



# Fossil Fuels in Economic Theory - Back to the 19th century British Debates

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# Fossil Fuels in Economic Theory- Back to the 19<sup>th</sup> century British Debates

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## Introduction

- 1 In 1931, the American mathematical economist Harold Hotelling, who contributed to competition theory, welfare analysis, econometrics and statistical methodology, published an article on optimal extraction, which is usually considered as the starting point of exhaustible resource and fossil fuel economics.<sup>1</sup> Hotelling, however, was not the first to be interested in this topic.<sup>2</sup> A careful historical inquiry shows that the British economist W. Stanley Jevons was the founding father of this field.<sup>3</sup> At the time of his work on coal (1865), he was little known but his career was clearly boosted by the publication of his book, *The Coal Question*.<sup>4</sup> Jevons' analysis of fossil fuels was both original and comprehensive, dealing, on the one hand, with applied issues in the coal sector, and, on the other hand, with macroscopic concerns about economic development and social progress. It paved the way for further theoretical developments in the economics of fossil fuels at the turn of the 19<sup>th</sup> and 20<sup>th</sup> centuries.
- 2 Between the 1860s and the 1930s, economists considered fossil fuels with ambivalence: sometimes as a priority, requiring new theoretical tools and concepts; sometimes as a secondary issue, to be included in well-known mechanisms (the differential principle, asset management, capital discounting, etc.). This paper explores and analyses some episodes of this moving attitude, in particular in British economic debates at the end of the 19<sup>th</sup> century. It focuses on the history of economic thought. Obviously, many questions related to the political reception of ideas, and to the role of economists in the

design of public policy would merit attention, but they are outside the scope of this article.<sup>5</sup> The emphasis is on economic theory, in order to highlight the originality of the British debates at the end of the 19<sup>th</sup> century, and to draw historical lessons on how economists, perhaps still today, approach energy and environmental issues. Section 1 sheds light on Jevons' contribution to the birth of an autonomous economic analysis of fossil fuels. Section 2 shows, through the example of the mining rent, how British economists treated the exhaustion of resources immediately after Jevons. The concluding section provides insights about the subsequent history of fossil fuels in economic theory, when, at the beginning of the 20<sup>th</sup> century, discourses moved from Britain to the US.

## Jevons' 1865 coal question

- 3 Historically, Jevons was the first economist who extensively wrote on fossil fuels, in particular on coal. In 1865 (2<sup>nd</sup> ed. in 1866), he published *The Coal Question. An Inquiry Concerning the Progress of the Nation, and the Probable Exhaustion of our Coal Mines*. This book was successful and had an important impact on British politicians.<sup>6</sup> William E. Gladstone launched a Royal Commission on coal in 1866 after reading Jevons, and John Stuart Mill invited his fellow MPs to consult the book, and to think about Jevons' statements.<sup>7</sup>
- 4 In *The Coal Question*, Jevons analysed the energy dependency of the British economy. Insofar as British development rested upon the extraction of a high quality ore, it could be threatened by coal depletion. This fear was not original in comparison with other discourses at the time.<sup>8</sup> Even at the end of the 18<sup>th</sup> century, some observers had already warned of the end of coal and its consequences on economic activity, and then on general progress.<sup>9</sup> All along the 19<sup>th</sup> century, engineers, physicists, geologists and manufacturers considered shortages as a real threat.<sup>10</sup> In 1865, Jevons' novelty was not to address fossil fuels exhaustion, but to address it in economic terms. He clearly distinguished physical depletion from economic scarcity. In the preface to the second edition, he answered his critics who accused him of being naive in the denunciation of a future complete physical exhaustion of coal:

The expression "exhaustion of our coal mines", states the subject in the briefest form, but is sure to convey erroneous notions [...]. Many persons perhaps entertain a vague notion that some day our coal seams will be found emptied to the bottom, and swept clean like a coal-cellar. Our fires and furnaces, they think, will then be suddenly extinguished, and cold and darkness will be left to reign over a depopulated country. It is almost needless to say, however, that our mines are literally inexhaustible. We cannot get to the bottom of them; and though we may some day have to pay dear for fuel, it will never be positively wanting.<sup>11</sup>
- 5 Market mechanisms regulate physical depletion. Serious issues might however arise, but from economic scarcity rather than from mere ore shortages. This was the core of Jevons' concerns. According to him, the competitiveness of the British economy was deeply rooted in the exploitation of a high quality and cheap coal. It locally gave all the fuel needed by the manufactories of England and Wales. It could be exported, which enabled the equilibrium of the trade balance. These various pillars of economic dynamism could be weakened by the rise of coal prices resulting from depletion.<sup>12</sup> Price rather than physical exhaustion was the key concept. With respect to competitiveness, in modern terms, exhaustion might lead to internal inflation, then to a fall in exports, and finally to a general economic collapse:

