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Unconventional gas: the economic theory is challenged*

Very preliminary version-First Draft

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Abstract

This article aims at proposing new ways in which economic analysis can be applied to important issues related to security of energy supply. More particularly, we show how the real options theory may be a convenient tool to analyze the uncertainties surrounding the development of unconventional gas. We lay emphasis on the main economic features related to investment in this highly sophisticated technology which may contribute to address the needs of a world increasingly hungry for energy.

Keywords: energy security, real options, shale gas

JEL Classification: D81, Q30, Q40.

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1 Introduction

In a complex and multipolar world, ensuring reliable access to sufficient quantities of energy is more than ever a priority. The challenge we face today is to provide new options for and solutions to one of the most important strategic issues, security of energy supply. Recent times have seen an increasingly complex environment for the energy industry. As stated in Figure 1, the energy sector is characterized by heterogeneous markets, by regulatory risk and also by different industrial structures. It also involves different players (governments which must understand the hurdles for large scale investments, companies which must adapt to new technical changes), fragmented regulatory regimes, various infrastructures and geologies with different skillsets, and also distinct public perceptions.

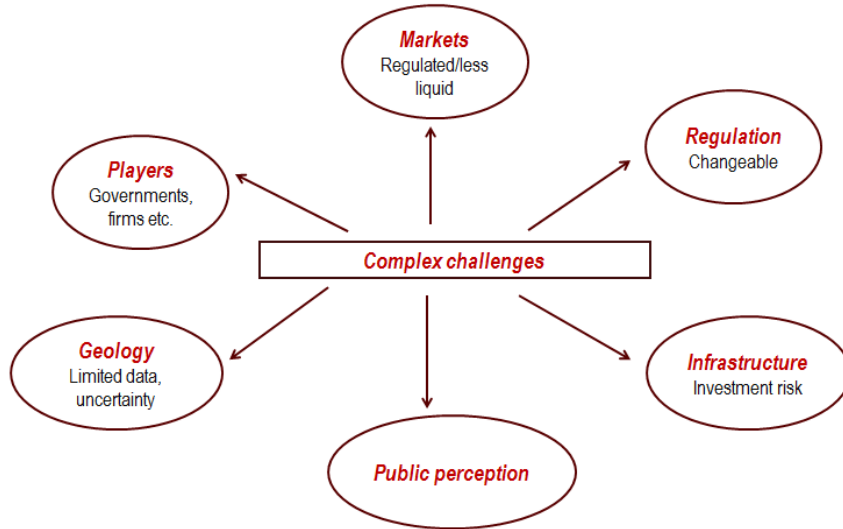


Figure 1: Main drivers in energy field

In this context, the energy security issue must be studied within a multidisciplinary framework where technical, economic and political aspects are treated together. Economic theory is increasingly applied for the decision-making process in this field. In a world where resources are limited (some much more than others) and forecasts are very difficult, it is essential to make a selection and prioritization of investment projects. In this sense, the application of economic principle is necessary, as it helps to compare the benefits of a project with the costs incurred to obtain them. Although trivial, this approach faces

important challenges like heterogeneous benefits and costs or different time horizons: some projects have known benefits, but uncertain costs, or vice versa. Investments in the energy sector provide an example of such tricky features.

Our paper investigates the applicability of the real options theory to security of energy supply, with a main focus on the highly challenging issue of the development of unconventional gas. The objective here is to show how real options provide an adequate toolbox to answer the following research question: how economic modeling may complement institutional analysis to tackle the investment decision in a context characterized by uncertainty and flexibility?

We organize the study into four sections including this introduction. In the second section, we explain the main context of the gas market with particular emphasis on the shale gas development. In the third section, we draw attention to the foundations of real options analysis and we present some important directions to be used in our modelling framework. The last section concludes the paper.

