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Innovation and The Precautionary Principle

Abstract

Recent environmental policies favour the polluter pays principle. This principle points out the pollutant financial liability for the eventual incidents induced by his activities. In this context, we analyse the decision of an agent to invest in new industrial activities, the consequences of which on human health and the environment are initially unknown. It is not possible for him to delay investing, but the agent has the opportunity to acquire information and to reduce the cost of an accident. This allows the agent to reduce uncertainty regarding dangers associated with the project and to limit potential damages that it might cause. However, the agent's chosen level of these actions may be considered as insufficient and not acceptable by Society as response in the face of a possible danger. Precautionary state regulation may then be introduced. We get that this regulation may slow down innovation and may favour innovation in countries with less safety requirements. We find that agent may get around the goal of the regulation by ignoring the information on the dangerousness of its project. We then propose some policy tools which stimulate innovation and impose a certain level of risk considered as acceptable for Society to the agent. Finally, we use a numerical analysis based on the Monsanto Company for studying the agent's behaviour with different regulatory frameworks.

Keywords: environment, information acquisition; irreversible investment; the precautionary principle; uncertainty.

JEL Classification: D21, D81, D83, H25, O38.

Introduction

Investing in new industrial activities, such as pharmaceutical or chemical manufacturing, fertilizer or pesticide processing, or other new technologies, generates uncertainty about the future returns, as well as the costs of damages that such innovations could involve. To reduce this uncertainty, the agent has the opportunity to acquire information on the project's potential consequences on human health and the environment, through basic research activities. Recent health and environmental policies in the European Union (EU) and the United States (US) favour the polluter pays principle. In international environmental law, the polluter pays principle states that the polluting parties are made liable to pay for the damages they cause. To reduce potential damage costs of an accident, the agent may carry out technological and developmental research into how to reduce the impact by improving, for example, the environmental quality or the safety testing of the product.

However, the agent's chosen level of these actions may be viewed as insufficient in the face of a possible danger to human health, or to protect the environment. **Each country has its own approach of the precautionary principle but all these approaches advocate that evidence of harm to human, animal or plant health, or to the environment, rather than definitive proof of harm, should prompt protecting actions.** The strong precautionary principle says that an activity should not proceed if there are potential adverse effects on human health and the environment that are not fully understood, that is, any degree of uncertainty is sufficient to stop an activity. The problem with this interpretation is that there can never be full scientific certainty on anything, and therefore the precautionary principle is sufficient to stop any activity. Furthermore, uncertain damages can occur in both directions. Consider the case of a vaccine that is developed to control spread of a new virulent strain of flu. The new vaccine could possibly have adverse effects on human health, and hence one might invoke the precautionary principle to block a proposed program to inoculate the public. But not inoculating the public means that the virulent flu stain might spread, thereby resulting in adverse effects on human health on a global scale. Is it precautionary to inoculate or to not inoculate? In such cases, the strong version of the precautionary principle provides no guidance on what to do. Hence, from the 1992 Rio Declaration,¹ Von Schomberg (2006) has defined a weak precautionary principle for the EU as follows: *"Where, following an assessment of available scientific information, there are reasonable grounds for concern for the possibility of adverse effects but scientific uncertainty persists, provisional risk*

¹The 1992 Rio Declaration, Principle 15 states that: *"In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."*

management measures based on a broad cost/benefit analysis whereby priority will be given to human health and the environment, necessary to ensure the chosen high level of protection in the Community and proportionate to this level of protection, may be adopted, pending further scientific information for a more comprehensive risk assessment, without having to wait until the reality and seriousness of those adverse effects become fully apparent". By reflecting this weak precautionary approach, precautionary state regulation may be introduced. To a certain extent, information acquisition and cost reduction can be viewed as precautionary efforts in so far as they allow agent under uncertainty to limit potential damages the project could entail and to improve protection of human health and the environment. By invoking the weak precautionary principle, State may require a certain level of information collection and of cost in order to lead the agent to respect a certain level of risk considered as acceptable for Society. But what are the consequences of precautionary state regulation on the agent's investment decision? **Through examples of the regulation of arsenic in water by the Bush administration, of genetic modification of food, of nuclear power plants and for the trade-off between the protection of marine mammals and military exercises, Sunstein (2002-2003) denounce the possible paralyzing effect of regulation by the precautionary principle. Hence, does the precautionary state regulation slow down innovation as suggesting in Sunstein (2002-2003)?**

To address these questions, we consider an agent² who wants to invest in new industrial activities which cannot be delayed. Indeed, in the race for new technologies, the agent may not be willing to delay investing. For instance, competitive industries, as pharmaceutical industries (medicines, vaccines) and chemical industries (Genetically Modified Organism, GMO), are not willing to delay their investment that could may cause them to lose a patent. The agent has a limited initial knowledge on his project's returns, and he has financial liability for eventual incident induced by his activity (the polluter pays principle). He has the opportunity to collect information through basic research, at a cost, and to update his beliefs in a Bayesian way. A degree of information precision is associated with this level of cost: a higher cost implies a higher precision. Through information acquisition, the agent develops a better understanding of the level of danger associated with his investment project, and can then decide to prematurely stop the project and therefore limit the potential damage to human health and the environment. Moreover, the agent has also the possibility to conduct applied research and experimental development in order to reduce the potential financial costs of the project.³ Indeed, through applied

²The private agent considered in our approach can also be viewed as a firm.

³As the Organisation for Economic Co-operation and Development (OECD), we define applied research and experimental development as follows: *The goal is to find possible applications for the results of basic research; to find new solutions making it possible to reach an objective chosen in advance; and*

research and experimental development, the agent limits both financial expenses and the potential damage to human health and the environment in case of an accident. Using such an approach allows us to consider the problem of managing new activities and to contribute to a better understanding of the issues being faced by the innovator.

We then introduce precautionary state regulation reflecting the precautionary principle. In this paper, precautionary state regulation then consists of imposing a certain level of information collection and of damage cost which lead the agent to respect a certain level of risk considered as acceptable for Society. Different regulatory environments may occur. Each state may propose precautionary state regulation. As an example, the EU precautionary regulation on GMOs establishes a case by case and step by step procedure in which the applier for a GMO release has to demonstrate safety of its product (Von Schomberg, 2006). This constrains the applier to identify, through research, and to reduce the ecological or potential health risks attached to its production. **This precautionary regulation is specific to Europe and is scientifically justified by the uncertainties about the impacts of the GMOs uses and the lack of scientific information to resolve these uncertainties (Johnston and Santillo, 2006).**

Our approach relies on two building blocks. First, our paper is linked to the literature that examines the interaction of irreversibility, uncertainty, and information acquisition. Arrow and Kurz (1970) conducted pioneering work on irreversible investments under certainty. Their work was expanded through the introduction of uncertainty (Charles and Munro, 1985, Clark, Munro and Charles, 1985, Pindyck, 1981, Viscusi, 1985).

The role of information in irreversible investment decisions is covered in a large body of work by Arrow and Fisher (1974), Crabbe (1987), Dixit and Pindyck (1994), Fisher (1978), Freeman (1984), Freixas and Laffont (1984), Gollier and Treich (2003), Henry (1974), and Jones and Ostroy (1984). These works propose a conventional "option value" approach, in which the investment is irreversible (i.e., it cannot be recovered in the future) and investment decisions are made under uncertainty about future returns. An agent can postpone investing in order to be able to acquire more information about the possible future consequences of the project. This leads one to evaluate the option value of waiting in order to get new information. We propose to analyse the irreversible investment decision made in a context of uncertainty about future returns by an agent who does not have the option to postpone his investment. Moreover, we integrate endogenous information in a literature, real option theory (Arrow and Fisher, 1974, Dixit and Pindyck, 1994, Henry, 1974, Schwartz and Trigeorgis, 2001), that usually deals with exogenous information, by

to use the knowledge obtained through research or practical experience to undertake, by means of a prototype or pilot installations, to launch new products, establish new processes, or bring about a substantial improvement in existing processes and products.

allowing the agent to initially decide whether or not he will acquire information in the future.