The exhaustion of our mines will be marked *pari passu* by a rising cost or value of coal; and when the price has risen to a certain amount comparatively to the price in other countries, our main branches of trade will be doomed.<sup>13</sup>

- 6 Jevons' insistence on cost and price suggests an emancipation of economic discourse from geology. As mentioned earlier, geologists had been interested in the depletion of coal for a long time before 1865.<sup>14</sup> But they mainly focused on the amount of reserves and on the physical constraints that limited deep extraction. Jevons' statement was different from these geological concerns: "[...] *the exact amount of [the] stock of coal is not the matter of chief moment*".<sup>15</sup> Moreover, coal depletion was not only a supply issue, but also and mostly a demand issue: "[...] *the exact quantity of coal existing is a less important point [...] than the rate at which our consumption increases, and the natural laws which govern that consumption*".<sup>16</sup>

In *The Coal Question*, the emancipation from geology is completed by a second emancipation, from engineering. Jevons' analysis is essentially known for the so-called rebound effect.<sup>17</sup> This effect is a paradox: energy efficiency does not lead to a decrease of the total energy consumed, but to an increase, because of the reduction of energy costs, producing an incentive to use more energy.<sup>18</sup> By focusing on demand mechanisms, the rebound effect contributes to the emancipation of economic analysis from the engineers' discourse, usually optimistic towards technical progress and the postponement of resource depletion.<sup>19</sup> Looking at past decades, Jevons expressed his scepticism about technical innovation:

Economy [...] does not tend to reduce the industrial consumption of coal, but acts in the opposite direction: by increasing the profitability of coal-labour, it extends its use. Almost every improvement in the engine for the last century and a half has been directed to economizing the consumption of coal; and yet the use of the engine and the quantities of coal consumed advanced *pari passu* with its economical performance.<sup>20</sup>

- 7 With a focus on economic scarcity rather than physical reserves, with an insistence on demand mechanisms to contradict the engineers' optimism, Jevons gave birth to a *properly economic* analysis of fossil fuels, emancipated from both geology and engineering.
- 8 In addition, he provided a comprehensive description, both microscopic and macroscopic, and both theoretical and empirical, of fossil fuel issues. Chapters 4, 5, 6, 7 and 8 of *The Coal Question* explore the technical possibilities of extraction for the individual producer, and the energy needs of industrial manufacturers. Replacing coal by other resources would be impossible in many practical cases, in which high power intensity could only be reached by coal combustion.<sup>21</sup> Many technical details are given, from the physical specifications of the deposits to the material conception of the rails used for ore transport. In the subsequent chapters, the focus is enlarged, with a description of the role of fossil fuels in international trade and British competitiveness.<sup>22</sup> A public finance policy to compensate future generations for future coal depletion is also sketched.<sup>23</sup> This scale of analysis appears as different and complementary from the individual or sector-oriented scales. In that sense, Jevons' contribution was both microscopic and macroscopic.
- 9 *The Coal Question* is commonly considered as chiefly empirical.<sup>24</sup> Obviously, it consists of many statistical series, and historicized discussions – what is at stake is British development in the 19<sup>th</sup> century. Yet *The Coal Question* also contains theoretical proposals. The rebound effect is a typical case: Jevons not only described a paradox in past statistics, he also gave theoretical foundations, with demand mechanisms, to explain this paradox. The consequences of coal depletion for British development are also described through a theoretical framework, mobilising the balance of trade and cost

competitiveness. The Coal Question is not a theoretical masterpiece, but it is not a purely empirical study either.

- 10 By giving birth to the economics of fossil fuels, Jevons opened a new field of research. Even if he referred to his predecessors in natural resources analysis, in particular to Malthus,<sup>25</sup> he was perfectly clear about the analytical novelty of fossil fuels in comparison with crops, wood and fisheries:

There is [...] this most serious difference to be noted. A farm, however far pushed, will under proper cultivation continue to yield for ever a constant crop. But in a mine there is no reproduction, and the produce one pushed to the utmost will soon begin to fail and sink towards zero.<sup>26</sup>

- 11 Jevons' impetus was a first step in the elaboration of an economic analysis of fossil fuels. What about resources management? What kind of income for the owners of ore deposits? What sort of public policy to meet intergenerational social justice and economic efficiency? Jevons gave preliminary answers to these questions. But further developments were needed.