2 Energy security in Europe: the gas example

Security of energy supply requires the solution of a double challenge: diversifying energy sources while securing supply routes. To understand how this double challenge can be resolved in Europe, it is necessary to study European energy policy. In this sense, we lay emphasis in this section on security of gas supply and the main choices made in Europe.

2.1 General context

The growth of electricity demand in Europe, the environmental constraints due to the greenhouse effect and the uncertainty related to the nuclear sector make natural gas the preferred fossil fuel for electricity production in the future. Since the late 1990s, gas has become a strategic commodity to rival even oil. In a context where priority is given to the reduction of greenhouse gases, gas has a comparative advantage since it generates less CO₂ compared to other fossil fuels (coal, oil) and requires less government support

than renewables. It also has a great flexibility in its use: it can be engaged to generate electricity or increasingly in the operation of vehicles. Therefore, the gas consumption has been widely projected to grow worldwide.

According to World Energy Outlook of the International Energy Agency (IEA) from 2011, gas could contribute to the transition from a world dominated by fossil fuels to the one where the renewable sources would begin to significantly weigh in the long-term future, well beyond 2030. Still, whether natural gas will have an important role in meeting energy demand will depend on its price. In the European Union, which currently imports more than a half of its gas, international trade has been made through long-term contracts (20 to 30 years) with clauses that index gas prices to those of petroleum products (Figure 2).

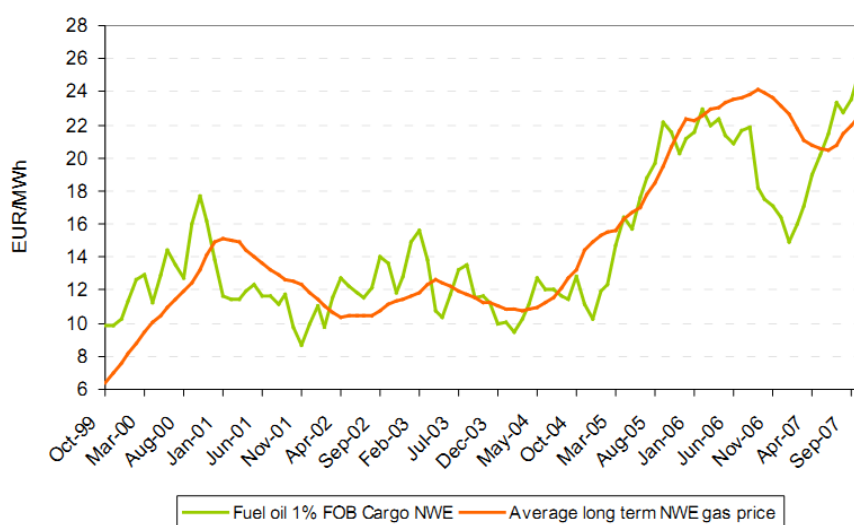


Figure 2: The gas price correlated to the petroleum products Source:

In the following figure we can observe a significant disconnection from the month of April 2009 between the market prices and the long-term prices indexed to oil.

