, pp. 7-8; Legoyt, 1857, pp. 203; 1863, pp. 10 and 23; 1864, pp. 63 and 76). Yet the figures that Legoyt presents for France—namely a ratio of population over births of 39 in 1853 and 1854, 38.2 in 1860 and 37.2 in 1861, compared to a ratio of population over deaths for the same periods of 45, 46.7 and 43.1 respectively, while the mean age at death was 36.8 from 1850 to 1854, 37.4 in 1860 and 34.1 in 1861—do not obviously favour the hypothesis of a stationary population. And in Dupuit's view, if the population is not stationary, then the ratio of total population to the number of births⁸ or deaths is no longer an expression of life expectancy, although the mean age at death remains "a fairly good approximation" (1865a, p. 8; S.S.P., 1862, p. 36).

Dupuit makes the observation that "nothing is so variable as the mean length of life, not only from one country to the next, but even within the same country. Clearly, however, if I can demonstrate that the length and brevity of the average life are at all times and in all places accompanied by the same circumstances, I shall be entitled to conclude that there exists, between these circumstances and the mean length of

to still earlier work by d'Ivernois and Villermé (although without specifying his references).

⁶Throughout this article, "life expectancy" implies "life expectancy at birth" and is used interchangeably with "mean length of life". In the quoted material, the expression *vie moyenne* is occasionally rendered as "average lifespan", which should be understood here as just another synonym—Translator.

⁷ Dupuit's own demonstration of these results is presented in the Annex. Among the opponents of this system of evaluation was A. Bertillon, who advocated the Quételet method of deriving the mean length of life from a mortality table by establishing the ratio of deaths for each age cohort to the total population for that cohort (S.S.P., 1862, p. 35; A. Bertillon, 1866).

⁸ Unlike Dupuit, Guillard (1855, pp. 276-288) felt that the ratio of population over births was the best measurement of the mean length of life, even when the population was not stationary. As the population, in his view, was fixed at the level allowed by the available subsistence, he deduced (1855, p. 75) an inverse relationship between the number of births and the mean length of life.

life, a relationship of cause and effect"⁹ (1865a, pp. 9-10). To support his demonstration, he draws on statistics from the *Mouvement de la Population* survey of 1858 published in 1863 in *Statistique générale de la France* (2nd series: XI). For each département of France he compares: the mean age at death; the number of inhabitants per birth (i.e. the inverse of the birth rate); the number of children per marriage and the number of natural children per 10,000 inhabitants.¹⁰ After sorting the *départements* in ascending order of birth rate, he retains fifteen from either end of the scale and adds a fictional average instance, asserting that "the intervening départements, which I have removed, present no anomalies capable of infirming the conclusions drawn from those at either extremity" (p. 10).

⁹This is only instance in all of Dupuit's writings where he accords the power of proof to factual observation. This point is discussed in the conclusion to the contribution on subsistence crises.

¹⁰Dupuit had already sketched the outline of just such a study with an earlier comparison of the birth and mortality rates in the 1st and 12th *arrondissements* of Paris (S.E.P., 1863, p. 347).

Table 1

<i>Departments</i>	Number of inhabitants per birth	Mean length of life or mean age at death	Number of children per marriage	Number of natural children (per 10 000 pop.)
Lot et Garonne	55.47	48.64	2.21	5.64
Orne	53.66	46.99	2.23	7.32
Gers	52.96	46.92	2.15	8.36
Eure	51.67	44.85	2.15	18.30
Calvados	48.68	47.13	2.25	21.40
Indre et Loire	47.47	45.28	2.11	12.73
Tarn et Garonne	47.23	40.74	2.24	6.48
Sarthe	47.07	43.34	2.25	14.50
Haute Garonne	46.19	41.74	2.60	15.90
Manche	45.96	43.87	2.69	14.48
Maine et Loire	45.76	41.70	2.57	10.96
Deux Sèvres	44.83	36.39	2.65	14.70
Côtes d'Or	44.76	42.02	2.64	13.03
Gironde	44.65	43.85	2.14	23.00
Charente	44.48	42.59	2.37	10.17
<i>Average</i>	<i>37.18</i>	<i>36.80</i>	<i>2.91</i>	<i>20.72</i>
Corse (Corsica)	33.33	31.37	3.00	15.00
Seine Inférieure	33.04	34.80	3.10	37.00
Ardèche	33.00	30.96	4.00	8.00
Lozère	32.90	34.02	4.00	12.21
Cher	32.83	32.64	3.00	20.20
Pas de Calais	32.71	34.74	3.45	28.65
Pyrénées Orientales	31.99	25.79	4.32	13.50
Gard	31.29	28.67	3.94	10.03
Loire	31.21	29.47	3.62	13.59
Haut Rhin	30.58	31.07	3.79	31.84
Bouches du Rhône	30.36	28.95	3.47	34.75
Bas Rhin	30.20	33.57	3.50	37.00
Finistère	30.19	30.42	3.33	13.61
Seine	29.89	30.86	2.38	88.15
Nord	27.68	29.24	3.58	35.56

Source: Dupuit, 1865a, pp. 10-11

These results are shown in Table 1, to which Dupuit added the following commentary: "The first conclusion to be drawn from this table is

that the mean length of life is the inverse ratio of the proportional number of births. Where 100 inhabitants produce only 2 births per year, the average lifespan is approximately 50 years; it falls to 33 and 25 years where the same population has 3 births or more. (...) Thus, for the average département, whose fertility comes out at 2.66 (i.e. 266 children per 10,000 inhabitants),¹¹ one can conclude that the mean length of life must be 100 divided by 2.66, or 37 years; this indeed is almost exactly equal to the figure of 36.8 years in the table, corresponding to the mean age at death in 1858. Clearly the coincidence between the mean length of life and the low fertility of a population—a coincidence to which there is not a single exception in all 89 départements of France—has a cause, namely that in these 89 départements the population is approximately stationary.¹² And when this is the case, (...) the mean length of life is inversely proportional to the number of births or deaths. Under such a condition of immobility or slow progression, the average lifespan can only attain 50 years if the number of deaths does not exceed 2% of the population. If one were to have 3% of births with this same proportion of deaths, the increase in population would be 1%, and it would double in 69 years, which is not possible in France.¹³ This is why newcomers, not finding the necessary subsistence, are pitilessly kept down by misery" (pp. 11-12).

Quite apart from the inaccuracy of the figures for the average département, this reasoning, along with the calculations on which it is based, rests on the assumption of a stationary population.¹⁴ In this case,

¹¹According to Table 1 the correct figure is the inverse of 37.18, i.e. 2.6896. The figure of 2.66 is actually the birth rate in France for the period 1856-1860 (Charbit, 1981, p. 35). Moreover, the inverse of 2.66 is not 37 but 37.594. The inverse of 2.6896 is 37.18: closer to 37 (and therefore to 36.8).

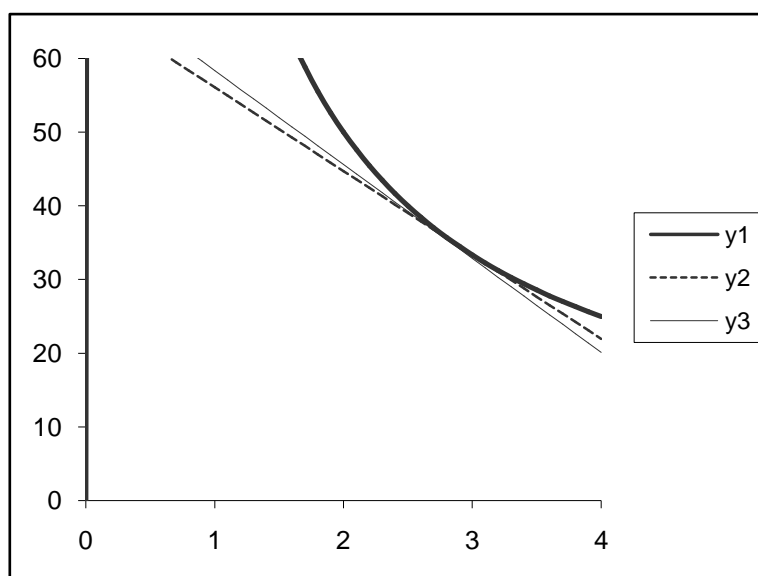
¹²This sentence suggests that Ekelund and Hébert are mistaken when they say that Dupuit, in this article, "concluded that relatively high life expectancy is correlated with 'stationary' populations" (1999b, p. 303). For Dupuit, the fact that population was stationary in all the départements meant that there was an inverse proportion between life expectancy and the birth rate.

¹³The logic of this argument is open to question: a life expectancy of 50 years corresponds to a mortality rate of 2% only if the population is stationary, a condition which Dupuit then overrides.

¹⁴The stationary character of France's population in the 1850s was often accepted as fact (S.E.P., 1857a, pp. 152-153); such disagreement as there was centred on whether the check on growth was preventive or repressive in origin.

if x and y represent respectively the birth rate per 100 inhabitants and the mean age at death, the relationship between these two variables is expressed as:

$$(1) \quad y = \frac{100}{x} \text{ or } x \cdot y = 100$$



Graph 1

This corresponds to curve y_1 in Graph 1, in which the birth rate is measured in the x-axis and the mean age at death in the y-axis. The elasticity of the mean age at death relative to the birth rate is -1 at every point in the curve: a 1% increase in the birth rate would result in a 1% decrease in the mean age at death, and vice versa. The figures announced by Dupuit are easily read off this graph: a birth rate of 2% corresponds to a life expectancy of 50 years, while a rate of 3% corresponds to a life expectancy of 33.33 years.

Dupuit cannot however perform this analysis in as far as the figures in Table 1 are not defined by curve y_1 . An econometric adjustment shows that they correspond to the regression line:¹⁵

¹⁵The regression is performed only on the 30 départements of Table 1 but, in the light of Dupuit's own comments on the missing départements it seems fair to assume that they would have had little impact on the results. This is confirmed by the fact that, for

$$(2) \quad \hat{y} = -11.378x + 67.476 \quad (R^2 = 0.8923)^{16}$$

(-15.23) (33.42)

This regression line corresponds to curve y_2 in Graph 1, very different to curve y_1 in most of the values of its variables. For a birth rate of 2%, for example, it yields a mean age at death of 44.72 years (much the same figures as for Eure in Table 1) and not the mean age of 50 defined by curve y_1 and announced by Dupuit.

These two curves intersect at two points (with the birth rates at 2.906% and 3.024% respectively), remaining very close to each other between these two values, as we see from Graph 1. It is also clear that for the average birth rate value of 2.6896%, the two curves yield very similar values for the mean age at death: 36.873 for y_2 and 37.18 for y_1 , as against 36.8 for the observed value. This similarity may explain Dupuit's error in asserting that the population was nearly stationary in all of the départements, when in fact this was untrue for most of them, as evidenced by the gap between the two curves across most of the values for birth rate and mean age at death.¹⁷¹⁸

an average birth rate across all the départements (not just the 30 presented by Dupuit) of 2.6896%, the line leads to a mean age at death of 36.873, compared to the observed average of 36.8 for all the départements.

¹⁶The results of the adjustment tests are: DW = 1.91; SER = 2.33; Arch test, p.value = 0.64; White heter. test, p.value = 0.69.

¹⁷Dupuit also fails to take into account migration between departments, although this phenomenon—especially from rural to urban areas—was already significant enough to be of concern to economists (Charbit, 1981, pp. 21-38). The oversight is all the more surprising in that Dupuit had taken part in a debate on the issue (S.E.P., 1857a). Legoyt (1847, pp. 188-189) pointed out that international migration skewed the calculation of life expectancy in each country, while the importance of in-migration and out-migration in determining fertility and natality was underlined by Cauderlier (1902a & b). Nor does Dupuit take account of exchanges of subsistence goods between départements.