Gollier et al (2000), Gollier (2001), and Gollier and Treich (2003) have focused on a precautionary approach to the interaction of irreversibility and uncertainty. **Gollier et al (2000) propose an economic interpretation of the precautionary principle within the standard Bayesian framework. They consider that more scientific uncertainty should induce Society to take stronger prevention measures today. They examine how the prospect of receiving information affects the current prevention effort and show that earlier prevention effort only if prudence is larger than twice absolute risk aversion. Under this condition, they then conclude that scientific uncertainties justify an immediate reduction of the consumption of a potentially toxic substance. Gollier (2001) proposes to balance the precautionary principle against the benefits of waiting to learn before we act by using a standard cost-benefit analysis. Finally, Gollier and Treich (2003) investigate how classical economic theory justifies the precautionary principle. They identify conditions so that the precautionary principle is an efficient economic guideline. However, none of these studies has ever specified the precautionary state regulation requirements emerging from the precautionary principle. To the best of our knowledge, we are the first to state exactly them and to analyse with a mathematical formalization their impacts on the irreversible investment, and so on innovation.**

Furthermore, our paper is also relied to the literature on the Porter Hypothesis. In its original writings, Porter (1991) suggested that environmental regulation will enhance a country's competitiveness. Jaffe et al. (1995) found evidence that was consistent with Porter's writings. But as for Brunnermeier and Levinson (2004) and Copeland and Taylor (2004) found evidence which contradicted these writings and supported the pollution haven hypothesis which states that stringent environmental regulation will induce firms to leave the country for less strict regulatory regimes. In other words, the stringent environmental regulation may favour the outsourcing decision.

In 1995, Porter proposed the Porter Hypothesis which states that *"properly designed environmental regulation can trigger innovation that may partially or more than fully offset the costs of complying with them"*. The Porter Hypothesis suggests the existence of "win-win" situation, in which Society and private firms could both be winners with the introduction of environmental regulation. This hypothesis is contrary to the traditional paradigm which says that environmental regulation restricts the firm's options and thus reduced their profit. Conflicting theoretical and empirical studies concerning

this hypothesis have been written. Oates et al (1995) suggest that environmental regulation may increase the firm's payoff by leading them to profitable innovation. However these are exception instead of the rule. Actually, they argue that firms should identify by themselves if there are opportunities to reduce costs and inefficiencies without the need for government intervention. On the other hand, Xepapadeas and Zeeuw (1999) find that environmental regulations have a negative impact on profit.

Three distinct variants of the Porter Hypothesis were presented by Jaffe and Palmer (1997): the "weak" version in which environmental regulation will stimulate certain kinds of environmental innovations; the "narrow" version which asserts that flexible environmental policy instruments, such as pollution charges or tradable permits, give firms greater incentive to innovate than prescriptive regulations, such as technology-based standards; and finally, the "strong" version which posits that properly designed regulation may induce innovation that more than compensates for the cost of compliance and improves the financial situation of the firm.⁴ In general, empirical studies have found strong support for the "weak" version (Jaffe and Palmer, 1997; Lanoie et al, 2011), limited support for the "narrow" version (Lanoie et al, 2011), and qualified support for the "strong" version with the studies of Gollop and Roberts (1983), Jaffe et al. (1995), and Lanoie et al (2011) which contradict this version, and the studies of Alpay et al (2002), Berman and Bui (2001), and Lanoie et al. (2008) which support it. In our paper, we contribute to this literature by analysing the impact of the precautionary state regulation based on the precautionary principle on innovation and competitiveness.

We find that precautionary state regulation may lead the agent to prefer not investing in the project while he would have done without regulation or/and under a less cautious regulation. In this situation, precautionary state regulation may then be considered as an obstacle to innovation. Moreover, in order to respect the regulation, the agent pays for acquiring information but he may not use it and stay ignorant about the dangerousness of its project. The agent may get around the goal of the precautionary state regulation to reduce the uncertainty. In order to avoid this kind of pervert effects, we propose some policy tools, subsidies, which stimulate innovation in a country and impose a certain level of risk considered as acceptable for Society to the agent.

Using an analytical approach and numerical analysis based on the Monsanto Company, we show that risk perception and the level of uncertainty influence the decision of acquiring information, and so the decision to reduce the uncertainty. Besides, the choice of policy tools has to be taken with caution. Indeed, State may not support the activity

⁴We have taken the description of the three variants of the Porter Hypothesis in Lanoie et al (2011).

when the subsidy that it should give to the company is so large. Finally, we find that the choice of the precautionary state regulation may be decisive for attracting innovators. An aggressive competition between the countries could lead to less cautious regulation, so less safety, and large subsidies in the worst case. **We have chosen the Monsanto Company case because this American multinational chemical industry is the world leader of the GMOs. The Monsanto Company was founded in Saint Louis, Missouri, in 1901, by John Francis Queeny (1859-1933). It has a vision of a future with "Abundant Food and a Healthy Environment". In 2013 the Monsanto Company was the world's largest supplier of vegetable seeds by value, selling 821m of seed. RoundUp, manufactured by the Monsanto Company, is the world's biggest selling herbicide. However, the Monsanto Company has a long and messy history of manufacturing hazardous chemicals. As examples, in 1929 the Monsanto Company became the largest producer of polychlorinated biphenyls (PCBs) which are one of the deadliest carcinogens and chemicals that can cause immune system disorder, birth defects, cancer and fatal death. From 1961 to 1971, the Monsanto Company was involved in production of Agent Orange which has created severe health problems for the Vietnamese citizens as well as the US military. In 1994 the recombinant Bovine Growth Hormone (rBGH), a genetically engineered hormone manufactured by Monsanto Company under the name of Posilac, is injected in the cows every week to force the cows to produce more milk than their bodies normally would. This causes a number of problems with the milk, among them, raising levels of pus, antibiotics residues and breast, prostate, and colon human cancers.**⁵

The remainder of paper is organized as follows. Section 1 introduces the model. Section 2 studies the agent's optimal investment in the project and its optimal expenses on information collection and in damage reduction. Section 3 introduces precautionary state regulation and different policy tools which favour innovation in the country and impose a certain level of risk considered as acceptable for Society to the innovator. A numerical illustration based on the Monsanto Company is provided in section 4. Finally, section 5 concludes. All proofs are in appendix.

1 The model

We consider a three period model. At period 0, an agent may invest $I \geq 0$ in a project that may cause damage to human health and to the environment. We consider two

⁵For more details on the Monsanto Company history and controversies see: [http : //www.monsanto.com/Pages/default.aspx](http://www.monsanto.com/Pages/default.aspx) and [http : //www.combat - monsanto.co.uk/spip.php?article233](http://www.combat-monsanto.co.uk/spip.php?article233).

possible states of the world, H and L associated with different probabilities of damage θ^H and θ^L , respectively. We assume that state H is more dangerous than state L , so:

$$\theta^L < \theta^H.$$

At period 0, the prior beliefs of the agent are p_0 on state H , and $1 - p_0$ on state L . The expected probability of the damage is thus given by:

$$E(\theta) = p_0\theta^H + (1 - p_0)\theta^L.$$

At period 0, the agent may pay $C^a \geq 0$, to undertake applied research and experimental development, specifically technological and development research about how to improve the environmental quality and the safety testing of the product. Getting a better quality and a better safety lead to limit damage given on accident occurs. So C^a is an expense in damage reduction. The agent may also pay $C^b \geq 0$ to undertake basic research for acquiring information at period 1 through a signal $\sigma \in \{h, l\}$ on the true state of the world. C^b is an expense on information collection.