## Mining rent and marginalism

- 12 In the 19<sup>th</sup> century, natural resources in economic theory were mostly a matter of income distribution between economic agents. Since David Ricardo's *Principles of Political Economy and Taxation* (1821 [1817]), natural resources had been supposed to provide a (differential) rent to their owners: those who owned the best plots could produce crops at a lower cost than others; because there was a single price on the market (equal to the cost of production of the worst plot), they could take a rent from the difference between this single price and their own cost of production.<sup>27</sup> In Ricardo's perspective, agricultural land was the main natural resource, but mines were also evoked.<sup>28</sup> At first Ricardo seemed to make a distinction between mines and crops,<sup>29</sup> but in the end he indicated that both provided the same kind of differential rent:

The return for capital from the poorest mine paying no rent would regulate the rent of all the other more productive mines. This mine is supposed to yield the usual profits of stock. All that the other mines produce more than this will necessarily be paid to the owners for rent. Since this principle is precisely the same as that which we have already laid down respecting land, it will not be necessary further to enlarge on it.<sup>30</sup>

- 13 At the turn of the 20<sup>th</sup> century, this quotation was a surprise for many participants in the mining debates, in Britain and abroad.<sup>31</sup> Ricardo does not seem to have paid attention to the exhaustible nature of subsoil resources. Yet this feature has an impact on the determination of the rent. Theoretically speaking, the classical differential rent appears because several plots of land are cultivated simultaneously, with different returns. A single plot cannot satisfy all the needs of the population. And every year, all the plots deliver crops at various costs. In the mining industry, still theoretically speaking, ore can be extracted from a deposit as quickly as needed, until the deposit is empty.<sup>32</sup> Deposits are *sequentially* (and not *simultaneously*) exploited, which means that there is only one level of production costs at any given time. When a deposit is depleted, capital is invested in another deposit. But there is still a single cost of production, because the former deposit is no longer exploited. As a result, because there are no differences in (simultaneous) costs to note, there can be no differential rent. The incomes of the owners of subsoil cannot obey the same theoretical laws as those of the owners of land.

- 14 Most British economists involved in mining debates at the end of the 19<sup>th</sup> century noticed this theoretical deficiency. They started searching for new tools and new explanations for the mining rent. Their attempts took place in a turbulent period for economic theory. In the 1870s, the marginalist movement, insisting on marginal utility, trade and economic calculus instead of social classes and costs of production, modified the basics of economics. The Ricardian theory of differential rent had a peculiar place in this movement, because, in a sense, it was a marginalist tool before time insofar as the *marginal plot* is the determinant of the market food price. British and American economists extended the differential rent mechanism to many factors of production: Clark (1899)<sup>33</sup> built a theory of marginal productivity; Marshall (1920 [1890])<sup>34</sup> elaborated a “quasi-rent” to complete his partial equilibrium framework. It is in this innovative context that the participants in the mining debates explored the issue of the subsoil rent.
- 15 The need for new theoretical explanations for the mining rent was due to the characteristics of ore resources. From the 1880s onwards, several authors, such as Edmund K. Muspratt (1888)<sup>35</sup> and Cornelius M. Percy (1888)<sup>36</sup>, underlined that in agriculture, the owner sells the right to exploit his land but with the security to get back his plot in its original state of fertility.<sup>37</sup> In mines, the owner does not sell a right to use the subsoil, but a right on what this subsoil contains; there is no way for the owner, at the end of the contract, to get back the ore that has been extracted from the deposits. Conceptually speaking, the payment for the subsoil thus cannot be the same as for land. In the case of land it is a rent for a use; in the case of mines it is a compensation for extraction. This crucial distinction was the starting point of many mining debates at the time. Since compensation was needed for what the owner lost, all the mines had to provide an absolute mining rent, which was not the case for the marginal plot in the Ricardian scheme.
- 16 With the theoretical specification of fossil fuels after Jevons, and with the observation of the discrepancy between the land rent and the mining rent, British economists had no clear reason to cross natural resources analysis and marginalism (based on the extension of the differential mechanism). In their *Economics of Industry* (1879), Alfred Marshall and Mary Paley confirmed the specificities of fossil fuels and ore resources, indicating that mining was not submitted to decreasing returns, unlike agriculture:
- Another difference between agriculture and mining is this. It is impossible to raise by any amount of labour ten times the ordinary produce from a well-cultivated garden in one year. But the produce raised in a year from a mine might be increased tenfold without increasing more than tenfold the labour employed on it; provided that there were a sufficient supply of mining plant and skilled miners<sup>38</sup>.
- 17 While a series of plots necessarily gives decreasing returns when new factors of production are implemented (in the Ricardian framework), a mine simply provides various amounts of ore according to the quantity of factors.
- 18 In the last decades of the 19<sup>th</sup> century, this theoretical reasoning was quickly challenged by reality. In practice, it was not true that different mines with various returns were never simultaneously exploited. Technical constraints, market adjustments, sunk costs led to the settlements of many extraction units at the same time, with cheap and more costly deposits. It meant that, in the Ricardian perspective, there was probably a marginal deposit. Therefore the way the owners of the subsoil got some rent could not be totally disconnected from the differential principle, as Marshall admitted some years later.<sup>39</sup> At the turn of the 20<sup>th</sup> century, some authors tried to make the synthesis between the

specificities of exhaustible resources (compensation, absolute rent) and the practices of exploiting simultaneously several mines with various returns. The marginalist tools were called to enter the analysis.