¹⁸ According to expression (2), the elasticity of the mean age at death relative to the

birth rate in curve y_2 is defined as:
$$e_{x/y} = \frac{-11.378x}{-11.378x + 67.476}$$

The elasticity is -1 at one point only (rather than at every point, as with curve y_1), namely for a birth rate of 2.965% and a corresponding mean age at death of 33.74 years: at this point a 1% increase in the birth rate results in a 1% decrease in the mean age at death, and vice versa. For smaller birth rate values, the elasticity is less than 1 in absolute value. Thus for a birth rate of 2% the elasticity is -0.509: a 1% decrease in the birth rate results in an increase of only 0.509% in the mean age at death. For birth rates above 2.965% the elasticity is greater than 1 in absolute value. For a birth rate of 3%,

One might legitimately wonder whether the data presented by Dupuit, rather than illustrating a fall in life expectancy when the birth rate rises, does not actually show the inverse relationship, i.e. a decrease in the birth rate when the mean length of life increases.¹⁹ This would give us the following regression line:

$$(3) \quad \hat{x} = -0.0784 y + 5.5762 \quad (R^2 = 0.8923)^{20}$$

(-15.23) (28.46)

The influence of the mean age at death on the birth rate appears in fact to be weaker than the impact of the birth rate on the mean age at death. Expression (3) rewrites to:

$$(4) \quad y = -12.755\hat{x} + 71.125$$

corresponding to line y_3 in Graph 1, which is always situated above curve y_1 (representing a stationary population), although approaching it very closely at certain points close to the average values. It intersects the other regression line, y_2 , at the point where the birth rate is 2.66% and the mean age at death 37.17. The inverse of this mean age at death would, for a

for example, the elasticity is -1.024. The influence of the birth rate on the mean age at death is therefore only truly substantial in départements where the birth rate is relatively high.

¹⁹This relationship was suggested in 1853 by Guillard in a letter to the *Journal des économistes* cited by Garnier. He noted that the population increases "by virtue of the simple fact the life becomes longer; for fewer men come into the world when those already in it are slow to leave" (Garnier, 1853, p. 460). Guillard took the idea further in his book of 1855, in the third part of which he examines the relationship by replacing the mean length of life by the mortality rate. The same relationship is expressed in purely arithmetical terms by J.-B. Say (1840, vol. 2, p. 162): "Wherever the average lifespan is longer, the population is larger in proportion to the number of births". This approach was adopted by Cauderlier in his study on the effects of improved hygiene: he saw hygiene as the key determinant of mortality (the birth rate being determined by economic factors), and of infant mortality in particular, the result being an increase in the size of the non-procreating population and a decrease in the overall birth rate (1902a, p. 19; 1902b, p. 123). It is, indeed, one of the reasons why Cauderlier preferred to study "fecundability" rather than birth rates.

²⁰Test results: DW = 1.69; SER = 0.1941; Arch test, P value = 0.566; White heter. test, P value, 0.193.

stationary population, yield a birth rate very close to 2.69%—the rate for the average département in Dupuit's table.²¹

The comparison of birth rates to life expectancy (or, alternatively, to mortality rates) by département is not, however, unique to Dupuit. Already in 1847 Legoyt had compared birth and mortality rates for European countries, albeit without consolidating his data²² into one table. Table 2 does just that, and expresses Legoyt's ratios in decimal as well as fractional form. On the strength of these figures, Legoyt claimed that "one could hope for no better proof that this fact [the decline in the number of births in Europe] and that of the decrease in deaths are correlated, than in the result of the comparison I have established between those States that have the greatest number of births and those that have the least number of deaths. They are, indeed, the self-same States, (...) though they may not be ranked in quite the same order" (1847, pp. 189-190).

²¹Expression (3) is associated with the elasticity of the birth rate relative to the mean age at death: $e_{x/y} = \frac{-0.0784y}{-0.0784y + 5.5762}$

The elasticity is -1 at the point where the mean age at death is 35.56 years and the birth rate is 2.785%: at this point a 1% increase in the mean age at death results in a 1% decrease in the birth rate. For higher mean age values, the elasticity is greater than 1 in absolute value. Thus for a mean age at death of 45, the elasticity is -1.732: a 1% increase in the mean age results in a decrease in the birth rate of 1.732%. By contrast, for any lower mean age, the elasticity is less than 1 in absolute value: for a mean age at death of 33, the elasticity is -0.87, which means that a 1% increase in the mean age results in a decrease of only 0.87% in the birth rate. The influence of the mean age at death on the birth rate is therefore only truly substantial in départements where the mean age at death is already relatively high.

²²These data are not homogeneous: they are based on a range of years (unspecified, save for France) with the exception of Russia (1842), Holland (1844) and Denmark (1840).

Table 2

States in ascending order of mortality	Ratio of deaths to population	Ratio of births to population
Norway	1 in 50.5 = 0.0198	1 in 30.59 = 0.0327
England	1 in 46.3 = 0.0216	1 in 31.10 = 0.0322
Denmark	1 in 46.0 = 0.0217	1 in 31.43 = 0.0318
France	1 in 43.3 = 0.0231	1 in 34.43 = 0.0290
Belgium	1 in 42.4 = 0.0236	1 in 29.04 = 0.0344
Hanover	1 in 42.0 = 0.0238	1 in 30.40 = 0.0329
Sweden	1 in 41.2 = 0.0243	1 in 29.44 = 0.0340
Holland	1 in 40.3 = 0.0248	1 in 27.80 = 0.0360
Prussia	1 in 35.5 = 0.0282	1 in 26.62 = 0.0376
Bavaria	1 in 35.5 = 0.0282	1 in 28.04 = 0.0357
Saxony	1 in 34.4 = 0.0291	1 in 25.88 = 0.0386
Sardinia	1 in 34.4 = 0.0291	1 in 28.37 = 0.0352
Austria	1 in 34.0 = 0.0294	1 in 26.00 = 0.0385
Russia	1 in 27.0 = 0.0370	1 in 22.45 = 0.0445

Source: Legoyt (1847), pp. 188 and 190.

Table 3

	N° of inhabitants per birth	N° of inhabitants per death
Département of the Seine	32	34
Urban population	35	39
Rural population	41	49
France as a whole	39	45

Source: Legoyt (1857), *passim*.

In 1854, after examining the mortality figures from the départements for 1853, Legoyt concluded: "The comparison appears to support the widely accepted notion of a correspondence between lower fertility and lower mortality (...). Were it not for the exceptional death rates of 1853, it seems likely that the relationship which surely exists between those départements with the most births and those with the most deaths would have been more clearly

established".¹More generally, from the 1853 figures for the Seine département, the urban and rural populations, and for France as a whole (which we have brought together in Table 3 above), he concluded that "There seems therefore to be a direct relationship between the intensity of mortality and that of fertility"(1857, p. 217). In 1867 he grouped 85 départements together in ascending order of their ratio of surviving 20-year-olds to births, and obtained, through for an unspecified timeframe, the figures in Table 4.²

Table 4

Number of départements	Limits of survivor-to-birth ratios	Average ratio	Life expectancy (mean age at death)	Fertility
6	53.0-56.5	54.8	26.1	3.83
13	57.1-59.7	58.1	31.0	3.22
11	60.1-61.8	61.2	32.0	3.13
12	62.0-62.9	62.5	33.1	3.02
9	63.2-63.9	63.7	33.2	3.01
12	64.0-65.8	64.9	34.4	2.90
9	66.0-67.7	66.7	36.8	2.72
7	68.8-69.8	69.4	38.4	2.60
6	70.3-76.6	72.2	41.7	2.40

Source: Legoyt, 1867, p. 209

Legoyt provides the following commentary on this table:"There emerges from these numerical data, with an almost irresistible clarity, the realisation that those départements with the least fertility are also those in which one observes at once the greatest number of surviving 20-year-olds and the longest mean length of life"(p. 209). This conclusion is identical to Du-

¹Introduction to the *Mouvement de la Population* of 1853 (SGF, 1854), quoted by Bardet and Le Bras (1988, p. 393). Note that here and in Table 2 Legoyt compares birth rates with death rates, rather than with mean length of life, as Dupuit, and indeed Legoyt himself, were later to do.

²By comparison with Dupuit's table one observes that Legoyt uses the birth rate to measure fertility while Dupuit uses the inverse rate, i.e. the number of inhabitants per birth. Legoyt, unlike Dupuit, also makes use of the ratio of surviving 20-year-olds to the number of births.

duit's. The result is confirmed by associating the following regression line with the table, despite the relative paucity of data:

$$(5) \hat{y} = \begin{array}{r} -10.8051 x + 66.2891 \\ (-15.39) \quad (31.42) \end{array} \quad (R^2 = \mathbf{0.9713})^3$$

This line, very close to the one adjusted for Dupuit's figures, intersects the curve " $x.y = 100$ " for the birth rate values 2.6742% and 3.4606%: the figures presented by Legoyt are every bit as incommensurable with a stationary population as those presented by Dupuit. The same data are associated with the regression line:

$$(6) \hat{x} = \begin{array}{r} -0.089895y + 6.04452 \\ (-15.39) \quad (30.14) \end{array} \quad (R^2 = \mathbf{0.9713})^4$$

These two lines intersect for a mean age at death of 34.0867 years and a birth rate of 2.98%. The inverse of this mean age at death would yield a birth rate of 2.93%. The final result is therefore close to that obtained from Dupuit's data.

Ultimately, none of this part of Dupuit's analysis seems to have been particularly original⁵ as it precisely matches the calculations of Legoyt. However, Dupuit and Legoyt give very different interpretations of the relationship between birth rate and life expectancy. Dupuit uses the birth rate to account directly for life expectancy, with a proof based on mortality curves, while Legoyt maintains that variations in birth rate and in life expectancy depend alike on changes in the standard of living.

2. DUPUIT'S ANALYSIS OF A DIRECT RELATIONSHIP BETWEEN BIRTH RATES AND LIFE EXPECTANCY

Dupuit establishes a direct relationship between the birth rate and the mean age at death for each département by comparing the mortality

³DW = 0.95; SER = 0.818; Ach test, P value = 0.50; White heter. test, P value, 0.0044.

⁴DW = 1.02; SER = 0.074; Arch test, P value = 0.51; White heter. test, p.value, 0.017.

⁵Dupuit's general reasoning also seems to have been rather unoriginal. In addition to Guillard, Boutowski (S.E.P., 1853, p. 451) noted the relationship between births and mortality figures in France and England, which he put down to inadequate means of existence.

tables of two départements from opposing categories: Lot et Garonne, which presents the lowest birth rate and the longest mean length of life (48.64 years), and Pyrénées-Orientales, which presents a high birth rate and the shortest mean length of life (25.79 years).⁶

He compares the two départements at length, observing that for 10,000 births the number of survivors for each birth cohort is far lower in “Pyrénées Orientales” than in “Lot et Garonne” (Table 5). He also underlines that the probable life expectancy of a new-born child is no more than 5 years in Pyrénées Orientales, compared with about 55 in Lot et Garonne⁷. He illustrates this description by plotting the mortality curves for the two départements, as reproduced in Graph 2 (with the exception of the curve for Gard) in which the age of the survivors is plotted in the x-axis and the number of survivors in the y-axis.⁸ He goes on to conclude: "One sees at once how much lower are the curves for “Pyrénées Orientales” and Gard than for “Lot et Garonne”. The distance between them is the measure of the ravages of poverty; it represents those parts of the population steadily carried off by death, and who would still be alive, had they only dwelt in an environment such as that of Lot et Garonne" (1865a, p. 17).

Straightaway he continues: "As, in a stationary population, the population is equal to the product of the number of births and the mean length of life, one observes that in Pyrénées Orientales, where the average lifespan is half that of Lot et Garonne, a number of births half as great would be sufficient to maintain the population at the present level. One can therefore affirm that at least one half of the number of its inhabitants is cut down by poverty, as there is also a certain number in Lot et Garonne" (p. 17). This reasoning is based on the assumption of a stationary population, which applies to neither of these départements, both of which are located, on curve y_2 in Graph 1, well below the curve " $xy = 100$ ". Life expectancy being measured here

⁶Dupuit also presents the mortality table for the Gard département but focuses his comments on the other two. In *Lot et Garonne*, there was strong social pressure in favour of the one-child family (J. Bertillon, 1911, pp. 108 and 318).

⁷It seems difficult to compare two departments so different on the geographical aspect. But we don't forget that, to Dupuit, the demographic aspect prime on all others economic facts.

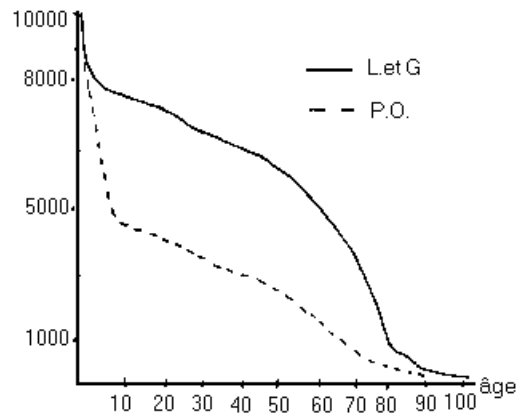
⁸Dupuit finds it necessary to back up his graph with a reference to Quetelet's article on mortality tables in the *Dictionnaire de l'économie politique*, which contains just such a curve (1854, p. 703). In a footnote (pp. 16-17) he presents a geometric interpretation of mortality curves, which we do not analyse here.

by mean age at death, and the population being non-stationary, the population cannot be equal to the product of the number of births and the mean length of life, d'où on ne peut pas affirmer que la même population serait obtenue avec un nombre de naissances réduit de moitié et une vie moyenne deux fois plus longue.