The precision of the signal is defined as the probability the signal corresponds to the state. Here it is represented as an increasing and concave function $f(C^b)$ such that:

$$P(h|H, C^b) = P(l|L, C^b) = f(C^b) \text{ and } P(h|L, C^b) = P(l|H, C^b) = 1 - f(C^b)$$

and

$$f(0) = \frac{1}{2}.$$

Hence, the information precision depends on the expense on information collection C^b . If the agent does not pay for information acquisition, i.e., $C^b = 0$, then the signal is not informative.⁶ On the other hand, a larger expense implies a higher precision.

According to the Bayes' rule, the probability of being in state H given signal h and C^b , and the probability of being in state H given signal l and C^b are, respectively:

$$P(H|h, C^b) = \frac{p_0 f(C^b)}{p_0 f(C^b) + (1 - p_0)(1 - f(C^b))} \text{ and } P(H|l, C^b) = \frac{p_0(1 - f(C^b))}{p_0(1 - f(C^b)) + (1 - p_0)f(C^b)}.$$

At period 1, according to signal $\sigma \in \{l, h\}$, let us define $x_\sigma \in \{0, 1\}$ as the agent's decision to either stop, or to continue his project. We assume that when the agent stops his project $x_\sigma = 0$, while $x_\sigma = 1$ if he continues it.

At period 2, an accident might happen. If the project has been stopped at period 1, then the returns from the project are equal to zero.⁷ On the other hand, if the project

⁶We do not consider exogenous information, as equivalent to public information. Our interest is the singular initiative of an agent to acquire information and his willingness to pay for it.

⁷Without loss of generality, we consider that a stopped project does not yield revenue.

has continued until period 2, it yields a payoff equal to $R(I) \geq 0$. From this payoff must be subtracted the cost of accident $K(I, C^a) \geq 0$ that occurs with probability θ^H or θ^L depending on the state of the world. This cost is damage -a negative consequence- on human health and the environment, and thus represents an externality. This externality has been fully internalized by some market or economic instrument, which renders this externality equivalent to a private cost. In other word, the agent is strictly liable for damages, as imposed by the polluter-pays principle. We assume that R is an increasing concave function such that $R(0) = 0$. K is an increasing convex function with I , while it is a decreasing convex function with C^a , such that $K(0, C^a) = 0$. We also assume that for all $K \geq 0$, $K_{IC^a} < 0$, i.e., the marginal damage of the project, K_I , decreases when additional funds are spent to reduce damages.

We note $\beta \leq 1$ the discount rate. So the expected payoffs at period 1 and period 0 may be expressed recursively:⁸

$$V_1(x_\sigma, \sigma, I, C^b, C^a) = \beta x_\sigma [P(H|\sigma, C^b)(R(I) - \theta^H K(I, C^a)) + (1 - P(H|\sigma, C^b))(R(I) - \theta^L K(I, C^a))]$$

and

$$V_0(x_h, x_l, I, C^b, C^a) = -I - C^b - C^a + \beta (p_0 f(C^b) + (1 - p_0)(1 - f(C^b))) V_1(x_h, h, I, C^b, C^a) + \beta (p_0(1 - f(C^b)) + (1 - p_0)f(C^b)) V_1(x_l, l, I, C^b, C^a).$$

We assume that the maximization problem linked to the expected profit $V_0(x_h, x_l, I, C^b, C^a)$ is always well-defined.

2 Optimal decision-making

At period 0, the agent chooses how much he is willing to invest in the project, to pay for reducing damage and for acquiring information, knowing that at period 1, he takes decision to stop or to continue the project.

We use the backward induction method in order to characterize the agent's optimal decisions.

2.1 Stopping or continuing the project

For $\sigma \in \{h, l\}$ and $C^b \geq 0$, denote both the equilibrium strategy by x_σ^* and the revised expected probability of damage by $E(\theta|\sigma, C^b) = P(H|\sigma, C^b)\theta^H + (1 - P(H|\sigma, C^b))\theta^L$. For $\sigma \in \{h, l\}$ and for $I, C^b, C^a \geq 0$, agent continues the project if his expected payoff by continuing the project is higher than when he stops it. That is:

$$V_1(0, \sigma, I, C^b, C^a) < V_1(1, \sigma, I, C^b, C^a).$$

⁸We do not take into account to the budget constraint of the agent. We consider that the agent is able to pay for his chosen investment and its chosen expenses on information collection and in damage reduction.

Conditions under which agent stops or continues his project are: for $\sigma \in \{h, l\}$ and $I, C^b, C^a \geq 0$, if $R(I) > E(\theta|\sigma, C^b)K(I, C^a)$, then the agent continues the project, i.e., $x_\sigma^* = 1$; If $R(I) < E(\theta|\sigma, C^b)K(I, C^a)$, then he stops the project, i.e., $x_\sigma^* = 0$; Finally, if $R(I) = E(\theta|\sigma, C^b)K(I, C^a)$, then he is indifferent between stopping and continuing his project, i.e., $x_\sigma^* \in \{0, 1\}$. So the agent continues his project unless its expected cost exceeds its payoff.

We can easily verify that:

Lemma 1 *For all $C^b \geq 0$, $\theta^L \leq E(\theta|l, C^b) \leq E(\theta) \leq E(\theta|h, C^b) \leq \theta^H$, and $E(\theta|h, C^b)$ is increasing with C^b while $E(\theta|l, C^b)$ is decreasing with C^b .*

Hence, a higher expense on information collection improves the knowledge of agent on the true state of the world and emphasizes the decision of stopping project when agent receives signal h , i.e., being in the most dangerous state of the world, and the decision of continuing project when the agent receives signal l . In addition, a higher expense in damage reduction strengthens the decision of continuing project and weakens the decision of stopping it.

Moreover, according to lemma 1, agent is confronted to three strategies. First, he always stops the project whatever the signal. Actually, the agent expects that, in the two states of the world, the consequences of his project will lead him to a negative return. Second, the agent always continues the project whatever the signal. Here, the agent expects that even in the worst state of the word, his project is profitable. Finally, the agent stops the project when he receives signal h (being the most dangerous state of the world), while when he gets signal l he continues it. So the agent considers that its returns will be negative if the state H occurred and if state L occurred, it will be positive.

2.2 Project investment and expenses on information collection and in damage reduction

We now turn to agent's optimal decisions to invest in the project, to acquire information and to reduce damage. The agent chooses optimally how much he is willing to invest in the project and pay for acquiring information and for reducing damage knowing that he will either always stop the project whatever the signal, or always continue it whatever the signal, or only continue it if he receives signal l .

Define by $I_{x_h x_l}$ the agent's optimal investment in the project, $C_{x_h x_l}^b$, the agent's optimal expense on information collection, $C_{x_h x_l}^a$, the agent's optimal expense in damage reduction, under the strategy $\{x_h, x_l\}$. The agent wants to maximise its expected payoff, he then solves the following problem:

$$\max_{I, C^b, C^a \geq 0} V_0(x_h, x_l, I, C^b, C^a). \quad (1)$$

Let us first study case in which agent anticipates that he will always stop the project, i.e., $\{x_h = 0, x_l = 0\}$. Agent's expected payoff under this strategy is:

$$V_0(0, 0, I, C^b, C^a) = -I - C^b - C^a.$$

Since $V_0(0, 0, I, C^b, C^a)$ is decreasing with I , C^b and C^a , then the agent does not invest in the project and does not make any expenses on information collection and in damage reduction. Overall, the optimal decisions are $I_{00} = C_{00}^b = C_{00}^a = 0$.

So when the agent anticipates that he always stops the project in the future, he considers that the project is not profitable for him and does not want to waste money by investing in the project. He is not willing to make expenses in information collection and in damage reduction either.