- 19 The British economist and philosopher William R. Sorley (1889)<sup>40</sup> played a crucial role in that synthesis.<sup>41</sup> Sorley kept insisting on compensation: obviously, mines with various returns are simultaneously exploited, but that means that an absolute rent must also exist on the marginal mine.<sup>42</sup> Otherwise, why would an owner accept the exploitation of his deposits, by simply losing his property (the ore they contain) with no reparation? Unlike what Ricardo pointed out for the rent of land, all mines provide a sort of absolute rent, which is constituent of prices.
- 20 Sorley's concern was chiefly with public regulation of the mining rent. If the rent is part of the ore prices, its regulation might have an effect on fossil fuel prices, which is an important issue for economic development.<sup>43</sup> Looking at the British economy, Sorley noticed that, in fact, the absolute component of the mining rent was negligible compared with the differential component that appeared when mines with various returns were simultaneously exploited (the owners of the best mines getting a rent because of lower costs of production). As a result, public regulation could not have any decisive effect on fossil fuels prices; it could only produce money transfers between economic agents:  

The reduction of royalty [i.e. mining rent] would simply have the effect of enabling the entrepreneur to keep 4d. a ton in his own pocket, which he would otherwise have had to transfer to the landlord's.<sup>44</sup>
- 21 In Sorley's analysis, compensation for extracted exhaustible resources, and the differential principle, are gathered in a single framework. On the one hand, it is a theoretical novelty to incorporate fossil fuels into economic theory. But on the other hand, this innovation is imbued with two priorities, which come rather from outside natural resources analysis: a theoretical priority (the development of marginalism), and a political priority (taxation).
- 22 In summary, in the 19<sup>th</sup> century British debates, economic discourses on ore shortages and resources depletion were both a source and a result of changes in theoretical frameworks. After Jevons' seminal contribution, which led to the constitution of an autonomous economic analysis of fossil fuels, British economists continued to create new concepts and tools (e.g. mining rent) to provide a better understanding of the exhaustion of natural resources. This reveals a persistent concern with coal depletion from the 1860s to the 1890s. The developments however took place in a context (the rise of marginalism and fiscal debates) that restrained, or at least shaped, the course of innovation. In that sense, 19<sup>th</sup> century British economic discourses on fossil fuels were, for a part, original and, for another part, embedded in the general history of the time.<sup>45</sup>

## Conclusion: Britain vs. America

- 23 After Sorley, British proposals were prolonged and modified by other scholars elsewhere in Europe. In particular, Luigi Einaudi (1900), then a young Italian economist, developed a "pure theory of the mining rent", with a very close link to marginalism.<sup>46</sup> His key contribution was to be found in the distinction between marginal rents and differential rents. Like Sorley, Einaudi also tried to combine the specificities of exhaustible resources (in particular supply inertia) with extended marginalism – his marginal rent could be related to Marshall's quasi-rent.



- 24 The history of the mining rent could have stopped here, or rather could have been refined in the lineage of those various works, most of them conducted by British economists. Yet in the first decades of the 20<sup>th</sup> century, some scholars chose to combine resources analysis with marginalism in a different way, and the specificities highlighted by Marshall, Paley, Sorley and Einaudi finally disappeared from the heart of economic theory.
- 25 This change occurred when some American economists took part in the debates. The idea of compensation was at the core of the new mining rent theory. But Frank W. Taussig (1911; 1917),<sup>47</sup> from Harvard University, decided to reject it, advocating that many commodities are limited, without any compensation for their owners. Ore resources are only one case among others. The payments to the owners of the subsoil have no reason to be specific:
- It is argued by some able economists that a royalty [i.e. mining rent] is in any case different from rent; or rather, that there is on every mine some sort of payment to the owner, or revenue for him, and that even the poorest mine will yield something [...]. But I am skeptical of the validity of this reasoning. The fact that a store is physically limited does not enable its owner to secure a price. [...] rent proper shows the same sort of development on mines as on other natural agents.<sup>48</sup>
- 26 Taussig's idea was that the marginal mines did not provide any absolute rent. Even if ore resources are exhaustible, they are not scarce (at a large scale) compared with the needs of the economy. The owners should not be compensated. If they do not want to exploit the subsoil, other deposits are available at the same costs of production elsewhere, and there must be an owner ready to enter the market without any absolute rent. In Taussig's framework, the mining rent was only differential, in the lineage of the narrow Ricardian tradition.<sup>49</sup>
- 27 To understand Taussig's attitude and why British innovations (absolute rent, compensation mechanisms, etc.) were finally abandoned, it is necessary to mobilise both economic and energy history, and the history of economic thought. Taussig's attitude was consistent with the practical realities of the fossil fuel sector at the time, at least in the economists' minds. In the 1910s, the forecasted reserves of coal and petroleum, in particular in the US, were considered larger than in the previous decades.<sup>50</sup> This was due to the first developments of oil extraction on a large scale, and to the implementation of new techniques (prospecting, methods, electrical machines, etc.) in coalmines.<sup>51</sup> By insisting on the abundance of ore rather than on its exhaustible feature, Taussig incorporated his practical observations into economic theory. This historical explanation needs to be completed by a theoretical explanation. In his handbook, Taussig indicated that he did not want to go into detail with respect to marginalism, but he did use the marginalist tools and lexicon ("marginal utility", "marginal cost", "marginal price", "marginal effectiveness", etc.).<sup>52</sup> Like many of his predecessors, he gave much place to the differential principle, not only for land, but also for the other factors of production. In a sense, by erasing the specificities of mines with respect to rent and income distribution, Taussig was fully committed to one of the marginalist projects: to incorporate all the payments into a single theoretical framework structured by the differential principle. It is a paradox, because this orientation transformed the mining rent into a Ricardian differential rent – a return to the situation of the 1820s, with no theoretical novelty after Jevons.