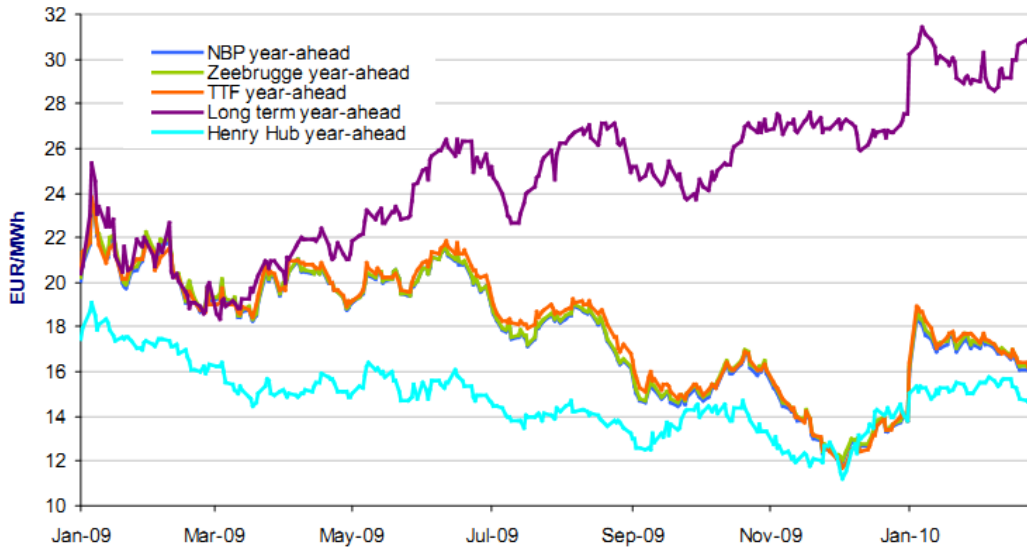


Figure 3 : Year-ahead gas prices, Source:

The explanation resides in the fact that in 2008 a number of forces converged to determine this disconnection. Given the economic crisis and the recession, gas demand felt sharply while the gas supply increased. In addition, the rapid developpement of the shale gas in United States had an important influence on the global gas market and on pricing systems.

Percebois (2011) points out that the global outlook for natural gas usage in the electricity production recently increased after the disaster at Fukushima. Some countries using nuclear power have decided to phase out the nuclear (Germany, Switzerland in particular), others have renounced to use it (including Italy), and others have decided to reduce the share in their electricity mix (Japan, Spain). In this new climat all these countries must decide what type of energy they can turn to. We know that coal is polluting, that oil is relatively expensive and polluting and that renewable energy (wind, solar photovoltaic) is expensive and requires subsidies. Given these constraints, it makes sense for many countries to turn to gas in order to generate electricity. But although gas prices remain high in Europe, in the United States prices are low because of the emergence of shale gas.

2.2 Unconventional gas: a resource for the future?

Unconventional gas¹ emerged as a promising solution for gas production in Europe in 2008, after rapid development in the United States. Nowadays, unconventional gas accounts for at least 25% of the American gas production. This makes the term "unconventional" somewhat strange².

In a recent report by the European Commission (Pearson et al., 2012) the unconventional gas is seen as a possibility to make it easier for the European Union to meet its future energy needs. This can be done by increasing domestic production or by reducing demand for gas in other parts of the world. The development of unconventional gas may also cause natural gas prices to fall. In addition, the high costs and uncertainties related to the long-distance transport may also explain why some countries from Europe are now interested in the exploitation of unconventional gas on their territories.

Even if unconventional gas is more expensive to produce than conventional gas, it has two major advantages: it may be an alternative energy to the polluting coal and nuclear energy and it helps to reduce the energy dependence of some countries. (to be completed)

However, the environmental constraints related to the utilization of this type of gas are not negligible. The extraction requires large amounts of energy and water (15000 m³ of water per well drilled). Also, the massive use of chemicals increases the risk of groundwater contamination. Related to these type of risks, the fact that population density is much higher in Europe than in the United States makes some concerns more active (the extraction places are often close to residential areas).

All these features imply that it is up to the scientists and experts in the field to debate the issue, by highlighting the risks and the benefits of the exploitation of such

¹Unconventional gas is natural gas which is extracted using additional processes beyond the standard drilling techniques. There are three categories of unconventional gas: shale gas, tight gas and coal-bed methane (Pearson et. al., 2012). The new report from the IEA on the potential "golden age" for gas (2011) mentions the discovery of significant reserves of unconventional gas. This may change the production and the energy supply in the future.

²United States possess more than one hundred years of consumption (60 Tm³ of unconventional gas and 7Tm³ of conventional gas), which is equivalent to the reserves of Russia.

deposits. However, given that we live in a world increasingly thirsty for energy and where significant technological advances are expected in the field of exploration and production, it is unlikely that unconventional hydrocarbons will be abandoned altogether.