Let us now study case in which agent anticipates he will always continue the project, i.e., $\{x_h = 1, x_l = 1\}$. Agent's expected payoff under this strategy is:

$$V_0(1, 1, I, C^b, C^a) = -I - C^b - C^a + \beta^2 (R(I) - E(\theta)K(I, C^a)). \quad (2)$$

Before investing the agent first checks the expected profitability of the project. If he expects that the project is not profitable, i.e., for all $I > 0$ and $C^b, C^a \geq 0$:

$$\beta^2 R(I) < I + C^b + C^a + \beta^2 E(\theta)K(I, C^a)$$

then the agent decides not to invest and not to do any expenses on information collection and in damage reduction, i.e., $I_{11} = C_{11}^b = C_{11}^a = 0$.

On the other hand, if he anticipates that the project is profitable, i.e., if there exists $I > 0$ and $C^b, C^a \geq 0$ such that:

$$\beta^2 R(I) \geq I + C^b + C^a + \beta^2 E(\theta)K(I, C^a)$$

then the agent never acquires information, i.e., $C_{11}^b = 0$, because $V_0(1, 1, I, C^b, C^a)$ is decreasing with C^b . However, he invests in the project $I_{11} > 0$, and makes an expense in damage reduction $C_{11}^a > 0$. So the agent pays for safety and quality measures without paying for the likelihood of an accident. We have assumed that the maximization problem linked to the expected profit $V_0(x_h, x_l, I, C^b, C^a)$ is always well-defined. Thus, we consider that $V_0(1, 1, I, 0, C^a)$ is concave. I_{11} and C_{11}^a are then characterized by the first order conditions:

$$\begin{cases} \beta^2 R'(I) - \beta^2 E(\theta)K_I(I, C^a) = 1; \\ \beta^2 E(\theta)K_{C^a}(I, C^a) = -1. \end{cases} \quad (3)$$

Let us turn to case in which agent anticipates to only give up the project if he receives signal h , i.e., $\{x_h = 0, x_l = 1\}$. Agent's expected payoff under this strategy is as follows:

$$V_0(0, 1, I, C^b, C^a) = -I - C^b - C^a + \beta^2 (p_0(1 - f(C^b)) (R(I) - \theta^H K(I, C^a))) + \beta^2 ((1 - p_0)f(C^b) (R(I) - \theta^L K(I, C^a))). \quad (4)$$

The agent first verifies the profitability of the project. If for all $I > 0$ and $C^b, C^a \geq 0$

$$\beta^2 (p_0(1 - f(C^b)) + (1 - p_0)f(C^b)) R(I) < I + C^b + C^a + \beta^2(p_0(1 - f(C^b))\theta^H + (1 - p_0)f(C^b)\theta^L)K(I, C^a)$$

then the agent decides not to invest and not to make any expenses on information collection and in damage reduction, i.e., $I_{01} = C_{01}^b = C_{01}^a = 0$.

On the other hand, if there exists $I > 0$ such that for all $C^b, C^a \geq 0$

$$\beta^2 (p_0(1 - f(C^b)) + (1 - p_0)f(C^b)) R(I) > I + C^b + C^a + \beta^2(p_0(1 - f(C^b))\theta^H + (1 - p_0)f(C^b)\theta^L)K(I, C^a)$$

then the agent invests in the project $I_{01} > 0$, makes an expense on information collection $C_{01}^b > 0$, and makes an expense in damage reduction $C_{01}^a > 0$. We have assumed that the maximization problem linked to the expected profit $V_0(x_h, x_l, I, C^b, C^a)$ is always well-defined. Thus, we consider that $V_0(0, 1, I, C^b, C^a)$ is concave. I_{01} , C_{01}^a and C_{01}^b are then characterized by the first order conditions:

$$\begin{cases} \beta^2 (p_0(1 - f(C^b))(R'(I) - \theta^H K_I(I, C^a)) + (1 - p_0)f(C^b)(R'(I) - \theta^L K_I(I, C^a))) = 1; \\ \beta^2(p_0(1 - f(C^b))\theta^H + (1 - p_0)f(C^b)\theta^L)K_{C^a}(I, C^a) = -1; \\ \beta^2(p_0(R(I) - \theta^H K(I, C^a)) - (1 - p_0)(R(I) - \theta^L K(I, C^a)))f'(C^b) = -1. \end{cases} \quad (5)$$

Finally, define I^* as the agent's optimal investment in the project, C^{b*} , the agent's optimal expense on information collection, and C^{a*} , the agent's optimal expense in damage reduction over all the strategies. To determine them, we compare agent's expected payoffs of the three strategies and select I , C^b and C^a that lead to the highest expected payoff. We obtain the next result.

Lemma 2 *If for $I_{01}, I_{11} > 0$ and $C_{01}^a, C_{01}^b, C_{11}^a, C_{11}^b \geq 0$,*

$$\beta^2 (p_0(1 - f(C_{01}^b)) + (1 - p_0)f(C_{01}^b)) R(I_{01}) \geq \begin{matrix} I_{01} + C_{01}^b + C_{01}^a \\ + \beta^2(p_0(1 - f(C_{01}^b))\theta^H + (1 - p_0)f(C_{01}^b)\theta^L)K(I_{01}, C_{01}^a) \end{matrix} \quad (6)$$

and

$$-I_{11} - C_{11}^b - C_{11}^a + \beta^2[R(I_{11}) - E(\theta)K(I_{11}, C_{11}^a)] \leq \begin{matrix} -I_{01} - C_{01}^b - C_{01}^a \\ + \beta^2 (p_0(1 - f(C_{01}^b)) (R(I_{01}) - \theta^H K(I_{01}, C_{01}^a))) \\ + \beta^2 ((1 - p_0)f(C_{01}^b) (R(I_{01}) - \theta^L K(I_{01}, C_{01}^a))) \end{matrix} \quad (7)$$

hold, then the agent invests $I^* = I_{01} > 0$, makes expenses $C^{b*} = C_{01}^b > 0$ for acquiring information and $C^{a*} = C_{01}^a \geq 0$ for reducing damage. Then if condition (7) does not hold and

$$I_{11} + C_{11}^b + C_{11}^a + \beta^2 E(\theta)K(I_{11}, C_{11}^a) \leq \beta^2 R(I_{11}) \quad (8)$$

holds, the agent then invests $I^* = I_{11} > 0$, makes an expense $C^{a*} = C_{11}^a \geq 0$ for reducing damage but does not make a spending for acquiring information, $C^{b*} = C_{11}^b = 0$; Finally, if conditions (6) and (8) do not hold, then the agent does not invest in the project $I^* = 0$, nor makes any expenses for acquiring information and for reducing damage, $C^{b*} = C^{a*} = 0$.

So we denote three behaviours: First, the agent decides not to invest because he anticipates that the project will not be profitable whatever the state of the world which will occur. Second, the agent decides to invest in the project and makes an expense for reducing damages by improving safety and the quality of the product. However, he refuses to make an expense on information collection, he does not decrease the uncertainty. Hence, the agent is more concerned by the potential financial cost of its project than by learning about the potential damages. Third, the agent invests in the project, makes an expense for reducing damage, and for acquiring information which allows him to withdraw the project when there exists a possibility for the worse state to be revealed. This behaviour may be considered as cautious. Indeed, the agent tries to reduce both the uncertainty on the state of the world and the consequences of a potential damages. However, through that, these actions may be judged as not acceptable for Society. Indeed, from the precautionary approach, they might be not sufficient to protect health and the environment.