- 28 The American economist Taussig finally won the theoretical fight. His rehabilitation of the narrow Ricardian scheme was confirmed by his followers, and has remained at the foundation of recent contributions.<sup>53</sup> The ability of the Ricardian scheme to incorporate exhaustible resources is however questionable.<sup>54</sup> Retrospectively, by insisting on compensation and inertia, the conceptions of Marshall, Paley, Sorley and Einaudi were perhaps more accurate.
- 29 This examination of the British 19<sup>th</sup> century debates, and of the subsequent evolution of these debates when American economists came in the discussions, provides some insights on the relation between fossil fuels and economic theory after Jevons. First, some authors were tempted by innovation, to build new tools and new concepts in order to understand the economic consequences of depletion. Second, these innovations took place in a paradigmatic shift towards marginalism. This had an impact on the way the new tools and concepts were set up. Third, historical realities and theoretical backgrounds finally combined to produce a theory of mining rent that paradoxically erased the specificities of exhaustible resources. Marginalism overwhelmingly invaded natural resources analysis, so fossil fuels entered the same theoretical framework as other factors of production, and economic discourses became less concerned with ore depletion as an issue for economic development.
- 30 What lessons can be drawn from this? Other cases and other periods should be scrutinised to provide a comprehensive answer to this question, but it seems that, on environmental and energy issues, probably as on other topics, economists are not only influenced by the historical context when they deal with a subject, they also have a theoretical bias that leads them to complete certain conceptual projects, at the risk of losing sight of the intrinsic characteristics of the objects they study.<sup>55</sup>
- 31 **Antoine Missemer est chargé de recherche CNRS (section 37 économie-gestion) au CIRED – Centre international de recherche sur l’environnement et le développement (UMR 8568). Ses travaux portent essentiellement sur l’histoire de l’économie de l’environnement, de l’énergie et des ressources naturelles. Il a notamment publié *Nicholas Georgescu-Roegen, pour une révolution bioéconomique* (2013, ENS Éditions) et *Les Économistes et la fin des énergies fossiles (1865-1931)* (2017, Classiques Garnier). Contact : missemer@centre-cired.fr | CNRS, CIRED – Centre international de recherche sur l’environnement et le développement, 45bis avenue de la Belle Gabrielle, F-94736 Nogent-sur-Marne Cedex.**

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## NOTES

1. Harold Hotelling, “The Economics of exhaustible resources”, *Journal of Political Economy* 39, 1931, pp. 137–175. See Maureen L. Cropper & Wallace E. Oates, “Environmental Economics : A Survey”, *Journal of Economic Literature* 30, 1992, pp. 675–740; Shantayanan Devarajan & Anthony C. Fisher, “Hotelling’s ‘Economics of Exhaustible Resources’: Fifty Years Later”, *Journal of Economic Literature* 19, 1981, pp. 65–73; Chennat Gopalakrishnan, “Classic papers in natural resource economics: an overview” in *Classic Papers in Natural Resource Economics* (London, MacMillan, 2000), pp. 1–10.

2. See Tim J. C. Robinson, “Classical foundations of the contemporary economic theory of non-renewable resources”, *Resources Policy* 6:4, 1980, pp. 278–289; Tim J. C. Robinson, *Economic Theories of Exhaustible Resources* (London & New York, Routledge, 1989).