3 Taking decisions under uncertainty

Many studies and discussions concerning the advantages and the disadvantages of unconventional gas focus on the qualitative analysis of the issue, but few studies give emphasis to a quantitative analysis from regulator's point of view. It is well known that every public policy involves some uncertainty and involves some risk taking, both at individual and at collective level. Faced with this inescapable fact, the policymaker is not totally helpless. Economic calculation may be an instrument of decision support. We show in this section how economic theory can incorporate the uncertainties, the irreversibility and the managing flexibility which may be available in the development of unconventional gas. Although we don't aim to provide a complete model of the problem, our intention here is to highlight some potential paths of how the economic theory, and especially the real options concept, can be used to evaluate investments in this field.

3.1 What type of economic analysis should be favored?

Policy makers in the energy field are faced with the task of balancing the objectives of security of energy supply with those of cost minimization and environmental preservation. All these objectives interact in the optimization problem of maximizing social welfare through the use of various policies. Consequently, the ability to adjust decision according to arrival of new information over time is essential.

When we research security of energy supply and investments in new sources of energy, we discover two specific aspects related to the issue of unconventional gas development: uncertainty and irreversibility.

Firstly, the significant uncertainties mainly refer to the evolution of energy demand, to unconventional gas resource potential outside the United States, to the cost of pro-

ducing unconventional gas (the technological progress is uncertain), to the strategies of conventional gas exporters, to the environmental risks associated to unconventional gas production or to changes in the cost of transport (we know that the unconventional gas is interesting if it is located close to markets, but what about the need to carry it over long distances). To these uncertainties one can add the uncertain potential impact on the energy mix, on energy prices or changes in the political and legal environment.

Secondly, the investment in the exploration of unconventional gas is a highly specific task that requires an enormous amount of technical and financial resources. This kind of project involves large sunk investments costs and thus, a strong degree of financial irreversibility. Moreover, some of the environmental damage resulting from unconventional gas production may also be irreversible. It will be some time before enough data has been collected to understand the risk associated with unconventional gas production.

The issue of controlling the uncertainty has given rise to a large and complex literature in the economic field. Many economists tried to tackle the problem of investment under uncertainty in a distant future, by creating different economical models which made history to this day. They tried to investigate how to represent the scientific uncertainty and how to integrate this criterion in a decision dilemma. Somehow they succeeded when they developed the benefit-cost analysis, which became over the time, one of the most applied theories on investment decision. This technique of analyzing choices has some characteristics and difficulties of economic ways of thinking that need to be reconsidered for each particular situation. When the information is uncertain or cannot be quantified, the benefit-cost analysis rapidly shows its inconsistency. On the contrary, the real options theory provides a more complete framework for project evaluation when uncertainty and irreversibility are central to the decision problem. In the following subsection we present the interplay between these two economic approaches.

3.1.1 Shortcomings of traditional tools under uncertainty

Generally, the traditional method of Discounted Cash-Flows implies the evaluation of costs and benefits over time of the possible allocations in order to choose the one whose

present value is highest. Even so, this procedure presents shortcomings: it undervalues investments under uncertainty.

When we deal with projects involving very large amounts of capital, high risks and uncertainty, we find that most of them have a negative Net Present Value during the evaluation. This traditional method cannot capture the flexibility because it focuses only on two components of value creation: discounted payoffs and investment cost. The decision is static, taken once for all, without the possibility to change the future characteristics of a project.

3.1.2 Characteristics of options perspective

In order to complement this traditional method and to take into account possible adjustments to the parameters of a project in an uncertain environment we may turn to the concept of *option value*. Deciding to invest immediately (a decision which is said to be irreversible) restricts the possibilities for action in the future. On the contrary, choosing to wait (a reversible decision) offers the opportunity to reconsider the decision later: in this way, a real option is created. In this sense, the real options theory considers the decision in a dynamic framework, meaning that it is not evaluated only on the basis of direct costs and benefits, but on all its consequences. The real options approach provides a more dynamic and proactive view of investment decision, viewed as “now or later” instead of “now or never”. The main advantage of the concept of real option comes from the fact that it overcomes the disadvantages of the traditional analysis of the investment.