3 Precautionary state regulation

In its strongest forms, the precautionary principle says that an activity should not proceed if there are potential adverse effects on human health and the environment that are not fully understood. In this form, the precautionary principle is literally paralyzing (Sunstein, 2003). However, from the 1992 Rio Declaration, a weakest version of the precautionary principle has been suggested implying that a lack of decisive evidence of harm should not be a ground for refusing to regulate. As Sunstein (2003) says the precautionary principle might be described both in terms of the level of uncertainty that triggers a regulatory response and in terms of the tool that will be chosen in the face of uncertainty (technological requirements). Regarding to this, we propose a precautionary state regulation aims for imposing a certain level of information collection and of damage cost which lead the agent to respect a certain level of risk considered as acceptable for Society. The choice of these levels determines the actual standards for health and the environment of a country.

As an example, the US Food and Drug Administration (FDA) regulation on GMO reflecting the precautionary principle shows a design of a precautionary regulatory framework. Food and feed made from GMOs can only be allowed on the market once they have received authorisation. Contrary to the EU precautionary regulation on GMOs there is no a case by case procedure. Firms producing GMOs have to demonstrate that their products are not dangerous to health and the environment. This constrains the firm to acquire certain level of information precision and to improve safety and quality of its product in order to reduce potential damage. If the firm does not respect the level of

protection imposed by the regulation, there is no delivery of authorisation of selling in US.

We then analyse the agent's behaviour with the introduction of precautionary state regulation in accordance with the precautionary principle. The government constrains agent to take all appropriate measures to avoid adverse effects of its production on human health and the environment. No respect of this regulation could justify restricted use or a ban of the agent's products. According to the court of Law and the state's policy, the level of risk considered as acceptable for Society may be specified by the legal framework in considering an acceptable cost of damage, $\bar{K} \geq 0$ and a sufficient reduction of uncertainty, i.e., a sufficient knowledge, $\underline{f} > \frac{1}{2}$.⁹

Under the precautionary state regulation, let us define $I_{x_h x_l}^R$ the agent's optimal investment in the project, $C_{x_h x_l}^{bR}$, the agent's optimal expense on information collection, $C_{x_h x_l}^{aR}$, the agent's optimal expense in damage reduction under the strategy $\{x_h, x_l\}$. $I_{x_h x_l}^R$, $C_{x_h x_l}^{bR}$ and $C_{x_h x_l}^{aR}$ maximise the agent's expected payoff under precautionary state regulation constraints:

$$\begin{cases} \max_{I \geq 0, C^b \geq 0, C^a \geq 0} V_0(x_h, x_l, I, C^b, C^a). \\ f(C^b) \geq \bar{f}, \\ K(I, C^a) \leq \bar{K}. \end{cases} \quad (9)$$

We do not consider the case in which the agent anticipates that he will always stop his project, i.e., the strategy $\{x_h = 0, x_l = 0\}$. Indeed, in this case, the agent does not undertake the project, so there is no need of regulation. We then only analyse the two other cases: the agent anticipates that he will always continue his project whatever the signal, he then maximises the expected payoff (2) under the precautionary state regulation constraints $f(C^b) \geq \bar{f}$ and $K(I, C^a) \leq \bar{K}$; And, the agent anticipates that he will only give up the project if he receives signal h , he then maximises the expected payoff (4) under the precautionary state regulation constraints $f(C^b) \geq \bar{f}$ and $K(I, C^a) \leq \bar{K}$. For each case, if the project is not profitable, i.e., for $x_h \in \{0, 1\}$ and $x_l \in \{1\}$ if for all $I > 0$ and $C^b, C^a \geq 0$, $V_0(x_h, x_l, I, C^b, C^a) < 0$, we get that $I_{x_h x_l}^R = C_{x_h x_l}^{bR} = C_{x_h x_l}^{aR} = 0$. Otherwise, if the project is profitable, I_{11}^R , C_{11}^{aR} and C_{11}^{bR} are characterized by equation (3) and the precautionary state regulation constraints $f(C^b) \geq \bar{f}$ and $K(I, C^a) \leq \bar{K}$; and I_{01}^R , C_{01}^{aR} and C_{01}^{bR} are characterized by equation (5) and the precautionary state regulation constraints $f(C^b) \geq \bar{f}$ and $K(I, C^a) \leq \bar{K}$.

Finally, define I^R as the agent's optimal investment in the project, C^{bR} , the agent's optimal expense on information collection, C^{aR} , the agent's optimal expense in damage reduction under regulation over all the cases. To determine them, we compare agent's expected payoffs of the two cases and select I , C^b and C^a that lead to the highest expected payoff. We obtain the results of lemma 2 by changing $I_{x_h x_l}$ by $I_{x_h x_l}^R$, $C_{x_h x_l}^b$ by $C_{x_h x_l}^{bR}$, $C_{x_h x_l}^a$ by $C_{x_h x_l}^{aR}$, I^* by I^R , C^{b*} by C^{bR} , and C^{a*} by C^{aR} .

⁹See Shavell (1980, 1992) and Miceli (1997) for more details.

Now we analyse the agent's decision to invest in the project. If the agent has decided not to invest in absence of regulation, in presence of regulation he will not invest. However, if it is optimal for the agent to invest in absence of regulation, it might occur that under regulation, it is not optimal anymore. Actually, under regulation the agent gets at best the same payoff than in absence of regulation. Indeed, in absence of regulation the agent chooses its first best solution. Regulation may be so constraining that the agent's payoff is negative. The project is not profitable anymore and the agent does not invest in it. **This does not support the Porter Hypothesis. However, if we only focus on the future payoff (at period 2), the precautionary state regulation may have a positive effect in the long run, in particular with a cost function strongly convex in C^a .**

Moreover, in order to respect the regulation the agent makes an expense on information collection however he may not use this information. Indeed, the agent may remain ignorant because its profit with information is lower than without information. Actually, this behaviour has already occurred by the past with for example of asbestos case. The dangerousness was already known by Greeks and Romans. In 1898, the annual reports of the Chief Inspector of Factories confirmed asbestos created health risks. However, asbestos industry refused this available information on the asbestos risks. In the Seventies, after many facts revealing the link between cancer and asbestos, the first regulation appears. The use of asbestos in new construction projects is now banned in many developed countries (Henry, 2003).

In addition, since the countries may have different regulatory environments, a pervert effect of the precautionary regulation might be to decrease innovation in the country with the most cautious regulation. Indeed, since under regulation the agent gets at best the same payoff than in absence of regulation, agent may decide to move on in another country without (or less) cautious regulation in order to reach its maximum (or a better) payoff. **This idea contradicts Porter's original writings and supports the pollution haven hypothesis (here we could call it the risk factor haven hypothesis) which says that the stringent regulation may favour the outsourcing decision.**

In this context, State might evaluate the acceptable cost of damage, $\bar{K} \geq 0$ and the sufficient reduction of uncertainty, $\underline{f} > \frac{1}{2}$ such that: if at least one country does not have any precautionary regulation, $\bar{K} = K(I^*, C^{a*})$ and $\underline{f} = f(C^{b*})$; otherwise if all States establish precautionary regulation, $\bar{K} = K(\bar{I}, \bar{C}^a)$ and $\underline{f} = f(\bar{C}^b)$ with \bar{I} , \bar{C}^a and \bar{C}^b , the investment in the project, the expenses in damage reduction and on information collection associated to \bar{V}_0 , the agent's highest expected payoff considering all the precautionary regulations of all the countries in the world, respectively. We note that $\bar{V}_0 \leq V_0(x_h, x_l, I^*, C^{b*}, C^{a*})$. However, this evaluation is not based on the level of risk acceptable by the Society, but it only depends on the innovation policy which favours a

large number of innovating firms in order to increase the growth and the employment. Precautionary state regulation favouring innovation in a country could be done to the detriment of the security. Hence, precautionary state regulation should not take into account of this evaluation.

So, how both to stimulate innovation in a country and to impose a certain level of risk considered as acceptable for Society to the agent? We then propose policy tools which reach these goals.