3. Antoine Missemer, *Les Économistes et la Fin des Énergies Fossiles (1865-1931)* (Paris, Classiques Garnier, 2017).

4. W. S. Jevons is considered as a major contributor to economics for his consumption theory, elaborated a few years later in *Theory of Political Economy* (W. Stanley Jevons, *Theory of Political Economy* (London, MacMillan, 1871)). On the influence of *The Coal Question*, see John K. Whitaker, “William Stanley Jevons” in Tiziano Raffaelli, Giacomo Becattini & Marco Dardi (eds.), *The Elgar Companion to Alfred Marshall* (Northampton, Edward Elgar Publishing, 2006), pp. 573–577; Michael V. White, “Where did Jevons’ energy come from?”, *History of Economics Review* 15, 1991, pp. 60–72.

5. General contributions in economic history sometimes address these questions for specific issues (e.g. growth, population). For instance, see Roderick Floud & Paul Johnson (ed), *The Cambridge Economic History of Modern Britain, vol. 2* (Cambridge, Cambridge University Press, 2004).

6. See M. V. White, “Where did Jevons’ energy come from? », *op. cit.*.

7. John Stuart Mill, *Malt Duty*, Parliamentary debates, House of Commons, Hansard, 17 April 1866.

8. See for instance Edward Hull, *The Coal-Fields of Great Britain: Their History, Structure, and Resources*, 2<sup>nd</sup> ed. (London, Edward Stanford, 1861).
9. In 1789, the mining surveyor John Williams wrote: “The result of [my] investigation refutes by inference [an] erroneous opinion concerning coal, which I have often heard asserted with great confidence, viz. that coal is inexhaustible. That the fund of coal treasured up in the superficies of the globe, for the accommodation of society, is very great, I readily acknowledge; but that it is inexhaustible, in the proper sense of the word, I deny.” (John Williams, *Natural History of the Mineral Kingdom* (Edinburg, T. Ruddiman, 1789), pp. 158-159).
10. For a survey, see Rolf Peter Sieferle, *The Subterranean Forest. Energy Systems and the Industrial Revolution* (Cambridge, The White Horse Press, 2001).
11. W. Stanley Jevons, *The Coal Question. An Inquiry Concerning the Progress of the Nation, and the Probable Exhaustion of our Coal Mines*, 2<sup>nd</sup> ed. (London, MacMillan, 1866), pp. v-vi.
12. For details, see Antoine Missemer, « La peur du déclin économique face à l'épuisement des ressources naturelles, de W. Stanley Jevons à Herbert S. Jevons (1865-1915) », *Revue économique* 66:5, 2015, pp. 825-842; Antonin Pottier, “L'Economie dans l'impasse climatique. développement matériel, théorie immatérielle et utopie auto-stabilisatrice” (PhD dissertation, EHESS, 2014), pp. 107-112.
13. W. S. Jevons, *The Coal Question*, *op. cit.*, p. 75.
14. See for instance E. Hull, *The Coal-Fields of Great Britain*, *op. cit.* and J. Williams, *Natural History of the Mineral Kingdom*, *op.cit.*
15. *Ibid.*, p. 242.
16. *Ibid.*, p. 26.
17. See Blake Alcott, “Jevons’ paradox”, *Ecological Economics* 54, 2005, pp. 9–21; Brett Clark & John Bellamy Foster, “William Stanley Jevons and The Coal Question: An Introduction to Jevons’s ‘Of the Economy of Fuel’”, *Organization & Environment* 14, 2001, pp. 93–98; Antoine, Missemer, “William Stanley Jevons’ *The Coal Question* (1865), beyond the Rebound Effect”, *Ecological Economics*, 82, 2012, pp. 97–103; Michel Robine, « La question charbonnière de William Stanley Jevons », *Revue Economique* 41:2, 1990, pp. 369–394.
18. W.S. Jevons, *The Coal Question*, *op. cit.*, pp. 132-133, 136 & 316-317; W. Stanley Jevons, “On Coal” in R. D. Collison Black (ed.), *Papers and Correspondence of William Stanley Jevons*, vol.7 (London, MacMillan, 1867), pp. 18–28; W. Stanley Jevons, “On the Probable Exhaustion of Our Coal Mines” in *ibid.* pp. 28–35. Jevons does not use the term ‘rebound effect’, which was coined later, when Brookes and Khazzoom rediscovered Jevons’ intuition. See Len Brookes, “A Low Energy Strategy for the UK by G. Leach et al.: a Review and Reply”, *Atom* 269, 1979, pp. 3–8; Daniel Khazzoom, “Economic Implications of Mandated Efficiency in Standards for Household Appliances”, *Energy Journal* 1: 4, 1980, pp. 21–40.
19. See for instance Rücker Arthur W., « Coal as a Source of Power » in *Coal: Its History and Uses*, Thomas E. Thorpe (ed.), London, MacMillan, 1878, p. 258–291.
20. W. S. Jevons, “On the Probable Exhaustion of Our Coal Mines”, *op. cit.*, p. 31.
21. W. S. Jevons, *The Coal Question*, *op. cit.*, pp. 138-168.
22. *Ibid.*, pp. 246-353.
23. *Ibid.*, pp. 354-369. See A. Missemer, « La peur du déclin économique face à l'épuisement des ressources naturelles, de W. Stanley Jevons à Herbert S. Jevons (1865-1915) », *op. cit.*, pp. 836-838.
24. See Sandra J. Peart, *The Economics of W. S. Jevons* (London, Routledge, 1996); Agnar Sandmo, “The Early History of Environmental Economics”, *working-paper*, 2014, pp. 1-38.
25. W. S. Jevons, *The Coal Question*, *op. cit.*, pp. 171-173.
26. *Ibid.*, p. 178.
27. This theory of land rent is attributed to Ricardo, but Turgot and Anderson preceded Ricardo with the same kind of reasoning (see Alain Béraud, « Ricardo, Malthus, Say et les controverses de