Table 5

Age of survivors	Number of survivors, Lot et Garonne	Number of survivors, Pyrénées Orientales	Probability of mortality per age, Lot et Garonne	Probability of mortality per age, Pyrénées Orientales
Births	10 000	10 000		
1 year	8 589	8 130	14.11	18.70
5 years	7 853	5 132	2.13	9.22
10 years	7 646	4 328	0.53	1.58
15 years	7 543	4 130	0.27	0.46
20 years	7 304	3 977	0.64	0.37
30 years	6 707	3 355	0.82	1.55
40 years	6 297	3 000	0.61	1.06
50 years	5 644	2 535	1.37	1.55
60 years	4 676	1 909	1.73	2.50
70 years	3 271	1 073	3.05	4.34
80 years	1 076	310	6.65	7.13
90 years	108	32	8.96	9.00
100 years	13	0	9.00	100.00

Source: Dupuit, 1865a, p. 13.



Graph 2 (source: Dupuit, 1865a, p. 16)

Dupuit adduces a further graph: "Instead of starting out from the same number of births and comparing the numbers of survivors at each age, one can consider the same population and look at how many of the individuals who compose it are of the same age. Thus, (...) in Lot et Garonne there is one birth for every 55.47 inhabitants, compared with one for 32 in Pyrénées Orientales; we deduce from these two figures that the proportion of births for an equal population will be as 32 is to 55.47, or as 10,000 is to 17,334" (p. 17). By applying the mortality table represented by Table 5 to these populations, Dupuit obtains Table 6 and Graph 3, indicating for each département the number of survivors of the same age for an equal overall population. As he points out, Pyrénées Orientales presents a larger population per age group up until the age of 10; beyond which point, that honour goes to Lot et Garonne. The difference is at its greatest between 40 and 50, the age, according to Dupuit "at which man, by physical strength and experience, is at the height of his productive powers. In Pyrénées Orientales, however, (as we are comparing populations of equal size) that surplus is replaced by the same number of children, who consume without producing. On the one side we have more mouths to feed and fewer productive forces, while on the other we have more productive forces and fewer mouths to feed; this perfectly explains the differences of condition and mortality" (pp. 18-20). Dupuit concludes his comparison with: "these two départements (...) are not exceptions: quite the contrary, they are the embodiment of a general fact to which there is

noexception. Where populations are roughly stationary, (...) the fertility of the population is a cause of mortality, and shortens the average lifespan" (p. 20).¹

Table 6

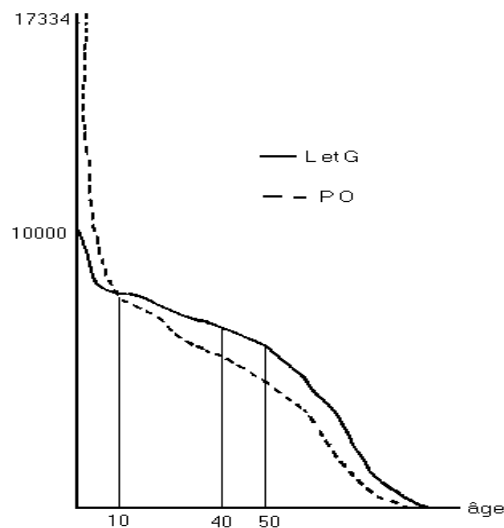
Ages	Lot et Garonne	Pyrénées Orientales
Births	10 000	17 334
Survivors at age 1	8 589	14 092
Survivors at age 5	7 853	8 896
Survivors at age 10	7 646	7 502
Survivors at age 15	7 543	7 159
Survivors at age 20	7 304	6 894
Survivors at age 30	6 707	5 816
Survivors at age 40	6 297	5 200
Survivors at age 50	5 644	4 394
Survivors at age 60	4 676	3 309
Survivors at age 70	3 271	1 860
Survivors at age 80	1 076	567
Survivors at age 90	108	55
Survivors at age 100	13	0

Source: Dupuit, 1865a, p. 18

For Dupuit the explanation is simple: "By his toil, man draws his subsistence from the land... The limitation of surface area determines an initial population figure beyond which lies poverty, increasing inexorably up to a final limit which cannot be crossed, as the population's fertility would then no longer suffice to fill the void left by its rapid mortality" (pp. 20-21). He goes on to specify that this limit depends not only on surface area but also the fertility of the soil, as well as on the ability to meet subsistence needs by exporting manufactured products. Finally he notes that in the nations of

¹Dupuit's analyses here seem original in so far as they demonstrate that the excess mortality in the Pyrénées Orientales affects all ages of the population (prior to old age) and is not due solely to infant mortality. It had previously been widely believed that the parallel between birth rates and death rates was attributable largely to infant mortality (Legoyt, 1857, p. 217; March in S.S.P., 1904, p. 268; Lowenthal, 1905, p. 52). Infant mortality in France rose steadily between the period 1840-1844 (15.9%) to 1865 (19%) (J. Lefort, 1878).

Europe, with their high population density, demographic growth is very low, whereas in the United States, where the density is low, demographic growth is very high. From this he concludes that: "where the means of subsistence are capable of rapid increase, the population will also progress rapidly. Where the means of subsistence increase only slowly, the population will also grow slowly, regardless of its fertility. In places where the population sets voluntary limits on its own fertility, there is greater welfare and greater longevity; in places where an imprudent population surrenders to its instincts, (...) death remorselessly eliminates the weak and sickly and leaves the rest in hardship and poverty. (...) this rule brooks no exception; (...) everywhere, the influence of environment pales before that of fertility. Once you know the figure for fertility, you need no longer seek that of the average lifespan. High fertility, low average lifespan; strictly limited fertility, high average lifespan" (pp. 24-25).²



Graph 3 (source, Dupuit, 1865a, p. 20)

²A little later he states that for the older developed nations: "the mean length of life is inversely proportional to the number of births; for it to be 50 years, there must be but one birth for every 50 inhabitants, and it can only attain 60 years on condition that there is but one birth for every 60 inhabitants" (1865a, p. 33). As all of these countries, with the sole exception of France, were a long way from his hypothesis of stationary population, as indeed Table 6 shows, Dupuit's reasoning is invalid.

His entire analysis adheres strictly to the orthodox Malthusian line. The population will adjust (or be adjusted) to the food supply, either through positive checks—in this case, high fertility, resulting in poverty and low life expectancy—or through preventive checks, in which case low fertility will result in increased well-being and higher life expectancy. Dupuit rejects the idea ascribing "improvement in well-being to progress in agriculture and industry (...) insofar as all such progress would have been fruitless in that respect, had it not been accompanied by a fall in fertility... There is no progress, however great, that cannot be transformed into a decline in welfare by an increase in population.³ This is, moreover, borne out by the statistics. One hundred years ago, the average lifespan in France was a mere 24 years and 6 months; today one finds the same average in those départements where the ratio of births to population is still the same as it formerly was throughout the whole of France. And this is so, despite all the progress of industry and science, of which these départements have had their share"(p. 28).

Dupuit's conclusion is clear: any increase in the general welfare, and therefore any extension of life expectancy, can only be obtained through a decrease in fertility. To prove the point for France, he uses the example of the United States, where, he observes, the population has risen (for an unspecified period) at an annual rate of 4.4%, of which he ascribes 0.4% to immigration and 4% to the surplus of births over deaths. He assumes a mortality rate of 2% "as this corresponds to a life expectancy of 50 years"(p. 26)⁴ and thus arrives at a birth rate of 6%, which he takes to be the rate attained in the absence of any subsistence constraints. Because the rate in France never goes over 3%, it must therefore be voluntarily limited by the population. Accordingly, although the population rose from 12 million in 1771-1775 to 36 million in 1852-

³Likewise Guillard had previously written: "Agricultural shows and associations, model farms, regional schools, societies for self-improvement and mutual support, factory and farm academies, (...) if you believe you are working for the good of the people, then either you are mistaken, or the law of population is false. For, as the wisdom of the nations—and the statistics—will tell you, wherever your patriotic experiments produce one more loaf of bread, nature creates another mouth to eat it." (1855, p. 95). The argument is used here to demonstrate the impossibility of improving living standards through agricultural progress. As noted in J.-P. Simonin's contribution on the subsistence question, the same argument was employed by Dupuit (1859a) and by Briaune (1857) to show that agricultural progress could not prevent the periodic recurrence of scarcities.

⁴Once again Dupuit's reasoning is faulty in that it assumes a stationary population, which is incompatible with an annual growth rate of 4%.

1856, the actual number of births declined slightly, with the birth rate falling from 4% to 2.6%. For Dupuit "this massive diminution is the principle cause of the greater well-being that the present generation enjoys compared to their forebears of a century ago" (p. 27).⁵

Starting out from the same comparison of fertility and life expectancy by département, Legoyt arrived at a different explanatory framework.

3. LEGOYT'S ANALYSIS OF THE INFLUENCE OF STANDARD OF LIVING ON BIRTH RATE AND LIFE EXPECTANCY

Legoyt, like Dupuit, brings out the inverse relationship between the birth rate and mean age at death (or mortality rate) of various départements (or countries), but his explanation is quite different. We should point out, however, that Legoyt's explanation for the link between mortality and birth rates changed over time, no doubt in line with the author's own shift from Malthusianism⁶ to populationism (Charbit, 1981, *passim*). In 1847, on the basis of the comparison of birth and death rates reproduced in Table 2, Legoyt asserted: "We therefore have every reason to think, I repeat, that these two facts [the decline in both mortality and birth

⁵Dupuit's position was clearly disproved by the subsequent development of the French départements. Reporting on a paper by Dr. Lagneau, Lefort observed that, out of 26 départements where the population had fallen between 1836 and 1881, seven (Eure, Lot et Garonne, Calvados, Gers, Orne, Tarn et Garonne—all situated at the top of Table 1—and Basses Alpes) presented more deaths than births. He concluded that "the départements of Normandy and the Garonne basin, where mortality exceeds the birth rate, nonetheless have a low mortality, but the birth rate is far lower still. Their low birth rate is voluntary and quite unrelated to lack of subsistence" (1883, p. 444). In a debate at the Société d'Economie Politique Dupuit admitted that in the case of Eure (Normandy) the fall in the birth rate was excessive with regard to the availability of subsistence (S.E.P., 1863, p. 345). Eure is a curious case: although one of Dupuit's "model" départements, it had an almost record rate of infant mortality (Lefort, 1878, p. 215), which Lefort attributed to a lack of breast-feeding (*idem*, p. 217). Valsèrres (1878, p. 341) attributed the decline in Normandy's population to the predominance of cattle-rearing.

⁶Bardet and Le Bras position his article of 1854, cited in note above, "in the great Malthusian tradition of the positive check" (1988, p. 393). This overlooks the fact that the relationship between fertility and life expectancy in each département could be read as the sign of a preventive—as well as a positive—check, as Dupuit's conclusion showed.

rates]proceed one from the other, for which I tender this explanation: where wealth is more equally distributed, where the general well-being is better shared out, (...) the spirit of order and conservation tends to propagate. Rather than relying (...) for the maintenance of their children, on charity (...) parents know that they can count only on the product of their own hard toil and privation; from this comes greater reserve and greater prudence in the enlargement of the family. On the other hand, (...) sweeping changes in industry and the necessities of trade have created entirely new conditions of internal and external competition, demanding from the current population a greater quantity of work than at any preceding period. The difficulties of this new situation have been compounded by the higher price of all objects of consumption other than manufactured goods, due to domestic taxation, a barbarous system of customs and excise, and a stationary agriculture. In this situation, the worker has clearly sought to avoid exacerbating his burden prematurely (...). It is therefore easy to understand that by not increasing the size of his family beyond reason, or by marrying only when his level of wages, his savings, or the inherent advantages of the union upon which he enters (...) allow, he must have augmented the sum of his material well-being; therein lies part of the explanation for the decline in mortality"(1847, p. 190), the other part being progress in health care. Thus, like Dupuit eighteen years later, Legoyt accounts for the fall in mortality by the fall in the birth rate, although he explains the relationship in terms of a gain in welfare that goes beyond subsistence alone. The piece is notable, however, for its reference to the price of subsistence goods and to the stationary character of agriculture (a position he would later abandon), and for the importance it accords to preventive checks. One also detects a certain ambiguity as to the origin of this preventive behaviour, with Legoyt pointing both to better distribution of wealth and welfare and to a worsening in the workers' economic situation.