First, State may promote a funding for compensating the agent's expected payoff loss. We propose subsidies or allocations that the state could give to the agent to lead him both to invest in the project in the country and to respect a certain level of risk considered as acceptable for Society.

Proposition 1 (i) *If $V_0(0, 1, I_{01}^R, C_{01}^{bR}, C_{01}^{aR}) < V_0(1, 1, I_{11}^R, C_{11}^{bR}, C_{11}^{aR}) < \bar{V}_0$, State may promote a funding to lead the agent to invest in the project in the country, $\tau_1 \geq 0$, and a funding to lead him to respect a certain level of risk considered as acceptable for Society, $\tau_2 \geq 0$, such that:*

$$\begin{cases} V_0(1, 1, I_{11}^R, C_{11}^{bR}, C_{11}^{aR}) + \tau_1 = \bar{V}_0, \\ V_0(0, 1, I_{01}^R, C_{01}^{bR}, C_{01}^{aR}) + \tau_2 = V_0(1, 1, I_{11}^R, C_{11}^{bR}, C_{11}^{aR}). \end{cases}$$

(ii) *If $V_0(1, 1, I_{11}^R, C_{11}^{bR}, C_{11}^{aR}) \leq V_0(0, 1, I_{01}^R, C_{01}^{bR}, C_{01}^{aR}) < \bar{V}_0$, State may promote a funding to lead the agent to invest in the project in the country, $\tau \geq 0$ such that:*

$$V_0(0, 1, I_{01}^R, C_{01}^{bR}, C_{01}^{aR}) + \tau = \bar{V}_0.$$

Second, we propose subsidies or allocations for research that the state could give to the agent to lead him both to invest in the project in the country and to respect a certain level of risk considered as acceptable for Society.¹⁰

Proposition 2 (i) *If $V_0(0, 1, I_{01}^R, C_{01}^{bR}, C_{01}^{aR}) < V_0(1, 1, I_{11}^R, C_{11}^{bR}, C_{11}^{aR}) < \bar{V}_0$, State may promote a funding for reducing damage, and so a funding for applied research, to lead the agent to invest in the project in the country, $C_{\tau_1}^a \geq 0$, and another funding for applied research to lead him to respect a certain level of risk considered as acceptable for Society, $C_{\tau_2}^a \geq 0$, such that:*

$$\begin{cases} V_0(1, 1, I_{11}^R, C_{11}^{bR}, C_{11}^{aR} + C_{\tau_1}^a) + C_{\tau_1}^a = \bar{V}_0, \\ V_0(0, 1, I_{01}^R, C_{01}^{bR}, C_{01}^{aR} + C_{\tau_2}^a) + C_{\tau_2}^a = V_0(1, 1, I_{11}^R, C_{11}^{bR}, C_{11}^{aR}). \end{cases}$$

(ii) *If $V_0(1, 1, I_{11}^R, C_{11}^{bR}, C_{11}^{aR}) \leq V_0(0, 1, I_{01}^R, C_{01}^{bR}, C_{01}^{aR}) < \bar{V}_0$, State may promote a funding for reducing damage and for acquiring information, so a funding for applied and basic*

¹⁰Actually, we do not include a subsidy for investment because a higher investment will yield to an increase of the damage cost.

research, $C_\tau^a + C_\tau^b \geq 0$. $C_\tau^a \geq 0$ and $C_\tau^b \geq 0$ are characterized by:

$$V_0(0, 1, I_{01}^R, C_{01}^{bR} + C_\tau^b, C_{01}^{aR} + C_\tau^a) + C_\tau^b + C_\tau^a = \bar{V}_0. \quad (10)$$

State may choose the combination of (C_τ^a, C_τ^b) which verifies (10) in accordance with its R&D policy.

From propositions 1 and 2, we note that when the expected payoff under regulation is lower than the agent's highest expected payoff considering all the precautionary regulation of all the countries in the world, State may give compensation to agent in order to yield him to invest in the country. In addition, if the highest expected payoff under regulation leads the agent to pay for acquiring information but do not use this information, the security is involved. State may give a funding to the agent which incentives him to get and use the information in order to reduce its uncertainty on the project and allows him to stop it. In this context, the agent respects a certain level of risk considered as acceptable for Society.

In period of financial crisis, it might be surprising to propose subsidies. However, in Europe, there already is support to innovation with the Competitiveness and Innovation Framework Programme (CIP). The CIP have run from 2007 to 2013 with an overall budget of 3 billion of euros. A new Programme for the Competitiveness of Enterprises and Small and Medium-sized Enterprises (COSME) will run from 2014 to 2020, with a planned budget of 2.5 billion of euros. In US, the total of innovating project funding in 2008 was 89\$millions, in 2009, 146\$millions and in 2010, 46\$millions.

Moreover, there also exist funding for research program. In Europe, there is the Seventh Framework Programme for Research and Technological Development (FP7) which has a budget of around 50 billion of euros for 2007-13. In US, funding for research represent 27\$bn for basic research, 99\$bn for applied and development research in 2008, and 32\$bn for basic research, 100\$bn for applied and development research in 2009.¹¹

4 Numerical analysis

Relying on an analytical approach based on an industry which is faced with scientific uncertainty, we analyse the impact of the introduction of precautionary state regulation in accordance with the precautionary principle on the industry's behaviour.

We propose to simulate the model by specifying the information-precision function, the revenue function and the cost function. These expressions are useful for applications and numerical simulations, and also allow us to obtain more precise information on the

¹¹For more details see: http://ec.europa.eu/cip/eip/innovation/index_en.htm, Data from the science and engineering indicators 2012 (Appendix Tables, Tables 4.42 and 4.30).

optimal investment in the project, on the optimal expenses on information collection and in damage reduction in different contexts.

We assume that:

- $f(C^b) = \frac{C^b+1}{C^b+2}$;
- $R(I) = rI^\gamma$ with $r > 0$ and $0 < \gamma < 1$;
- $K(I, C^a) = I^{\kappa_1}(C^a + 1)^{\kappa_2}$ with $\kappa_1 > 1$ and $\kappa_2 < 0$.

We study the chemical industry giant, the Monsanto Company. The Monsanto Company is an American multinational, specializing in chemical and biotechnology industry. It is considered the world leader of the genetically modified organisms (GMOs). The Monsanto Company is notable for its involvement in a number of class action suits, where fines and damages have run into the hundreds of millions of dollars, usually over health and environmental issues related to its products.¹²

Actually, GMOs are characterized by uncertainty about future returns as well as monetary damages cost to human health and the environment that could occur. Environmental policies, such as the polluter-pays principle is applied to all GMOs. The Monsanto Company then has financial interest to acquire information in order to reduce uncertainty regarding dangers associated with the project and to improve safety and quality products for reducing the cost of potential damages.¹³

The evaluation of the discount rate is an important topic in investment decision theory (Kumbaroglu et al, 2008). Areas ripe for innovation, such as chemical production, are characterized by a long-term return on investment. A company like the Monsanto Company investing in this kind of project has a low preference for the present, so a discount rate close to one (here, $\beta = 0.90$). Moreover, through the class action suits, the Monsanto Company continues to invest in GMOs so, the Monsanto Company may think that the worse state of the world has a lower probability to occur, we then consider $p_0 = 0.30$ and $p_0 = 0.40$. Finally, we suggest a situation in which the probabilities of damage θ^H and θ^L are close, and another situation in which θ^H is close to one and θ^L is close to zero. Table 1 below sums up the four studied cases.

Table 2 below presents the information precision and the monetary worth of the Monsanto Company, in terms of million euros: investment in the project, expenses on information collection and in damage reduction, return on investment, profit and cost of damages for the years 2008 and 2009.

We then calculate r , γ , κ_1 and κ_2 on the basis of Table 2. Table 3 lists the corresponding values of our coefficients such that the maximization problems linked to the expected

¹²For more details on the Monsanto Company see: <http://www.monsanto.com/Pages/default.aspx>.