Since the '80s, real options theory is a modern approach used to better analyze strategic decisions in domains with a high degree of uncertainty and a significant dimension of temporality: the natural resource exploration, the energy industry, the biodiversity, etc. At least two reasons explain the success of real option theory. On the one hand, it permits us to take into account the dynamic feature of innovation, and more generally, the accumulation of information over time (scientific, geopolitical, ...). The discount rate and distribution of future earnings are no longer the only central points of the evaluation. On the other hand, the theory comes within the scope of the theories of decision and

basically helps us to answer the following question: what is the cost to be supported today in order to preserve a wider flexibility for a future decision? This cost can involve the technical costs or constraints, but also the social constraint (it is possible to consider a "willingness to pay" for current generations).

The main contribution of the optional approach is that it recognizes from the outset that the company may adjust its investment strategy to the circumstances of the moment. The idea supporting the concept of real options is that an investment opportunity can be compared to an option: the firm making an investment acquires the option, and then retains this option until a specific date, or until an opportunity arises. Depending on whether the circumstances are favourable or not, it will exercise the option - and reap the gains - or abandon it. This "managerial flexibility" has value, and must be considered in evaluating a project. The total value of a project consists of a part of the NPV, and secondly the value of option on this project. It is therefore understandable why a project can be attractive despite the NPV negative.

The implication of uncertainty and irreversibility for projects involving potential environmental impacts was widely examined in the economic literature.

Brennan and Schwartz (1985) are the first to create a general model to generate the appropriate time to develop a project to extract natural resources. They include in the decision to change the status of the project three types of real options: the option to wait, the option of close and the option to reopen the mine. They show that precisely this option value of changing between the various states should be included in the analysis. For example, they demonstrate that a project should remain open until the point where the income plus the value of the option to reopen will equal the value of variable costs. On the contrary, a project is expected to remain closed until the point where revenue equals the variable costs plus the option of closing.

Fisher and Hanemann (1987) also study an investment project concerning the development of an environmental resource. They consider that the potential environmental costs are uncertain like other costs and returns.

Pindyck (2000) consider that there are two main uncertainties that must be treated

in a project with environmental implications: the uncertainty over the environmental evolution, i.e. ecological uncertainty and the uncertainty over the future returns, i.e., economic uncertainty. He concludes that an increase in the uncertainty of future costs and benefits of a project aiming to reduce the negative impact on the environment, may lead to an increase in the estimated threshold for adoption.

More recently, Bretschger and Smulder (2006), Lin et al. (2007) and Saltari and Travaglini (2011) refine these seminal works by taking into account the ecological uncertainty, i.e. the influence of the pollution seen as an externality on the decision-making process.

We follow this recent strand of literature and we propose in the following section a simple model which simultaneously includes the uncertainty, the irreversibility and the negative externality on the environment for an investment project of unconventional gas.

3.2 Unconventional gas: a real option example

The policy-makers in the field of unconventional gas are facing the special features mentioned above. They must learn to manage them and to adapt to them. In this sense, a number of guiding principles can help them to manage this complexity.

First of all, it is better to follow a gradual exploration process and to keep the investment options opened, in order to clearly understand the uncertainty and the potential upside. Also, learning the processes and the continuous improvement can be a key to focus on core areas and reduce unit cost and externalities.

Secondly, flexibility may be also a key issue. It is better to "keep all the options". It is advantageous to have flexible plans, to be able to make decisions today that can be reversed tomorrow, when we are in possession of new information (ie adapt quickly to technological changes or political developments). Generally, it is important to maintain some flexibility in choosing long term decisions.