Ten years later, commenting on his own conclusions with regard to Table 3, Legoyt wrote:"This must indeed be the case, since for a population to remain stationary or begin to grow, when there are many deaths, the generations must succeed each other rapidly. Moreover, as childhood is subject to an exceptional rate of mortality, there will be more deaths wherever a greater number of children are born"(1857, p. 217). This, somewhat summarily, posits a direct relationship between the two variables: on the one hand, taking an unsophisticated accounting approach which hardly ranks as an explanation, a high death rate implies a high birth rate; on the other, due to the high level of infant mortality, a high birth rate entails a high death rate. Later Legoyt suggested that, while lower fertility may be a response to economic difficulties, that explanation does not stand up for the pre-

vious quarter-century, during which the phenomenon of the declining birth rate"has coincided with a growing number of marriages, with the greatest development and most equal distribution of public wealth known to history, and with a considerable increase in the human life span such that it cannot be deemed the effect of a long and worsening deterioration in the well-being of the masses"(1863, p. 7). A little further on, he asserts that the decline in the fertility of marriages"is certainly due in large part to the progress of that spirit of order, prudence and caution which always arises within a population whose well-being is on the increase; but it is also due to the ever higher age at which people marry in France"(1863, p. 17), especially as the decline in early marriages seems to be associated, one year later, by a decline in infant mortality (1864, p. 59). This one comment aside, Legoyt no longer links the fall in mortality to lower fertility, but instead explains it by the increase in well-being, of which greater longevity is one of the best indicators. He suggests moreover—and here his analysis is worth contrasting with Dupuit's—that the growth of France's population is not restricted by the amount of subsistence:"It has been said that the movement of a population is determined by the limits of its subsistence, and from this it has been inferred that France must be about to reach that limit, as her population is becoming stable. This inference is contrary to fact and to reason. In fact, it is certain (...) for one thing, that her agricultural produce has more than doubled since 1790, while the number of her inhabitants has grown by but one third; and for another, that the profits derived from her trade and industry have risen more than fivefold. Her means of existence, whether she finds them on her own soil or obtains them from elsewhere, through trade, have thus increased in far greater proportion than her inhabitants. (...) ⁷ France has therefore not reached the limits of her means of existence. ⁸ Nor is this all: I believe that in ordinary times (...) she has a manifest tendency to distance herself ever further from that limit, and is precisely this happy development which everywhere—in France and abroad—constitutes the progress of public wealth"(1857b, p. 362). Placed in this context, Dupuit's argument is emptied of much of its validity.

⁷At this point Legoyt alludes to the fact that income distribution was less unequal in France than in England.

⁸One wonders whether Legoyt meant the same thing by that phrase (*moyens d'existence*) as Bastiat, i.e. "the satisfaction of moral, intellectual, and physical wants,"(Bastiat, 1850/1996, 16.94), which goes beyond mere subsistence. Fontenay (1863, pp. 456-457) pours ridicule on this distinction in his critique of Malthus. Legoyt's argument is identical to that upheld by the anti-Malthusian liberals, most of whom were disciples of Bastiat, in the debates at the S.E.P. (1862e, 1863).

The conclusion of the text just quoted hints at a shift from increased subsistence to increased public wealth. On this point we can compare Dupuit and Legoyt. The latter follows on from the preceding passage with: "For a country, as for an individual, there are two ways to become rich: either by increasing revenue while maintaining expenditure, or by reducing expenditure while maintaining revenue. France is in the fortunate position of enjoying, to some degree, the advantages of both modes of enrichment: on the one hand her revenue is increasing; on the other, she is reducing her expenditure by wisely limiting the obligations of her fertility" (1857b, pp. 362-363). The issue is no longer how population can grow in line with subsistence, but rather how population growth can still allow for higher revenues and standards of living. Dupuit, by contrast, hangs onto the idea of the quantity of available subsistence, although his reasoning is essentially the same at the formal level: "what makes for the well-being of a population is the ration of subsistence apportioned to each of its members. This ration can increase in either of two ways: by an increase in total production or by a decrease in population; it is from the relation between these two quantities that welfare results" (Dupuit, 1865a, p. 28).⁹ Two such divergent conceptions are bound to conflict in their explanations of the relationship between fertility and life expectancy.

The results presented in Table 4 lead Legoyt to put forward a more complete explanation for the decline in fertility than in his earlier articles. He starts by noting, in his exposition of the table, that the low rate of population growth attendant on this decline "has the great advantage that our adults shall not be deprived of the means of existence (...). This represents, for our working populations, a cause of well-being that one would seek in vain elsewhere, at least in the same proportion" (1867, p. 209). This comment is totally in keeping with Dupuit's position, but Legoyt imme-

⁹ Instead of the word "ration" Ekelund and Hébert (1999b, p. 304) use the term "wealth per capita", which brings us back to the language used by Legoyt. We feel that the difference is a significant one. Just as in 1859 Dupuit applied the same reasoning to suffering as Malthus had applied to corn prices, here he is using the same reasoning for quantity of subsistence as Legoyt had used for wealth. Dupuit's distrust of evaluations in terms of price or value may be explained in part by his engineering background, but also by the influence of Bastiat. Referring to the latter, Dupuit affirmed: "If you want to assess a fact or an economic measure, rid yourself of the price, substitute the good itself for the value, and all cloudiness, all indecision will melt away" (S.E.P., 1866, p. 489). This approach was common at the time. As Marqfoy wrote: "it is not the price of things, but the quantity of consumption which is the measure of a population's well-being and degree of progress" (1863, p. 125).

diately turns his back on it to ask "what, given this indisputable increase in the public prosperity, could lie behind the curious phenomenon of our nation's ever-declining fertility?"(p. 209).¹⁰

Legoyt distinguishes between the primary and secondary causes of the diminution. The most important of all is "the development of the public wealth (...), and above all the spread of affluence among the working classes as labour take an ever greater share in the profits of production"¹¹ (pp. 209-210). "(...)And as the theory (borne out in this respect by the facts, as we shall see) tells us, the populations that grow richer are those that exercise prudence" (p. 210) and "research of the utmost reliability attests that a population's fertility is inversely proportional to its degree of affluence"(p. 211).¹²He supports his thesis with quotations from Quetelet, Thornton, H. Passy and Malthus¹³ before adding his own observation that in France "the maximal fertility is found in the least affluent départements or in those with the highest working-class population.—Thus, according to the official statistical reports,

¹⁰Legoyt is attempting a question that Cournot refused to address: "For a certain number of years now, the annual growth in our population has declined most notably, despite the fact that the public wealth has grown steadily, and despite the fact the lot of the working classes has far from worsened; this fact is most definitely not ascribable to the publication of the works of Malthus and his school (...). In such matters, the world takes care of its own business, or unwittingly gives way to superior principles, the workings of which remain obscure even to the most learned of minds" (Cournot, 1863/1981, p. 249).

¹¹Further on, Legoyt also mentions the spread of affluence among the rural classes, evidenced "by their ever-increasing access to the ownership of the land" (p. 212).

¹²This widely accepted opinion was later contested by Cauderlier, who concluded from his study of France throughout the 19th century that "the birth rate and total number of births per département are influenced mainly by economic circumstances, (...) the number of births everywhere increases when the economic situation improves and diminishes whenever the economic situation worsens" (1902a, p. 22). He supports his statement with a passage from Arsène Dumont, in which he observes that in low birth-rate communities "most of the population is formed of very poorly educated individuals, most inactive both of brain and body, generally weak-willed, timid creatures of routine, at times shamefully lazy, and who, if by chance they should happen to be neurotic, most assuredly owe it in no way to the excessive development of their cerebral faculties, or to the injudicious exercise of their intellectual powers" (idem, p. 50), which Cauderlier links to the consequences of emigration.

¹³"Any measure which acts to reduce mortality by improving the lot of mankind, also acts, by the same token, to reduce the number of births" (unreferenced quotation). The same quotation could be used to support J. Bertillon's position, below, when he argues that the birth rate depends on the death rate.

the *départements* most often appearing in the group with the highest fertility are as follows: *Pyrénées Orientales, Basses Pyrénées, Ardèche, Lozère, Finistère, Hautes Alpes, Gard, Corse, Vaucluse, Aveyron, Loire, Isère, Nord, Bas Rhin, Côtes du Nord, Haute Loire, Loire Inférieure, Bouches du Rhône, Moselle, Morbihan, Ille et Vilaine and Pas de Calais*.— With the exception of *Haut and Bas Rhin, Moselle, Loire, Bouches du Rhône, Pas de Calais and Loire Inférieure*,¹⁴ which have a large working-class population, the highest legitimate birth rate is found in the mountainous *départements* and in the former Brittany, namely in those parts of France where prosperity has thus far made the least inroads.— In the group of the least fertile *départements*, one most often encounters: *Indre et Loire, Gironde, Gers, Eure, Lot et Garonne, Tarn et Garonne, Orne, Sarthe, Calvados, Charente, Seine, Haute Marne, Aube, Charente Inférieure, Mayenne, Seine et Oise, and Creuse*. With the exception of the latter, whose low fertility is due, as is well known, to the repeated emigration of the adult population,¹⁵ married or otherwise, all belong to the category of those departments where affluence is the most widespread.— Four of the five *départements* in the former Normandy rank among the least fertile. However, they have the longest life expectancy observed in France. The latter fact is the consequence of the former" (p. 211). Apart from this last comment, which corresponds to Dupuit's position, Legoyt clearly associates lower fertility with increased welfare.

Among the other causes for lower fertility that Legoyt cites are uncertainty due to political unrest (p. 212), the inability of large families to afford advanced education (p. 213), the absence of public welfare such as the British poor laws (p. 213), anxiety caused by the continuous rise in the price of subsistence foods (p. 214), the absence of a spirit of adventure (p. 214), the rise in the average age of marriage for men (p. 217), the considerable increase in military recruitment (p. 218), the massive increase in the number of poorly-paid state employees in the face of "a general rise in the cost of living" (p. 218), the rise of domesticity "which is the consequence of the progress of public wealth" (p. 218), and the increase in rank-and-file clergy (p. 218). By contrast he rejects the influence of the increased urban population (pp. 214-216) and of France's laws of succession (pp. 216-217), as well as the hypothetical degeneration of the French race (p. 210-211). Among the moral causes that might account for the decline in fertility, he cites the weakening of religious

¹⁴Legoyt notably forgot to include "Nord".

¹⁵For Cauderlier, emigration—driven by economic factors—is the main determinant of the birth rate: "emigration precedes, and always accompanies, the decline in fertility" (1902a, p. 49).

sentiment (p. 219), the spread of prostitution (p. 219), the increase in abortion and infanticide (pp. 219-220), the love of luxury and well-being (p. 220) and the difficulty of divorce (p. 220). This list is followed by a battery of measures for restoring the fertility of the French population.

The length of this quirky and at times contradictory list should not blind us to the fact that, for Legoyt, the main determinant for the decline in fertility is the improvement in welfare, for which one of the main indicators is greater life expectancy. The decline in fertility and the increase in life expectancy are both therefore consequences of material progress.¹⁶ This brings us right round to the opposite of Dupuit's view, according to which there could be no increase in the standard of living without a decrease in birth rates, implying that the rise in life expectancy could not result from the decline in fertility. Despite a few comments akin to Dupuit's analysis, the whole of Legoyt's argument ultimately implies that the relationship between fertility and life expectancy is not a direct one, but results from the improvement in welfare in France over the period under study.¹⁷¹⁸ What is so remarkable is the evolution in Legoyt's thinking:

¹⁶Bardet and Le Bras (1988, p. 394) confirm this conclusion with their discovery of a correlation coefficient of 0.62 between the mortality figures for 1856 (measured by female life expectancy at birth) and the level of land tax payments per département in 1840. This is not the place to go into the authors' rich explanatory framework.

¹⁷Their contemporaries probably saw no difference between the two approaches. Loua, for example, one of Legoyt's deputies, cited Dupuit as an authority in a debate at the Société de Statistique de Paris to justify Legoyt's conclusions: "Mr Legoyt has brought to light the curious fact that it is in the countries—and within those countries, the provinces—with the lowest birth-rate that life expectancy is at its highest. This same fact was observed by the late Mr Dupuit (...). By way of example, our eminent colleague cited the département of Pyrénées Orientales, which for a constant population, presents the greatest number of births, and yet preserves, even in absolute terms, fewer young people under the age of 20 than does Lot et Garonne, where there are twice as many births. This comparison, which could be extended to other départements, strikes me as conclusive, and it persuades me to rally to the position of my honourable friend and master, Mr Legoyt" (S.S.P., 1867, p. 293).