¹³For more details on the research and development of the Monsanto Company see: <http://www.monsanto.com/products/Pages/monsanto-science-and-research.aspx>.

Table 1: Studied cases.

	Case 1	Case 2	Case 3	Case4
β	0.90	0.90	0.90	0.90
p_0	0.30	0.30	0.40	0.40
θ_H	0.70	0.90	0.70	0.90
θ_L	0.30	0.10	0.30	0.10

Table 2: The Monsanto Company data. Source: the 2009 and the 2010 EU Industrial R&D investment scoreboard, and the science and engineering indicators 2012 (Appendix Tables, Tables 4.4, 4.5 and 4.6). The cost of damage and the information precision are evaluated by using the model and the parameters values of the studied cases.

Year	I	C^b	C^a	$R(I)$	V_0	$f(C^b)$
2008	658.09	30.32	674.72	8330.31	2107.57	0.97
2009	638.20	42.09	723.16	8182.16	2119.18	0.98

Year	$K(I, C^a)$ (case 1)	$K(I, C^a)$ (Case 2)	$K(I, C^a)$ (case 3)	$K(I, C^a)$ (Case 4)
2008	11754.63	18943.63	3614.61	9552.32
2009	10687.86	17499.66	2870.83	7832.73

profits (2) and (4) are well-defined. It also presents the optimal investment in the project, the optimal expense on information collection, the optimal expense in damage reduction and the associated profit in absence of precautionary state regulation.

Table 3: Simulated coefficients and optimal decisions in million euros in absence of regulation.

	Case 1	Case 2	Case 3	Case 4
κ_1	1.95	1.85	3.19	2.97
κ_2	-0.51	-0.32	-1.92	-1.55
r	187.42	187.42	187.42	187.42
γ	0.58	0.58	0.58	0.58
x_h	1	0	1	1
x_l	1	1	1	1
I^*	344.07	504.41	1634.63	756.07
C^{a*}	590.60	302.45	2887.92	1751.61
C^{b*}	0	67.62	0	0
$V_0(x_h, x_l, I^*, C^{b*}, C^{a*})$	2398.52	2071.59	5066.69	3455.21

In all the cases, the project is profitable and the Monsanto Company decides to invest in the project and to pay an expense in order to reduce the cost of a potential accident. Actually, as the company is made liable to pay for the damages it causes, its interest is to find a solution to reduce its financial cost. **The polluter pays principle incentives then the Company to make technological and developmental research, and so to technological change.**¹⁴ However, in cases 1, 3 and 4, the company refuses to acquire information while it acquires it in case 2. Actually, case 2 is the most uncertain case in which the company has the lowest prior belief on the realization of the worst state of the world. The company is aware that if it under-evaluates the possibility that the worst state of the world occurs, the financial consequences will be large. Hence, information in order to reduce this uncertainty is useful for it. In the other cases, either the company has the highest prior belief on the realization of the worst state of the world and so has less possibility to be surprised in case of its realization (cases 3 and 4); or the difference between the financial consequences of the two states of the world are closer (cases 1 and 3). So information has less interest in those cases for the company which prefers not paying for it ($C^{b*} = 0$).

Now, Table 4 presents the optimal investment in the project, the optimal expense on information collection, the optimal expense in damage reduction and the associated profit levels with the introduction of different precautionary state regulation.

Situations A and B considers a level of information precision, 0.97, similar to the one chosen by the Monsanto Company (see Table 1) while situations C and D are more cautious with a level of 0.99. In addition, in situations B and D, 10,000 million euros is an acceptable cost of damage. We note that the cost taken by the Monsanto Company

¹⁴See **Huergo (2006), Palmberg (2004) and Paraskevopoulou (2012) for interesting discussions on the role of technological management and the implications of regulation and policies on technological change.**

Table 4: Optimal decisions in million euros with precautionary state regulation.

		Case 1	Case 2	Case 3	Case 4
Situation A $\underline{f} = 0.97$ and $\bar{K} = 0.001$	x_h	1	-	0	1
	x_l	1	-	1	1
	I^R	0.62	0	0.86	1.39
	C_R^a	33.49	0	27.27	62.42
	C_R^b	31.34	0	31.34	31.34
	$V_0(x_h, x_l, I_R, C_R^b, C_R^a)$	49.58	0	23.01	88.92
Situation B $\underline{f} = 0.97$ and $\bar{K} = 10000$	x_h	1	0	1	1
	x_l	1	1	1	1
	I^R	344.07	381.55	750.14	756.07
	C_R^a	590.59	264.83	1411.68	1751.61
	C_R^b	31.34	57.4	31.34	31.34
	$V_0(x_h, x_l, I_R, C_R^b, C_R^a)$	2367.19	2009.46	4372.82	3423.88
Situation C $\underline{f} = 0.99$ and $\bar{K} = 0.001$	x_h	-	-	-	1
	x_l	-	-	-	1
	I^R	0	0	0	1.39
	C_R^a	0	0	0	62.42
	C_R^b	0	0	0	98
	$V_0(x_h, x_l, I_R, C_R^b, C_R^a)$	0	0	0	22.26
Situation D $\underline{f} = 0.99$ and $\bar{K} = 10000$	x_h	1	0	1	1
	x_l	1	1	1	1
	I^R	344.07	381.90	750.14	756.07
	C_R^a	590.59	266.25	1411.68	1751.61
	C_R^b	98	98	98	98
	$V_0(x_h, x_l, I_R, C_R^b, C_R^a)$	2300.52	1992.98	4306.16	3357.21

in cases 3 and 4 in Table 1, are lower than this acceptable cost of damage. However, in situations A and B, the acceptable cost of damage is more cautious, it is 1,000 euros. In those situations the Society may be qualified as more risk averse than in the two other situations. So we can say that situation C is the most cautious precautionary state regulation while situation B is the less one.

There are four important remarks.

Remark 1. *From Table 4, we note that a decrease of the level of the acceptable cost of damage decreases more the optimal level of investment in the project than an increase of the level of information precision.*

Remark 2. *From Tables 3 and 4, the optimal level of investment in the project under precautionary state regulation is always lower or equal to the one without regulation.*

Remark 3. *Precautionary state regulation may be so cautious that the company may decide not to invest. In this context, the actual standards for health and the environment restrict the innovation.*

As Sunstein (2002-2003) proposition, precautionary state regulation may stifle innovation.

Remark 4. *The company pays an expense on information collection in order to respect regulation however it may not use this information. Indeed, the company remains ignorant because its profit with information is lower than without information.*

In this context, the precautionary state regulation partially leads the company to take all recommended precautionary measures. The company may get around the goal of the precautionary state regulation to reduce the uncertainty.

Remark 5. *Except for the case in which the Company voluntary satisfies the actual standards for health and the environment, the precautionary state regulation restricts the firm's options and thus reduces its profit.*

This remark strengthens the traditional paradigm and is in contraction with the Porter Hypothesis which says that environmental regulation increases firm's profit.

So in Table 5, we calculate the subsidies defined in Propositions 1 and 2 which lead the company to invest in the project in the country and to respect a certain level of risk considered as acceptable for Society. We consider here that $\bar{V}_0 = V_0(x_h, x_l, I^*, C^{b*}, C^{a*})$, that is the highest expected payoff under precautionary regulation of all countries in the world is equal to the one without regulation. In other words, we suggest that at least one country do not apply precautionary state regulation.¹⁵

There is one important remark.

Remark 6. *State may not support the activity when the subsidy that it should give to the company is so large.*

We note that in our example, this situation occurs more often with research subsidies, i.e., subsidies for reducing damage and for acquiring information.

Besides, giving a subsidy for company as the Monsanto Company could also create

¹⁵Otherwise, we would have taken for each case an arbitrary value of \bar{V}_0 lower than $V_0(x_h, x_l, I^*, C^{b*}, C^{a*})$.