Moreover, the development of the unconventional gas industry in Europe is a problem that indicates the limitations of existing regulatory instruments and the future challenges that will face policy makers. However, this is a new industry which incorporates a familiar

economic theme: the exploitation of a natural resource. Given that this activity should take place in habited areas, there is an important social aspect which must be taken into account. Because the population is much richer than before and therefore she gives more value to her environment, she is not willing to sacrifice the quality of life at any price.

In this case the regulator must choose between preserving this natural resource or starting its use. The decision must take into account the presence of environmental externalities and the social welfare of undertaking an investment in the exploration and the extraction of this type of gas. The potential damage on the environment may be important and most of all, irreversible. Generally it is not fully known before the developement of the activity. If new information may become available over time, there may be a value to wait rather than start a project with a stochastic outcome. The uncertainty regarding the externalities may be reduced with the new information revealed over time. Therefore, the question is of how much to invest and which is the optimal time to begin development of the project. Under uncertain circumstances, the flexibility to wait or to invest has an option value which is a part of the project's total value and thus it must be evaluated.

Given the fact that the developpement of unconventional gas has characteristics of a public good like the non-excludability and the non-rivalness, the appropriate context to study the problem is the policy maker's point of view. The economic models of optimal extraction and the cost-benefit analysis are appealed to tackle the decision rule. For the first type of models, the decision rule influences the rate at which exploitation should be undertaken given expectations about the demand, the price of commodity or the cost of extraction. For the letter type of models, a project is developed if the net present value of benefits exceeds the net present value of costs.

When new information arrive over time, the policy maker has the flexibility to use it and thus to choose the optimal time and amount of development. Therefore, in the following model we question about when (if ever) is optimal to invest in the shale gas development which comes with potential environmental consequences, and how much (if any) investment should be used.

3.2.1 A simple model

We propose to focus in this model on the uncertainty of environmental costs, which are seen like a negative externality. This externality must be incorporated on the decision-making function.

Let us consider an undeveloped reserve of unconventional gas which is analyzed by a social planner. If the reserve is not developed, it may have a value derived from the preservation of the local ecosystem. If the reserve is developed there may be an economic value for its use because it can supplement the overall supply of energy. But the use of this reserve entails important costs for the infrastructure and the exploitation as well as unknown environmental costs. In order to construct an exhaustive evaluation of this alternative, the latter type of costs must be taken into account. We state that this costs (environmental externalities) are stochastic given that future information regarding tastes or discoveries are revealed with the passage of time. The social planner's knowledge about the environmental externalities changes continuously. The following diffusion process describes their evolution over time:

$$dm_t = \mu(m_t + I)dt + \sigma m_t dw, \text{ for } t > \tau \quad (1)$$

The evolution of this costs depends on the amount of investement only from the starting time of the development, τ . The new information concerning changes in the environmental impact is subject to the white noise process, dw . The drift and the instantaneous standard deviation of the process are represented here by μ and σ .

Before the investment begins, the social planner waits for new information which may change the expectation that environmental impacts are too costly to justify the use of the reserve. In this period, the environmental cost depends only on the current known impact and the stochastic change:

$$dm_t = \mu m_t dt + \sigma m_t dw, \text{ for } t \leq \tau \quad (2)$$

In the following we are interested to find the optimal level for the environmental cost, m_τ for which the level and the timing of the investment in the shale gas processing facility.

The value of the reserve development is given by the private net outcome (return) less the environmental externality stemming from the deployment of the resource. We assume that these impacts on the environment begin when the project is started and continue indefinitely:

$$V(m_t) = \max_{\tau, I} E_t(v(I)e^{-\tau r} - \int_{\tau}^{\infty} m_s e^{-sr} ds) \quad (3)$$

where $v(I)$ is the net present value of the private return, I is the level of investment, r is the discount rate, m_s is the incremental externality on the environment in the period s , τ is the starting time for development.

In order to find $V(m_t)$ we first calculate the level of environmental impact for which the social planner will undertake the development of the gas reserve.