¹⁸A position identical to Legoyt's was later expressed by March when, criticising the works of J. Bertillon, he suggested that: "the decline in mortality and the fall in the birth rate, which have continued now for a great many years, are the result of the same influences acting separately on the nation's birth and death rates" (S.S.P, 1904, p. 268), which led him to distinguish between the different positions analysed in this article: "From a distance, we see two bodies—A and B—advancing at the same speed and in the same direction: we have no way of telling whether A is pulling B along, or whether B is pulling A, or whether in fact A and B are both being pulled along independently

setting out in 1847 from a causal birth-rate/death-rate relationship analogous to the one Dupuit would later defend, he was led, thanks perhaps to his position as a privileged observer, to take into consideration the true economic and demographic development of France, a process which Dupuit, from the prison of his own theoretical framework, proved unable to apprehend.

4. EXPLAINING CHANGES IN THE BIRTH RATE BY CHANGES IN MORTALITY

It is interesting to contrast the two preceding approaches with those for which changes in mortality can be said to explain developments in the birth rate. A perfect example of such an approach is Jacques Bertillon's book on the depopulation of France (1911).¹⁹

The idea was around well before Dupuit's article. Already in 1835 Quetelet had written that: "there is a direct relationship between the amplitude of mortality and that of fertility. The number of births is regulated by the number of deaths."²⁰ But it was developed above all by Achille Guillard, the [ou plutôt "un"] *démographe anti-Malthusian, même si son "équation générale des subsistances" ou sa "loi de P" suivant laquelle "P (la population moyenne) se proportionne aux subsistances disponibles"* (1855, p. 55) *ressemble au principe de Malthus*. Guillard, who penned the formula "life is the measure of death; death the measure of life"²¹, wrote that "Births are less numerous where life is longer, and vice versa (...). As a rule, wherever the human species is swiftly harvested, marriages and births accelerate to keep pace with death" (1855, pp.

from each other by a third force, C; to find out, we must study their motion at closer quarters" (p. 268). For Cauderlier (1902a & b) birth rate and mortality are driven by different factors: economic for the first; improved hygiene for the second.

¹⁹In which he often reproduces his own earlier work wholesale, notably his article of 1904.

²⁰Quetelet, "*Physique Sociale*", cited in J. Bertillon (1904, p. 336; 1911, p. 69). Quetelet went on: "this fully confirms the ideas of the economists who hold that the population tends towards a certain level, determined by the quantities of products" (cited in Lowenthal, 1905, p. 20) thus demonstrating his attachment to the ideas of Malthus.

²¹"*La vie mesure la mort et la mort mesure la vie*". He is also thought to have coined the phrase "*Là où il y a un pain, il naît un homme*" (Wherever there is a loaf of bread, a man is born) which he calls the "general equation of subsistence" at least according to Lowenthal (1905, p. 22), who mistakenly assumes it to be of Malthusian inspiration. The very same formula is attributed to Buffon by Jacques Valsèrres (1878, p. 347).

75-76), expressing so the idea that, except in a catastrophic situation as a “disette”, the population adjuste itself to the subsistants by the way of births²². Writing around the turn of the century, Jacques Bertillon (the son of Adolphe Bertillon and the grandson of Achille Guillard) explored the idea systematically: “Every death naturally tends to elicit a birth, whatever the age of the deceased. If a child, its parents feel the need for another child to channel their affection (...). If an adult, the death leaves a job vacant; it makes way for the creation of a new household and the birth of new children. And if it was an old man? The conclusion is the same: if he was poor, his death removes a burden from his children which might have prevented them from marrying; if he was rich, his legacy will make it easier for them to marry and set up home. In this light, one can understand the fairly close relationship between the birth and death rates, and also how they both relate to the marriage rate” (1911, p. 74). At first view this approach, with its focus on individual as much as social behaviours, seems to differ from Dupuit's in a way that reflects Landry's (1945) opposition between “intermediate” and “primitive” regimes. In the intermediate or “demographic transition” regime, population regulation is social; it is the product of human strategies or calculations like those described by J. Bertillon, and which were already present in Legoyt's approach. In the primitive regime, to which Dupuit's thought belongs, regulation is biological and automatic: “equilibrium is the result of a chain of cause and effect in which man's will is nowhere to be seen: unrestricted procreation in marriage, the degree of welfare that ensues; and mortality, which determines the degree of that welfare” (Landry, 1945, p. 542). Such a mechanical process was bound to appeal to Dupuit's engineering mindset.²³

J. Bertillon bases his position on a rudimentary statistical study²⁴ demonstrating the parallel development of birth rates and mortality in

²²Note that Guillard also seems to accept that birth rates have an influence on mortality, a point picked up on by A. Bertillon: “one moment it is the birth rate that affects the overall mortality; the next, mortality that stimulates the birth rate” (cited in J. Bertillon, 1911, p. 70). Interestingly, Dupuit, though he quotes figures from Guillard's book, is not influenced by his idea.

²³For this comment, thanks to François Vatin, who drew our attention to the opposition between the two regimes. Cauderlier also defends a mechanical approach: the birth rate varies in line with economic prosperity “and one must never resort to the direct intervention of the head of the family and his desires” (1902a, p. 14), a position which was heavily criticised (S.S.P., 1902).

²⁴Bertillon reused a study from an earlier work (1904), making no revisions, although it had been severely criticised by Lowenthal (1905).

every European country during the second half of the 19th century, the strongest drop in birth rates being in France. He concludes with "this general law: if mortality is high, the birth rate is high. If mortality is low, the birth rate is low. If mortality rises, the birth rate rises; if mortality falls, the birth rate falls" (1911, p. 74). He illustrates this law with a hydraulic metaphor that makes for an interesting contrast with another, employed by Dupuit. Writing about the comparative effects of emigration and poverty on population levels, Dupuit wrote: "poverty sweeps away the excess of population, but not enough to expunge poverty itself. It acts like those little overflows in our park ponds that hold back some of the water at their spouts and cannot make it flow further down. Clearly, poverty has to exist in order to remove the excess population; it is merely a prophylactic against that excess of misery that the population cannot bear. Emigration, which almost exclusively removes adults, is a still less energetic remedy" (1865a, p. 32). Any further influx of water into the pond (i.e. any rise in the birth rate) will result in more water pouring through the overflows (an increase in poverty and mortality) in order to keep the pond (the population) level. Bertillon, in contrast, invokes Malthus' preventive check: "Nature does not expel from the great feast of life those for whom there is no longer any place at the table; she employs a gentler means: she prevents them from being born"²⁵ (1904, p. 338; 1911, p. 72) and illustrates his general law thus: "Human society can be compared to a tank with a given capacity,²⁶ equipped with a float, so that it always remains full of water. There is an inlet valve (birth and immigration), but it cannot open unless the outlet valve (mortality and emigration) is also open. You cannot open one without opening the other" (1911, p. 86). With this toilet-flush metaphor,²⁷ Bertillon asserts that it is impossible to increase

²⁵Bertillon is simply echoing Guillard's position (1853, p. 188).

²⁶In a footnote, Bertillon specified that "it can however grow over time, thanks to human effort (progress in agriculture, the advance of industry, etc.)".

²⁷As Chatzis and Coutard point out in their contribution, this valve system was discussed by Dupuit in his *Traité sur la distribution de l'eau*. Other metaphors also fit the model. Vatin (in Grall, 2003, pp 176-177), with reference to Dupuit, uses a road maintenance image, based on Dupuit's own analysis of the issue: the size of a stationary population is the result of an equilibrium between mortality and the birth rate, just as the stable maintenance status of a road depends on an equilibrium between the removal and addition of materials: removal is adjusted to the addition of new materials just as mortality adjusts to the birth rate. In addition to his hydraulic metaphor, Bertillon (p. 87) also uses the image of a forest in which the young saplings replace the trees cut down by the woodsmen: the lives of the old trees are prolonged at the expense of the renewal of the forest. Lowenthal (1905, pp. 18, 49-50) rejects the water-tank image

France's population by reducing mortality, as that would lead to a fall in birth rates, whereas for Dupuit it was impossible to increase the population by increasing the birth rate as one would thereby increase mortality. This reveals a certain ambiguity in Bertillon's thinking, as in Legoyt's: he partly subscribes to a demographic transition analysis, which leads him to examine the behaviours associated with the falling birth rate, while partly remaining within the framework of Malthusian thought, in which the birth rate is determined by the available subsistence, which sets the level of the population.²⁸

The rest of Bertillon's book is given over to his analysis of the causes of France's declining birth rate, in the course of which he revives a number of Legoyt's arguments,²⁹ offers an outline of neo-Malthusian propaganda and enters a powerful plea in favour of a policy of family assistance. We are a long way from the positions defended by Dupuit. To assess the pertinence of these two approaches relative to the reality of their respective epochs, we can compare the links between birth and mortality rates at the time of Dupuit's article and for the period analysed

(whatever its purpose) considering it, along with the forest metaphor, to be equivalent to Malthus' feast. The tank (or 'basin') metaphor had already been used by Bastiat (1850/1860b, p. 475), but in a quite different way from Dupuit and J. Bertillon. For Bastiat, the variable dimensions of the tank represented the size of the population, while the water inlet represented the provision of subsistence, and the resulting water level the population's standard of living. *Un peu plus tard, A. Guillard illustre sa loi de Population par une image un peu différente : "La Population est, par rapport aux récoltes annuelles, comme une plante aquatique de belle venue, une Algue, un Potamot, qui occupe entièrement l'eau d'un bassin à niveau mobile et inconstant, et qui, selon la loi de végétation, remplace chaque année par de nouveaux bourgeons ceux qui ont accompli leur évolution. Quand le niveau de l'eau s'élève, la plante, incessamment vigoureuse, donne avec plus d'abondance des pousses nouvelles, qui garnissent en peu de temps l'eau surajoutée. Quand le niveau s'abaisse, les rameaux qui restent à nu, se dessèchent, périssent et ne sont pas remplacés."*(1855, p. 80).

²⁸This Malthusian linkage crops up again in Cauderlier in connection with Prats-de-Mollo in the Pyrénées Orientales, once studied by Dupuit: he accounts for the falling birth rate of this isolated mountain district by the fact that it "has reached the limit for the population that it can sustain. (...) The birth rate has fallen because of a lack of food: as one cannot sacrifice the oldest, one must sacrifice the youngest" (1902a, p. 53). Cauderlier concludes his article with the assertion that one cannot raise the birth rate of a territory until one has either increased its resources or reduced its needs (1902a, p. 62).

²⁹Unlike Legoyt, Bertillon (1911, pp. 140-150, 290-291) feels that France's inheritance laws are a significant factor in the decline of the birth rate, and for that reason advocates freedom of testation. Dupuit (1865b) is opposed to such a freedom, but for reasons unconnected to the population question.

by Bertillon. The rates are presented in Table 7, which is based on Bertillon's data (1911, pp. 312-316) on the national averages for twenty European countries over the periods 1851-1860, 1861-1870 and 1891-1899.³⁰

Adjusting the regression lines from these data, between the mortality rate M and the birth rate N , yields the following results for the period 1861-1870:

$$\hat{N} = 16.8583 + 0.691720 M^{31}; \hat{M} = -4.23636 + 0.866408 N^{32}$$

(4.79994) (5.18871) (-0.724083) (5.18871)

with $R^2 = 0.599312$. For the period 1891-1899 we get the following results:

$$\hat{N} = 14.3848 + 0.827994 M^{33}; \hat{M} = 2.63879 + 0.586154 N^{34}$$

(3.27047) (4.11995) (0.56980) (4.11995)

with $R^2 = 0.485332$. Note the inversion in the regression coefficients between the two periods: that of mortality over birth rate is the higher of the two in 1851-1870, in line with Dupuit's analyses, whereas the one for birth rate over mortality is higher in 1891-1899, in line with Bertillon's theory.

³⁰The countries in question are not quite the same as those in Legoyt's 1847 study (Table 2).

³¹DW = 1.95; SER = 2.93; Arch test, P value = 0.27; White heter. test, P value = 0.598.

³²DW = 1.36; SER = 3.29; Arch test, P value = 0.56; White heter. test, P value = 0.249.

³³DW = 1.66; SER = 3.62; Arch test, P value = 0.22; White heter. test, P value = 0.649.

³⁴DW = 1.41; SER = 3.05; Arch test, P value = 0.27; White heter. test, P value = 0.386.