Table 5: Policy tools: subsidies in million euros.

	Subsidy	Case 1	Case 2	Case 3	Case 4
Situation A $\underline{f} = 0.97$ and $\bar{K} = 0.001$	τ_1	2348.93	-	-	3366.29
	τ_2	67.08	-	-	81.51
	τ	-	2071.59	5043.68	-
	$C_{\tau_1}^a$	$+\infty$	-	-	$+\infty$
	$C_{\tau_2}^a$	$+\infty$	-	-	$+\infty$
	C_{τ}^a	-	$+\infty$	$+\infty$	-
	C_{τ}^b	-	$+\infty$	$+\infty$	-
Situation B $\underline{f} = 0.97$ and $\bar{K} = 10000$	τ_1	31.33	-	693.87	31.33
	τ_2	754.32	-	2307.83	1391.47
	τ	-	62.13	-	-
	$C_{\tau_1}^a$	32.63	-	$+\infty$	32.06
	$C_{\tau_2}^a$	$+\infty$	-	$+\infty$	$+\infty$
	C_{τ}^a	-	109.55 (62.33)	-	-
	C_{τ}^b	-	0 (40.6)	-	-
Situation C $\underline{f} = 0.99$ and $\bar{K} = 0.001$	τ_1	-	-	-	3432.95
	τ_2	-	-	-	81.14
	τ	2398.52	2071.59	5066.69	-
	$C_{\tau_1}^a$	-	-	-	$+\infty$
	$C_{\tau_2}^a$	-	-	-	$+\infty$
	C_{τ}^a	$+\infty$	$+\infty$	$+\infty$	-
	C_{τ}^b	$+\infty$	$+\infty$	$+\infty$	-
Situation D $\underline{f} = 0.99$ and $\bar{K} = 10000$	τ_1	98	-	760.53	98
	τ_2	720.44	-	2339.90	1339.12
	τ	-	78.61	-	-
	$C_{\tau_1}^a$	111.77	-	$+\infty$	105.56
	$C_{\tau_2}^a$	$+\infty$	-	$+\infty$	$+\infty$
	C_{τ}^a	-	152.92 (105.56)	-	-
	C_{τ}^b	-	0 (100)	-	-

some arguments. This could be a delicate political and societal topic.

5 Conclusion

The most common approach to irreversible investment under uncertainty consists in determining whether the optimal decision is to invest today or to invest tomorrow (Dixit and Pindyck, 1994, Epstein, 1980, Henry, 1974). However, in the race for new technologies, the agent may not be willing to delay investing. The agent has to decide how much he should invest in these new activities today, even if not enough scientific knowledge is available about the risks for human health and the environment. To reduce this uncertainty, the agent has the option to pay for acquiring information. Indeed, spending some money today for acquiring information enables the agent to withdraw from a project if it

is considered too risky. Hence, with information the agent may revise its decision to make the project by stopping it. In addition, the agent is financially liable for the potential damages on health and the environment (Polluter pays principle). In order to reduce its potential cost, the agent may improve the quality and the safety of his product at a cost. These two actions may be considered as precautionary measures for protecting health and the environment.

However, the agent's level of these actions may be not sufficiently acceptable for Society. Precautionary state regulation has then to be required. We have found that the consequences of precautionary regulation may be harmful for the innovation. Indeed, some new activities may not be undertaken by the agent under regulation while it could have been done without regulation. Precautionary state regulation may then be paralyzing for the innovation.

Moreover, in order to respect the regulation, the agent pays for acquiring information but he may not use it and stay ignorant about the dangerousness of its project. The agent may get around the goal of the precautionary state regulation to reduce the uncertainty.

In addition, we have raised that since the countries may have different regulatory environments, a pervert effect of the precautionary regulation might be to decrease innovation in the country with the most cautious precautionary regulation.

Our work does then not verify the Porter Hypothesis. Actually, as Ambec et al (2013) suggest the impact of regulation on innovation and competitiveness depends on the type of regulation that is implemented. From empirical evidence, the Porter Hypothesis is premised on flexible market-based regulation, not rigid command-and-control regulation. Here, we have used a command-and-control regulation by imposing standards for health and the environment to the innovator. Although, our work deals with precautionary regulation for health and the environment and not about environmental regulation, ours results are in accord with the Porter Hypothesis literature.

We have then proposed some policy tools, subsidies, which could stimulate innovation in a country and impose a certain level of risk considered as acceptable for Society to the innovator.

Using an analytical approach and numerical analysis, we have showed that risk perception and the level of uncertainty influence the decision of acquiring information, and so the decision to reduce the uncertainty. The precautionary state regulation constraint on the level of acceptable cost of damage, \bar{K} , implies a higher change in the level investment in the project decision than the constraint on the level of information precision, \underline{f} . Moreover, the regulated level of investment in the project is always lower or equal to the non-regulated one.

Besides, the choice of policy tools allowing to stimulate innovation in a country and

to impose a certain level of risk considered as acceptable for Society to the innovator, has to be taken with caution. Indeed, State may not support the activity when the subsidy that it should give to the company is so large.

Furthermore, in this world crisis context, countries may be in competition for innovation. The choice of the precautionary state regulation may be decisive for attracting innovators. An aggressive competition could lead to less cautious regulation, so less safety, and large subsidies in the worst case. Currently, developed countries may subsidize research and development, and so may preserve a high safety level of its production and attract innovators. But, how developing countries may bring innovators when they cannot afford subsidy? Do they have to sacrifice their safety? Countries should probably require a same level of safety for new activities and countries should cooperate for applying the same precautionary regulation. In this regards, the cooperation would benefit to health and the environment protection, and would allow to avoid subsidies, so public spending.

Appendix

Lemma 1

Proof. We have:

$$E(\theta|l, C^b) - E(\theta) = \frac{(1-p_0)p_0(\theta^H - \theta^L)(1-2f(C^b))}{(1-p_0)f(C^b) + p_0(1-f(C^b))}$$

and

$$E(\theta) - E(\theta|h, C^b) = \frac{(1-p_0)p_0(\theta^L - \theta^H)(2f(C^b) - 1)}{p_0f(C^b) + (1-p_0)(1-f(C^b))}$$

which are negative or equal to zero because $\theta^H > \theta^L$, and for all $C^b \geq 0$ we have $f(C^b) \geq \frac{1}{2}$.

$$E(\theta|l, C^b) - \theta^L = \frac{p_0(1-f(C^b))(\theta^H - \theta^L)}{(1-p_0)f(C^b) + p_0(1-f(C^b))}$$

and

$$\theta^H - E(\theta|h, C^b) = \frac{(1-p_0)(1-f(C^b))(\theta^L - \theta^H)}{p_0f(C^b) + (1-p_0)(1-f(C^b))}$$

which are positive or equal to zero because $\theta^H > \theta^L$, and for all $C^b \geq 0$ we have $f(C^b) \geq \frac{1}{2}$.

We then differentiate $E(\theta|h, C^b)$ with respect to C^b , we obtain:

$$\frac{\partial E(\theta|h, C^b)}{\partial C^b} = \frac{(1-p_0)p_0f'(C^b)(\theta^H - \theta^L)}{[(1-p_0)(1-f(C^b)) + p_0f(C^b)]^2}$$

which is positive because f is increasing and $\theta^H > \theta^L$.

We now differentiate $E(\theta|l, C^b)$ with respect to C^b , we obtain:

$$\frac{\partial E(\theta|l, C^b)}{\partial C^b} = \frac{(1-p_0)p_0f'(C^b)((\theta^L - \theta^H))}{[p_0(1-f(C^b)) + (1-p_0)f(C^b)]^2}$$

which is negative because f is increasing and $\theta^H > \theta^L$. ■

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