la 'seconde génération' » in Alain Béraud & Gilbert Faccarello (eds.), *Nouvelle Histoire de la Pensée Economique*, tome 1 (Paris, La Découverte, 1992, pp. 365–508).

28. David Ricardo, *The Principles of Political Economy and Taxation* (London & New York, Dent & Dutton, 1821), chap. 3.

29. *Ibid.*, p. 34.

30. *Ibid.*, p. 46.

31. See Luigi Einaudi, *La Rendita Mineraria* (Torino, Unione Tipografico Editrice, 1900), p. 391; Lewis C. Gray, "Rent under the assumption of exhaustibility", *Quarterly Journal of Economics* 28: 3, 1914, pp. 466–489; Alfred Marshall, *Principles of Economics*, 8<sup>th</sup> ed., (London, MacMillan, 1920), p.139f.

32. This is valid only if there is no technical obstacle to increase ore extraction in a given deposit. This assumption may seem unrealistic, but it is consistent with the Ricardian framework, in which an almost similar assumption is formulated for the (constant) fertility of each plot overtime (see Antoine Missemmer, *Les Économistes et la fin des Energies Fossiles (1865-1931)*, *op. cit.*, chap. 3).

33. John Bates Clark, *The Distribution of Wealth. A Theory of Wages, Interest and Profits* (New York, MacMillan, 1899).

34. Alfred Marshall, *Principles of Economics*, *op. cit.*.

35. Edmund K. Muspratt, "Preface" in Cornelius MacLeod Percy (ed.), *Mine Rents and Mineral Royalties* (Liverpool, Financial Reform Association, 1888), p. 1.

36. Cornelius MacLeod Percy, *Mine Rents and Mineral Royalties* (Liverpool, Financial Reform Association, 1888).

37. Under the assumption of non-erosion.

38. Alfred Marshall & Mary Paley, *The Economics of Industry* (London, MacMillan, 1879), p. 25.

39. Alfred Marshall, *Industry and Trade*, 4<sup>th</sup> ed. (London, MacMillan, 1923), p. 188.

40. William R. Sorley, "Mining Royalties and their Effect on the Iron and Coal Trades", *Journal of the Royal Statistical Society* 52: 1, 1889, pp. 60–98.

41. See T. J. C. Robinson, *Economic Theories of Exhaustible Resources*, *op. cit.*.

42. W. R. Sorley, "Mining Royalties and their Effect on the Iron and Coal Trades", *op. cit.*, p. 76.

43. See also Edward Cockburn, "The Strike in the Coal Trade - Mineral Royalties" in John Benson & Quentin Outram (eds.), *Coal in Victorian Britain, part.1, vol.3* (London, Pickering & Chatto, 1885), pp. 73–74; C. M. Percy, *Mine Rents and Mineral Royalties*, *op. cit.*, p. 29.

44. W. R. Sorley, "Mining Royalties and their Effect on the Iron and Coal Trades", *op. cit.*, p. 79.

45. As mentioned in the introduction, the political reactions to these theoretical debates and the role of economists in the design of British public policy would deserve attention, but are beyond the scope of the present article.

46. L. Einaudi, *La Rendita Mineraria*, *op. cit.*, pp. 395–407. "Pure theory" was the credo of many marginalist economists at the time, starting with Léon Walras. Einaudi explains (*ibid.*, p. vii) that Enrico Barone played an important role for him, and Barone was such a marginalist economist. His correspondence with Walras started in 1894 (see Léon Walras, "Letter to Enrico Barone (Aug. 26th, 1894)" in William Jaffé (ed.), *Correspondence of Léon Walras and Related Papers, vol.II (1884-1897)* (Amsterdam, North-Holland Publishing Company, 1894), pp. 613–616).