Table 7

Country	Births per 1 000 pop. 1851-1860	Deaths per 1 000 pop. 1851-1860	Births per 1 000 pop. 1861-1870	Deaths per 1 000 pop. 1861-1870	Births per 1 000 pop. 1891-1899	Deaths per 1 000 pop. 1891-1899
England & Wales	34.2	22.2	35.3	22.5	30.1	18.2
Scotland	33.8	20.7	35.0	22.0	30.6	18.6
Ireland			26.1 *	16.5 *	22.8	18.1
Denmark	32.6	20.6	31.0	20.0	30.3	17.5
Norway	33.0	17.1	30.9	17.9	30.5	16.3
Sweden	32.7	21.7	31.4	20.1	27.2	16.3
Finland	35.8	28.6	34.6	32.6	32.3	19.5
Austria	37.0	30.8	38.6	30.7	37.6	27.0
Hungary			41.5 *	34.0 *	40.6 **	29.9 **
Switzerland			30.0 *	26.0 *	28.7	19.4
Prussia	36.5	26.5	37.6	26.4	37.0	21.9
Bavaria	33.2	27.7	36.9	29.8	36.4 **	25.3
Saxony	39.2	27.1	40.5	28.1	39.3	24
Wurtemberg	35.8	29.5	40.9	31.5	34.2	23.3
Baden	33.0	26.0	37.0	27.4	33.1	22.0
Netherlands	33.1	25.5	35.2	25.1	32.5	18.4
Belgium	30.3	22.6	31.5	23.1	28.8	19.0
France	26.2	23.9	26.1	23.5	22.2 **	21.6 **
Spain			37.5	30.1	35.1 **	29.8 **
Italy			37.6 *	30.3 *	34.6 **	24.1

*: Ireland (1864-1870), Hungary (1866-1870), Switzerland (1868-1870), Italy (1863-1870) ;**: 1891-1900.

These conclusions have to be qualified, however, when one looks at the elasticity of birth rates over mortality, $e_{N/M}$, and of mortality over birth rates, $e_{M/N}$. For 1861-1870 this gives us, using the previous adjustments:

$$e_{N/M} = \frac{0.69172M}{16.8583+0.69172M} < 1, \quad e_{M/N} = \frac{0.866408V}{-4.23636+0.866408V} > 1$$

A 1% rise in the mortality rate leads to a rise of less than 1% in the birth rate ($e_{N/M}$ between 0.4037 and 0.5825 for the extreme values of M) whereas a 1% rise in the birth rate leads to a rise of greater than 1% in the mortality rate ($e_{M/N}$ between 1.1335 and 1.2305 for the extreme values of N), confirming Dupuit's theory.

For 1891-1899, by contrast, we obtain:

$$e_{N/M} = \frac{0.827994M}{14.3848+0.827994M} < 1, \quad e_{M/N} = \frac{0.586154V}{2.63879+0.58154V} < 1$$

It emerges that $e_{N/M} < e_{M/N}$ for $M < 3.86N$, which is again confirmed by Table 7. The influence of mortality on the birth rate appears to be weaker than the converse, which puts Bertillon's theory into context. The value of $e_{N/M}$ lies between 0.4804 and 0.6325 for the extreme values of M , and $e_{M/N}$ is between 0.7822 and 0.8691 for the extreme values of N .

Table 8

Country 1861-1870	Deaths per 1 000 pop. (adjusted)	Deviation* from actual n° of deaths	Births per 1 000 pop. (adjusted)	Deviation** from actual n° of births
England & Wales	26.34786	- 3.84786	32.42199	+ 2.87801
Scotland	26.08794	- 4.08794	32.07613	+ 2.92387
Ireland	18.37690	- 1.87690	28.27167	- 2.17167
Denmark	22.62230	- 2.62230	30.69269	+ 0.30731
Norway	22.53566	- 4.63566	29.24007	+ 1.65992
Sweden	22.96887	- 2.86887	30.76186	+ 0.63814
Finland	25.74137	+ 6.85862	39.40836	- 4.80836
Austria	29.20701	+ 1.49299	38.09409	+ 0.50591
Hungary	31.71959	+ 2.28041	40.37677	+ 1.12323
Switzerland	21.75590	+ 4.25441	34.84301	- 4.84301
Prussia	28.34060	- 1.94060	35.11969	+ 2.48030
Bavaria	27.73412	+ 2.06588	37.47154	0.57154
Saxony	30.85318	- 2.75318	36.29562	+ 4.20438
Wurtemberg	31.19975	+ 0.30025	38.64746	+ 2.25254
Baden	27.82076	- 0.42076	35.81141	+ 1.18859
Netherlands	26.26122	- 1.16122	34.22046	+ 0.97954
Belgium	23.05551	+ 0.04449	32.83702	- 1.33702
France	18.37690	+ 5.12310	33.11371	- 7.01371
Spain	28.25396	+ 1.84604	37.67906	- 0.17906
Italy	28.34060	+ 1.95940	37.81740	- 0.21740

* Plus (minus) sign: adjusted deaths in excess of (short of) real death figures

** Plus (minus) sign: adjusted births in excess of (less than) real birth figures

These results are confirmed when the adjustments are performed on the logarithms of the mortality and birth rates, LM and LN , the regression coefficient values being those of their respective elasticities. For 1861-1870 this gives us:

$$\hat{LN} = 1.90724 + 0.504854 LM^1; \hat{LM} = -0.8755125 + 1.16080 LN^2$$

(5.88533) (5.04796) (-1.07430)
(5.04796)

with $R^2 = 0.586035$.

And for 1891-1899:

$$\hat{LN} = 1.74167 + 0.563049 LM^3; \hat{LM} = 0.456737 + 0.750017 LN^4$$

(3.67027) (3.62737) (0.637779)
(3.62737)

with $R^2 = 0.42296$. Whatever type of adjustment is used, the elasticity of the birth rate relative to the mortality rate increases slightly between the two periods, whereas the elasticity of the mortality rate relative to the birth rate falls sharply, though remaining higher than the other elasticity, probably on account of improvements in standard of living and hygiene (especially lower infant mortality). It is perhaps this last development which is most characteristic of demographic transition, as the birth rate responds to the mortality rate to much the same degree at either period.

¹DW = 1.94; SER = 0.89; Arch test, P value = 0.38; White heter. test, P value = 0.475.

²DW = 1.25; SER = 0.135; Arch test, P value = 0.56; White heter. test, P value = 0.050.

³DW = 1.75; SER = 0.125; Arch test, P value = 0.60; White heter. test, P value = 0.601.

⁴DW = 1.12; SER = 0.144; Arch test, P value = 0.25; White heter. test, P value = 0.191.

Table 9

Country 1891-1899	Deaths per 1 000 pop. (adjusted)	Deviation* from actual nbrs of deaths	Births per 1 000 pop. (adjusted)	Deviation** from actual nbrs of births
England and Wales	20.28201 20.57508	- 2.08201 - 1.97509	29.45434 29.78554	+ 0.64566 + 0.81446
Scotland	16.00309	+ 2.09691	29.37154	- 6.57154
Ireland	20.39924	- 2.89924	28.87474	+ 1.42526
Denmark	20.51647	- 4.21647	27.88115	+ 2.61885
Norway	18.58216	- 2.28216	27.88115	- 0.68115
Sweden	21.57155	- 2.07155	30.53073	+ 1.76927
Finland	24.67816	+ 2.32184	36.74069	+ 0.85931
Austria	26.43662	+ 3.46338	39.14187	+ 1.45813
Hungary	19.46139	- 0.06139	30.44793	- 1.74793
Switzerland	24.32647	- 2.42647	32.51792	+ 4.48208
Prussia	23.97478	+ 1.32522	35.33310	+ 1.06690
Bavaria	25.67462	- 1.67462	34.25671	+ 5.04329
Saxony	22.68524	+ 0.61476	33.67711	+ 0.52289
Wurtemberg	22.04047	- 0.04047	32.60072	+ 0.49928
Baden	21.68878	- 3.28878	29.61994	+ 2.88006
Netherlands	19.52001	- 0.52001	30.11674	- 1.31674
Belgium	15.65140	+ 5.94860	32.26952	- 10.06952
France	23.21277	+ 6.58722	39.05907	- 3.95907
Spain	22.91970	+ 1.18030	34.33950	+ 0.26049
Italy				

* Plus (minus) sign: adjusted deaths in excess of (short of) real death figures.

** Plus (minus) sign: adjusted births in excess of (less than) real birth figures.

These conclusions do not however take account of the fact that different countries may have entered the demographic transition phase at different times. What is borne out by the overall statistics is not necessarily the case for France, where the transition process started earlier. This is confirmed by Table 8, showing the adjusted mortality and birth rates and their deviation from the actual figures for the period 1861-1870. The deviations for France are particularly significant: the adjusted mortality rate comes out well below the real rate (only Finland shows a larger deviation) and the adjusted birth rate well above the real rate (far higher than for any other country). This confirms France's tendency to low fer-

tility and demonstrates that Dupuit's analyses were unsuited to the instance of his own country.⁴⁵⁷

This particular French exception is also evident for the period 1891-1899, as shown in Table 9. Again the adjusted mortality rate is significantly higher than the real rate, with the deviation being slightly greater than in 1861-1870.⁴⁵⁸ The adjusted birth rate, above all, is considerably higher than the real rate, reflecting the continuing decline in the nation's fertility between the two periods.

CONCLUSION

Ultimately, Dupuit's demographic analysis raises a certain number of questions. We have noted at several points his excessive reliance on the stationary population hypothesis, which the more cautious Legoyt always hedged round with caveats. The hypothesis might conceivably be admissible for France as a whole, but is definitely not applicable to most French départements, nor indeed to other European countries, and still less to the United States, for all Dupuit's efforts. His allegiance to the Malthusian doctrine, moreover, led him to overlook the changes taking place in the actual economic and demographic situation in France, even if his analysis was probably commensurate with the situation in a number of other European countries. By taking Malthus as his sole authority, he also passed over other approaches to the relationship between birth rate and life expectancy, or mortality, which had already been put forward by other authors. And even if these approaches, as we saw, in turn pointed back to Malthus, some of them contained elements that would later be developed in the demographic transition model.

⁴⁵⁷These deviations are far higher than would be derived from the line $M = N$ corresponding to the stationary population hypothesis. In this case the deviation would be 2.6 in absolute value.

⁴⁵⁸It is interesting to note that the deviation indicated by the regression is almost the same as that proposed by Lowenthal for the same period when he compares the real figure with the one that would result from a parallel development of birth rate and mortality: "one must in all logic recognise that the mortality rate of 21.5/should be 21.6 cf. Table 7 and calculation below‰ (in 1891-1900) is 5.1‰ above the norm. Without the need for any kind of miracle, but simply by the workings of 'parallel process', France's mortality rate should have fallen from 26.1‰ in 1811-1820 to 16.5‰ in 1891-1900" (Lowenthal, 1905, pp. 64-65).

ANNEX 1: DEFINITIONS OF LIFE EXPECTANCY

In a footnote to his article (1865a, pp. 7-8) Dupuit reminds the reader that—in a stationary population—life expectancy is equal, on the one hand, to the size of the population divided by the annual number of births or deaths (i.e. the inverse of the birth rate or death rate, the two being in this case identical) and, on the other, to the mean age at death. His proof corrects an earlier one that he had given three years before when footnoting a debate at the Société de Statistique de Paris (S.S.P., 1862, pp. 35-36). The earlier presentation ran:

"Let P , D , N , N_1 and N_2 be respectively the population, deaths, births and number of survivors aged 0, 2, 3[sic] years. This gives us, for any population:

$$P = N + N_1 + N_2 + N_3$$

And for any stationary population, $N = D$.

The average lifespan V_m will be expressed by the sum of the years lived by all the individuals born in any same year, divided by N .⁴⁵⁹ Clearly, of this number, there are $N - N_1$ who will live for 1 year, $N_1 - N_2$ who will live 2 years, $N_2 - N_3$ who will live 3 years; the sum of years lived can therefore be expressed as:

$$N - N_1 + 2(N_1 - N_2) + 3(N_2 - N_3) = N + N_1 + N_2 = P$$

which gives us $V_m = P/N$.

Likewise, the sum of the ages of the deceased can be expressed:

$$N - N_1 + 2(N_1 - N_2) + 3(N_2 - N_3) = N + N_1 + N_2 = P$$
⁴⁶⁰

As $N - N_1$ children will die at 1 year, $(N_1 - N_2)$ at 2 years... We can express the mean age at death as P/D and thus, since $D = N$, as P/N or V_m ."