The decision to develop the shale gas reserve may be analyzed within an optimal stopping problem where τ is the optimal stopping time and m_{τ} is the boundary between the stopping and the continuation regions.

The expected value of environmental costs is given by the second term from equation (3), $E \int_{\tau}^{\infty} m_s e^{-sr} ds$. In the stopping region $s \geq \tau$, the environmental cost evolves accordingly the process stated in equation (1).

After appropriate derivations (Appendix 1), the expected value of environmental impacts is given by the following expression:

$$\begin{aligned} E\left(\int_{\tau}^{\infty} m_s e^{-sr} ds \mid \tau, I, m_{\tau}\right) &= \int_{\tau}^{\infty} e^{-sr} E(m_s \mid \tau, I, m_{\tau}) ds \\ &= e^{-r\tau} \left(\frac{\mu I}{r(r - \mu)} + \frac{m_{\tau}}{r - \mu} \right) = e^{-r\tau} f(m_{\tau}, I) \end{aligned} \quad (4)$$

The optimal threshold may be found by solving the problem from the continuation region, before the investment is started. Let us note with $F(m_{\tau})$ the value of the project at the boundary:

$$F(m_{\tau}) = v(I^*) - f(m_{\tau}, I^*) \quad (5)$$

where I^* is the optimal investment.

Then, the maximization can be rewritten in order to find the solution of the problem

in the stopping region :

$$\max_{\tau} E \left[e^{-r\tau} (v(I^*) - f(m_{\tau}, I^*)) \right] \quad (6)$$

$$\text{for } dm_t = \mu m_t dt + \sigma m_t dw, t \leq \tau$$

In the continuation region, the optimization principle of Bellman yields:

$$rV - \frac{1}{2}\sigma^2 m_t^2 V'' - \mu m_t V' = 0 \quad (7)$$

with the additional conditions which must hold at the boundary:

$$V(m_t) = F, m_t \leq m_{\tau} \quad (8)$$

where F represents the value of the project after the developement and V is the value of the opportunity to develop. The equation (8) states that the value of the developed project is at least as large as the value of waiting for more information as long as the environmental impact is smaller than the threshold, m_{τ} .

$$V'(m_t) = \frac{\partial F(I^*, m_t)}{\partial m_t}, \text{ for } m_t \leq m_{\tau} \quad (9)$$

$$-rF + \mu m_t \frac{\partial F}{\partial m_t} \leq 0, \text{ for } m_t \leq m_{\tau} \quad (10)$$

$$V > F, \text{ for } m_t > m_{\tau} \quad (11)$$

The condition (11) states that as long as environmental costs exceed some critical level, it is more profitable to wait, maintaining the opportunity to invest, V .

In the continuation region the solution has the following form:

$$V = Am_t^{\alpha} + Bm_t^{\beta} \quad (12)$$

with the following expressions for parameters α and β :

$$\begin{aligned} \alpha &= \frac{\left(\frac{1}{2}\sigma^2 - \mu\right) + \sqrt{\left(\mu - \frac{1}{2}\sigma^2\right)^2 + 2\sigma^2 r}}{\sigma^2} \\ \beta &= \frac{\left(\frac{1}{2}\sigma^2 - \mu\right) - \sqrt{\left(\mu - \frac{1}{2}\sigma^2\right)^2 + 2\sigma^2 r}}{\sigma^2} \end{aligned} \quad (13)$$

The substitution of the solution for equation (7) to conditions (8) and (9) allows us to calculate the coefficients A and B. We also state that $m_t = m_\tau$

$$\begin{aligned} A\alpha m_\tau^{\alpha-1} + B\beta m_\tau^{\beta-1} &= -\frac{\partial f}{\partial m_\tau} \\ Am_\tau^\alpha + Bm_\tau^\beta &= F \end{aligned} \quad (14)$$