47. Frank William Taussig, *Principles of Economics* (New York, MacMillan, 1911); Frank William Taussig, "Exhaustion of the Soil and the Theory of Rent", *Quarterly Journal of Economics* 31: 2, 1917, pp. 345–348.

48. F. W. Taussig, *Principles of Economics*, *op. cit.*, vol. 2, pp. 96–97.

49. *Ibid.*, vol. 2, p. 92; F. W. Taussig, "Exhaustion of the Soil and the Theory of Rent", *op. cit.*, p. 347.

50. See for instance Herbert S. Jevons, *The British Coal Trade* (London, London and Norwich Press, 1915).

51. See Philippe Copinschi, *Le Pétrole. Une Ressource Stratégique* (Paris, La Documentation française, 2012); Alfred W. Flux, "Preface to the Third Edition", in W. S. Jevons, *The Coal Question. An Inquiry Concerning the Progress of the Nation, and the Probable Exhaustion of our Coal-Mines*, 3<sup>rd</sup> ed. (New York, Augustus M. Kelley, 1952 [1906], pp. ix-xxviii).
52. F. W. Taussig, *Principles of Economics*, *op. cit.*, vol. 1, p. viii, chap. 9, 10, 13, 19; vol. 2, chap. 38, 39, 48, 51.
53. See for instance John E. Orchard, "The Rent of Mineral Lands", *Quarterly Journal of Economics* 36: 2, 1922, pp. 290–318; see also Gérard Gaudet, « Théorie économique et prévision en économie des ressources naturelles », *L'actualité économique*, 60: 3, 1984, pp. 271–279; Heinz D. Kurz & Neri Salvadori, "Exhaustible Resources. Rents, Profits, Royalties and Prices" in Volker Caspari (ed.), *The Evolution of Economic Theory. Essays in Honour of Bertram Schefold* (London, Routledge, 2011), pp. 39–52; Heinz D. Kurz & Neri Salvadori, "Ricardo on Exhaustible Resources, and the Hotelling Rule" in Aiko Ikeo & Heinz D. Kurz (eds.), *A History of Economic Theory. Essays in Honour of Takashi Negishi* (London, Routledge, 2009), pp. 68–79; Heinz D. Kurz & Neri Salvadori, "Classical Economics and the Problem of Exhaustible Resources", *Metroeconomica* 52: 3, 2001, pp. 282–296; Quentin Outram, "Introduction" in John Benson & Quentin Outram (eds.), *Coal in Victorian Britain, part. 1*, vol. 3 (London, Pickering & Chatto, 2012), pp. xi–xix.
54. Antoine Missemmer, *Les Économistes et la fin des Énergies Fossiles (1865-1931)*, *op. cit.*, chap. 3.
55. For complementary views, see Erhun Kula, *History of Environmental Economic Thought* (London, Routledge, 1998); Antoine Missemmer, *Les Économistes et la fin des énergies fossiles (1865-1931)*, *op. cit.*; Antoine Missemmer, "Natural Capital as an Economic Concept, History and Contemporary Issue"s, *Ecological Economics* 143, 2018, pp. 90–96.

## ABSTRACTS

The interest of economists in fossil fuel exhaustion dates back to the mid-19<sup>th</sup> century, when, in Great Britain, W. Stanley Jevons published his 1865 essay on coal. In the subsequent decades, fossil fuels were considered with ambivalence: sometimes as a new theoretical and practical priority, sometimes as a secondary issue to be studied in standard frameworks. This paper explores, through the example of the mining rent, how fossil fuels were (partially) incorporated into economic theory at the time. It also explains why the original British view was finally relegated to the background in the early 20<sup>th</sup> century, when American economists took part in the discussions.

Les économistes se sont intéressés à l'épuisement des énergies fossiles à partir du milieu du XIX<sup>e</sup> siècle, quand, en Grande-Bretagne, W. Stanley Jevons a publié son essai sur le charbon (1865). Dans les décennies qui ont suivi, les énergies fossiles ont été étudiées avec ambivalence : parfois comme une priorité théorique et pratique, parfois comme un problème secondaire pouvant être étudié avec des outils connus. Cet article montre comment les énergies fossiles ont été (partiellement) introduites dans la théorie économique à l'époque, et pourquoi la plupart des contributions britanniques ont finalement été reléguées au second plan quand les économistes américains se sont emparés du sujet au début du XX<sup>e</sup> siècle.



## INDEX

**Keywords:** history of economic thought, fossil fuels, mining rent, Jevons, marginalism.

**Mots-clés:** histoire de la pensée économique, énergies fossiles, rente, Jevons, marginalisme.

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