This proof is erroneous, as Dupuit implicitly assumes that the deceased lived out their last year in full. Without mentioning the error, he corrects his formulae in the 1865 footnote, defining the population as:

$$P = \frac{N}{2} + N_1 + N_2 + N_3 + \dots$$

The sum of the years lived by N children equals:

$$\frac{N - N_1}{2} + \frac{3(N_1 - N_2)}{2} + \frac{5(N_2 - N_3)}{2} + \dots = \frac{N}{2} + N_1 + N_2 + N_3 + \dots = P$$

⁴⁵⁹The algebraic terms are transparent in French: V_m refers to *vie moyenne*, average life(span); N to *naissance*, birth.

⁴⁶⁰We have corrected the printing errors in the original text.

from which we get $V_m = \frac{P}{N}$ and, as $D = N$ in a stationary population, $V_m = \frac{P}{D}$. As the sum of the ages of the deceased is equal to the sum of years lived by the N children, and thus to the size of the population, the mean age at death is equal to V_m .

Jacques' father, Adolphe Bertillon (S.S.P, 1862, p. 35 ; A. Bertillon, 1866) rejects the measures of life expectancy employed by Dupuit and Legoyt, accepting only those calculations derived from mortality and survival tables. After a series of proofs technically more complex than those of Dupuit, he arrives at the following formula (1866, p. 58):

$$V_m = \frac{Aa + Bb + Cc + \dots + Uu}{A + B + C + \dots + U}$$

where A, B, C, \dots, U are the numbers of deaths at the successive ages of a, b, c, \dots, u years, the values a, b, c, \dots being generally taken from the middle of the age range for each group of deceased, with corrections for extreme ages. This formula therefore calculates life expectancy "by adding up all the years lived and dividing by the number of those who lived them" (1866, p. 58) which, aside from the corrections for extreme ages, does not seem so very different from Dupuit's final formula.

A. Bertillon compares the values given by this measurement with those derived by other methods. Retaining only those employed by Dupuit and Legoyt, along with the measurement $\frac{P}{0.5(N+D)}$ proposed by Price and by Dupin, one obtains the following table, which quantifies the margin of error inherent in the various approximate measures of life expectancy:

Table A.

Randomly selected departments 1840-1849	Life expectancy V_m	Mean age at death	$\frac{P}{N}$	$\frac{P}{D}$	$\frac{P}{0.5(N+D)}$
Lot	44.9	39.9	40.45	48.45	44.2
Gironde	45.3	41.7	43.25	47.3	45.2
Doubs	44.1	38.5	38.6	48.0	43.3
Dordogne	43.2	35.2	34.5	42.3	38.4
Ariège	41.9	35.0	36.45	45.85	40.6
Drôme	39.4	33.6	37.0	43.3	40.15
France 1840-1859	40.05	35.66	38.0	43.5	40.7

Source: A. Bertillon, 1866.

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ILLUSTRATIONS

1. Letter of Jules Dupuit

PONTS ET CHAUSSÉES.
— — — — —
SERVICE MUNICIPAL
de
LA VILLE DE PARIS
— — — — —
BUREAU DE L'INGÉNIEUR EN CHEF
DIRECTEUR
14, Rue du Cherche-Midi.



Le refus de la caisse des dépôts et
faucun, je ne doute pas cependant que vous
ne parveniez de manière ou d'autre à régulariser
l'emprunt; mais je crains un retard, dans
la réalisation des fonds, retard qui pourrait
entraîner au commencement des travaux, ceux
de la galerie filtrante et des puisards ne peuvent
être faits que dans les caux bœufs de la Seine.
Si nous laissons passer la saison, il faudrait
attendre à l'année prochaine. Or consécutivement,
les réservoirs auraient beau être faits qu'on
n'aurait pas une goutte d'eau, on perdrait ainsi
l'intérêt des fonds dépensés, mieux vaudrait donc

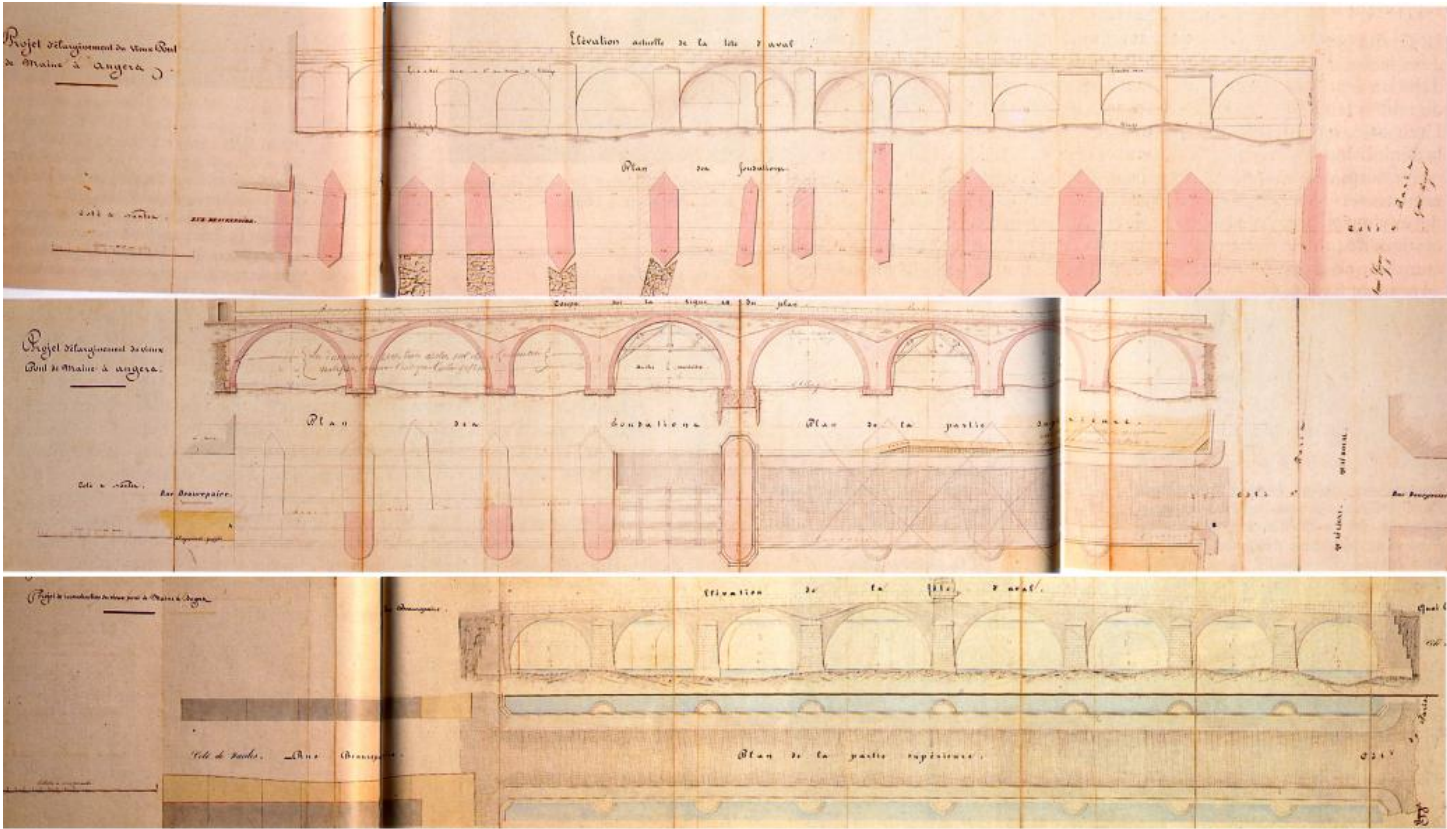
ne rien faire. Pour éviter un retard on pourrait
souscrire à ma disposition dans un autre
court délai 50 ou 60 mille francs pour
exécuter un travail de fondation, soit un
projet sur quelque article du budget
qui pourrait être donné sans inconvénient,
fait en faisant un petit emprunt local. Dans
ce dernier cas sous pouvoir justifié en demandant
des chiffres suivant les indications que donneraient
les banquiers d'Angers, on réaliserait le reste
plus tard. Vous connaissez de reste mieux que
moi les ressources locales, ce qui je tenais
à vous faire connaître, c'est la nécessité d'avoir
promptement une certaine somme disponible
et que le reste pourrait fournir un autre
sous-garant inconvénient.

Agreez Monsieur l'assurance
de mes sentiments bien sincères
Dujardin

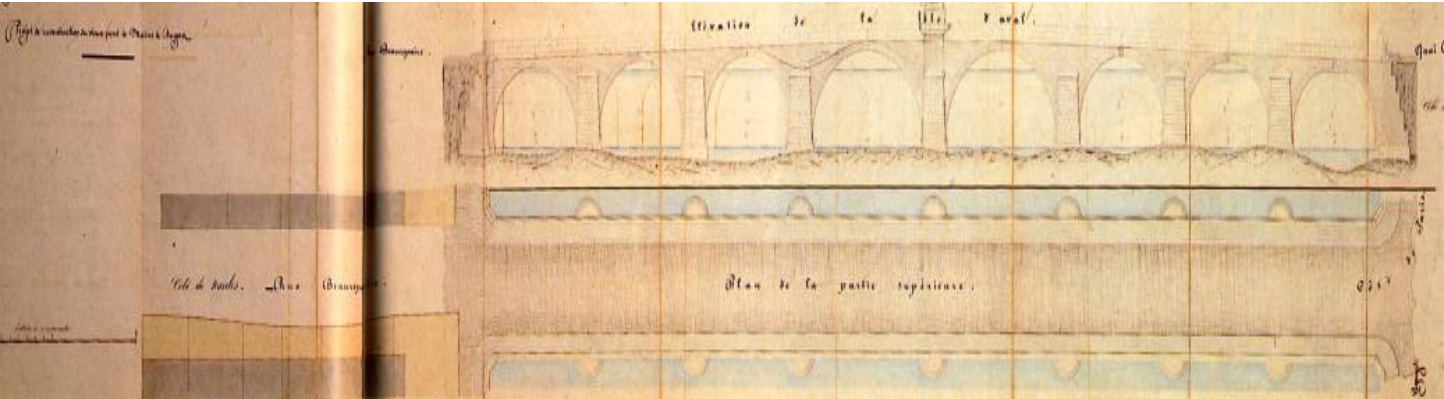
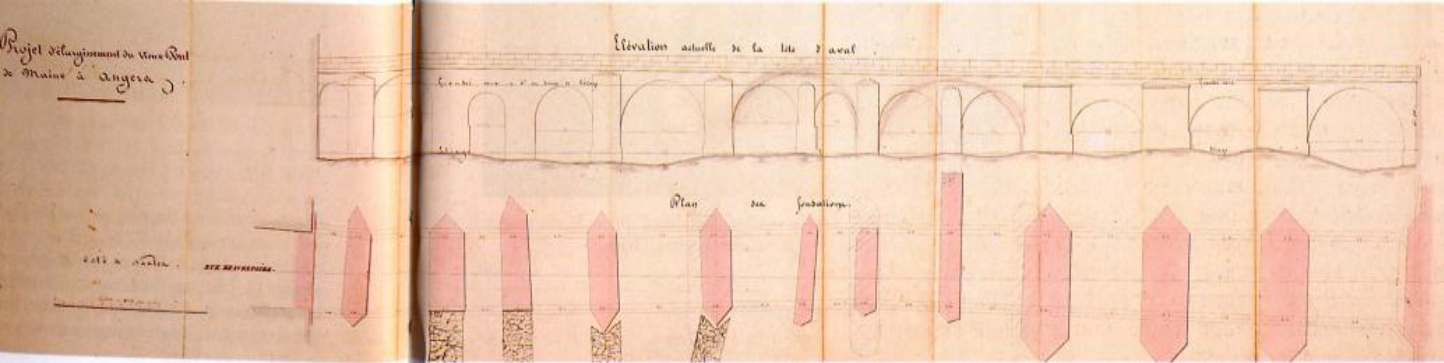
2. Bridge of Verdun (or Center Bridge)