Moreover, the use of Kramer rule gives:

$$\begin{aligned} A &= \frac{m_\tau \frac{\partial f}{\partial m_\tau} + \beta F}{m_\tau^\alpha (\beta - \alpha)} \\ B &= \frac{m_\tau \frac{\partial f}{\partial m_\tau} + \beta F}{m_\tau^\alpha (\alpha - \beta)} \end{aligned} \quad (15)$$

After substituting (5) for F into condition (10) and rearranging, we obtain the optimal level of environmental cost as follows:

$$m_\tau = rv(I) - \frac{\mu I}{r - \mu} \quad (16)$$

Knowing the threshold for the environmental costs we are interested to find the optimal investment level. By substituting equation (4) into the maximization function from equation (3), $V(m_t)$ becomes a function of investment, of the stopping time, and of the environmental cost when the investment is made. The solution will be given by the following program, with $r > \mu$:

$$\begin{aligned} I^* &= \arg \max E \left[e^{-r\tau} (v(I) - f(\tau, m_\tau, I)) \right] \\ dm_t &= \mu m_t dt + \sigma m_t dw, \text{ for } t \leq \tau, r > \mu \end{aligned} \quad (17)$$

The optimal time and environmental cost for undertaking the development of the reserve the optimal investment is found by differentiating (17) with respect to I and then equate to zero. With the transposable function $v(I)$, we obtain the relation for the optimal investment:

$$I^* = v'^{-1} \left(\frac{\mu}{r(r - \mu)} \right) \quad (18)$$

We observe that the socially optimal size of investment is smaller than the amount that a private firm would consider, $I^p = v'^{-1}(0)$. This is explained by the fact that generally the latter does not take into account the environmental externality.

If we differentiate equation (16) with respect to I (Appendix 2), we can study the relationship between the optimal accepted level of environmental costs and the level of investment as following:

$$\frac{dm_\tau}{dI} = rv'(I) - \frac{\mu}{r - \mu} \quad (19)$$

The substitution of (18) for $v'(I)$ involves that for $I = I^*$, m_τ reaches its maximum:

$$\frac{dm_\tau}{dI} = \begin{cases} > 0 \text{ for } I < I^* \\ = 0 \text{ for } I = I^* \\ < 0 \text{ for } I > I^* \end{cases} \quad (20)$$

The relation (20) implies that it is necessary to wait for a decrease in the environmental costs before starting the development. If $m_t < m_\tau$, waiting to invest is not justified because the incurred externality is sufficiently small and the social planner may have incentives to invest immediately. For any level of investment superior to I^* (the private optimum) may require a lower level of m_τ . A level of investment inferior to I^* will involve private benefits, but these benefits are too small to counterbalance an increase in the environmental cost.

The influence of the social time preferences on the optimal time of investment may be analyzed by differentiating m_τ with respect to r (Appendix 3) :

$$\frac{dm_\tau}{dr} = v + \frac{\mu I}{(r - \mu)^2} > 0 \quad (21)$$

If the future is less important for the society, then a greater amount of environmental costs is tolerated and a smaller amount of discounted future returns is required from the investment. If the society pays a small attention to the future environment, involving the use of a higher discount rate, there is a greater expected cost for the environmental externality.

4 Conclusion

Our paper illustrated the implications of the uncertainty, the irreversibility and the environmental externalities on the decision making process in the development of an uncon-

ventional gas reserve. We used the real options theory as a robust method to discipline the public decision-making in this specific context.

It is shown that if the environmental costs are uncertain and if the social planner is able to defer the starting time of an investment, then it is optimal to wait until an optimal level of costs related to environmental externalities before investing. The value of new information adds an economic value to the opportunity to delay the development of the gas reserve to a future date, until the environmental cost associated decreases. Moreover, because the government adds the externality to its objective function it is expected and it is shown in the model that the private optimal level of investment is higher than the socially optimal threshold. Clearly, the resource is worth less to society because the latter incurs the cost of the externality.

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