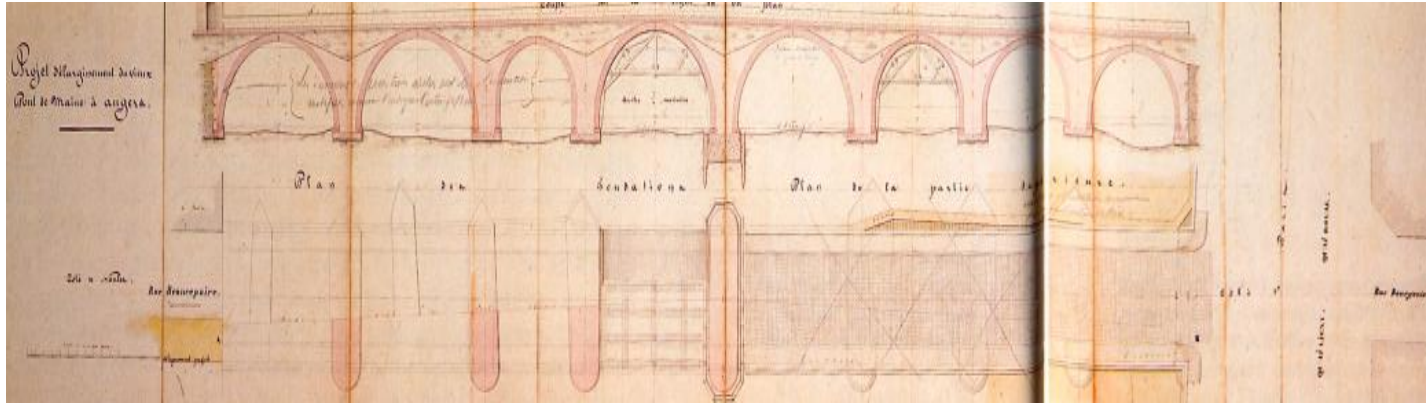


3. Drawings of Jules Dupuit

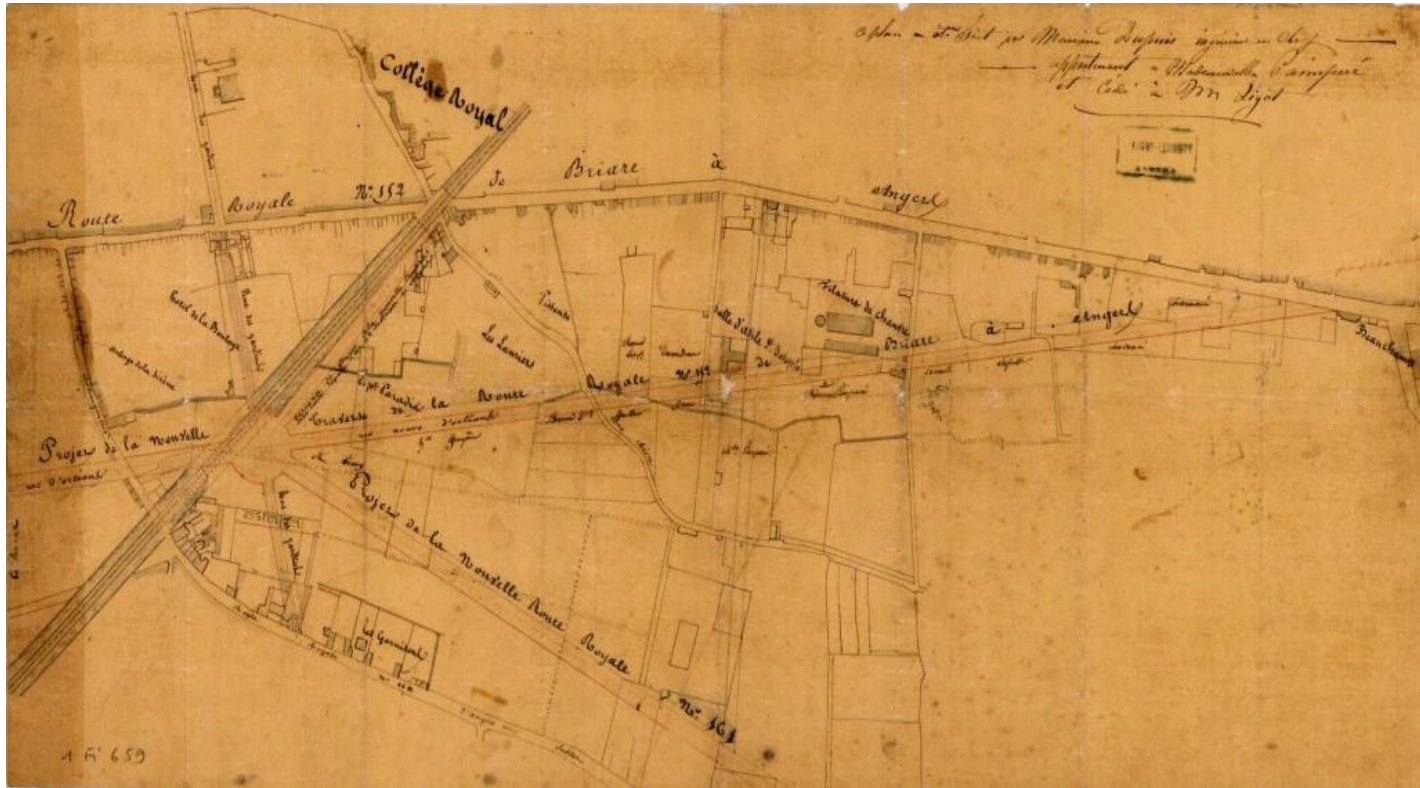


4. Other drawings of Jules Dupuit

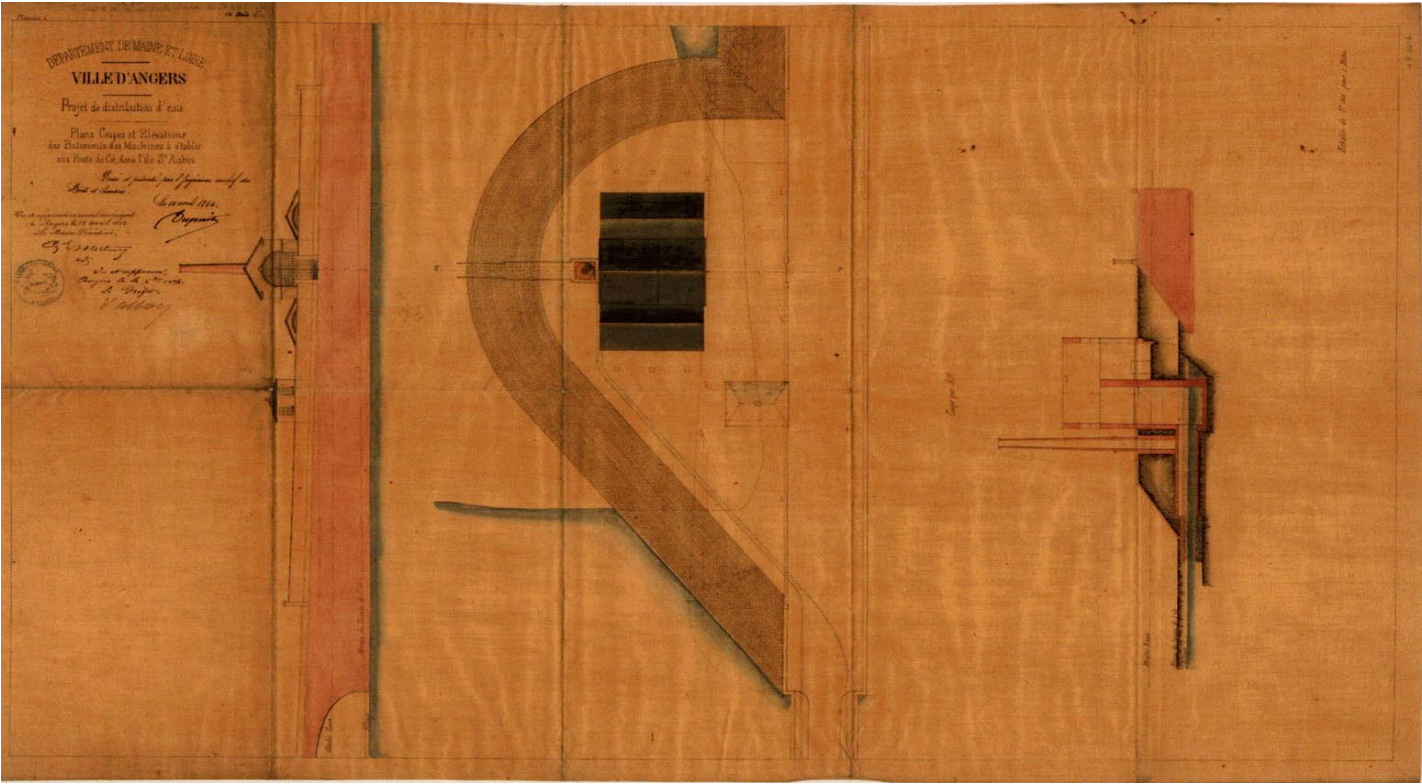




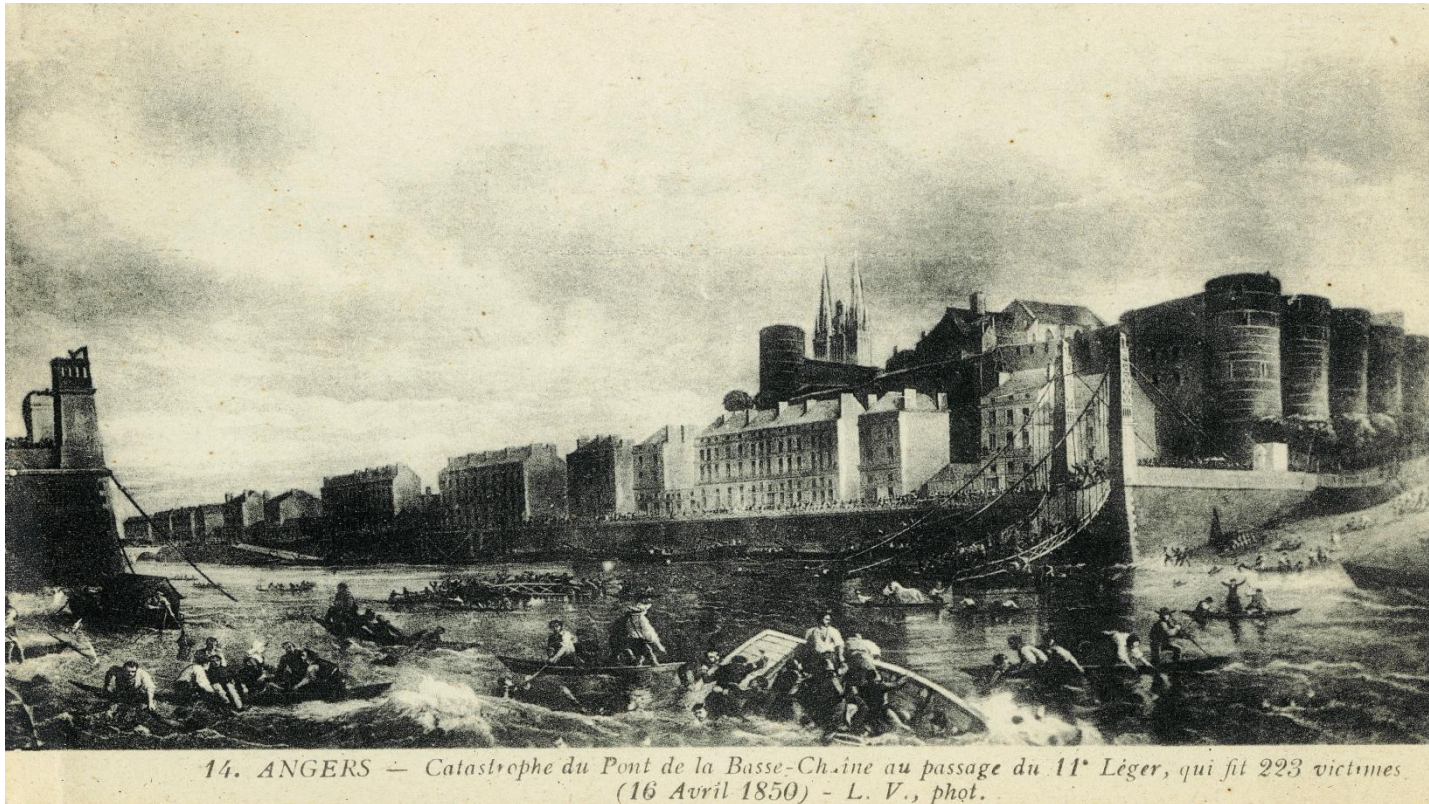
5. Plan of a new road in Angers



6. Drawing of Jules Dupuit on a water distribution project



7. Collapse of a bridge in 1850



8. View of the Angers' center



168 ANGERS. — La Place André-Leroy et la Rue Paul-Bert. — LL.

9. Portrait of Jules Dupuit



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