EconomiX
http://economix.u-paris10.fr/

Document de Travail
Working Paper
2010-13

# Security of supply in the European Gas Market
# A model-based analysis

Ibrahim Abada
Olivier Massol

FRE 3257

Université de Paris Ouest Nanterre La Défense
(bâtiments K et G)
200, Avenue de la République
92001 NANTERRE CEDEX

Tél et Fax : 33.(0)1.40.97.59.07
Email : secretariat-economix@u-paris10.fr

université Paris Ouest Nanterre La Défense

# Security of supply in the European Gas Market
# A model-based analysis *

ABADA Ibrahim † MASSOL Olivier ‡

**Abstract**

This paper introduces a general static Cournot-game model to study the Natural Gas market, taking into account disruption risks from suppliers. In order to most realistically describe the economical situation, our representation divides the market into two stages: the upstream market that links -by means of long-term contracts- local producers in exporting countries (Russia, Algeria, etc.) to foreign retailers who bring gas to the consuming countries to satisfy local demands in the downstream market. Thanks to short-run demand functions, we are able to introduce disruption costs to be paid to the consumers should disruption occur. First we mathematically develop our general model and write the associated KKT conditions, then we propose some case studies -under iso-elasticity assumptions- for the long-short-run inverse-demand curves in order to predict qualitatively and quantitatively the impacts of supply disruptions on Western European gas trade. In the second part, we study in detail the German gas market of the 80 to explain the supply choices of Germany, and we derive interesting conclusions and insights concerning the amounts and prices of Natural Gas brought to the market. The last part of the paper is dedicated to a study of the Bulgarian gas market, which is greatly dependant on the Russian gas supplies and hence very sensitive to interruption risks. Some thought-provoking conclusions are derived concerning the necessity to economically regulate the market, by means of gas amounts control, if the disruption probability is high enough [1].

**keywords** : security of supply, natural gas markets modelling.

## 1 Introduction

The security of energy supply is all but a new concern for energy importing countries[2]. However, this concern has clearly been rising in importance since the 1970s. It is not anticipated that this trend is going to stop as an increasing dependence on imported energy is expected in the coming decades (International Energy Agency, 2008). Among the different energy sources, natural gas clearly constitutes a particular case that attracts a lot of attention.

In this paper, though we focus explicitly on the European situation, the framework developed herein remains general and can be adapted to analyze the situation of large importing countries

*This work benefited from the support of a grant from the IFP.

†EDF Research and Development, IFP and EconomiX-CNRS, University of Paris 10 (France).

‡IFP School, IFP (France) and Deparment of Economics, City University (UK).

[1] Many people have provided helpful comments and suggestions on the analysis, and we are pleased to take this opportunity to thank them. We are especially grateful to Vincent Briat, Steve Gabriel, Pierre-André Jouvet and Jacques Percebois for helpful comments and suggestions. All remaining errors are ours. The views expressed herein are strictly those of the authors and are not to be construed as representing those of EDF or the IFP.

[2] According to Fouquet and Pearson (2006, p. 156), an early instance was observed in the UK during the 18th century. At that time, apprehension about possible supply disruptions were linked to the growing dependence of the Kingdom on imported whale oil, the - then dominant - fuel for street lighting in London.

(such as Japan, South Korea, Taiwan, China, India, to name but a few) without loss of generality. Nowadays, there are several factors at work which explain the rekindling debate on the security of gas supplies in those countries. Firstly, on the supply side: a growing reliance on imports over longer distances is observed and a significant increase in the concentration of foreign supplies is expected for some regions like Europe (Costantini et al., 2006). Secondly, speculations about the future behavior of the Gas Exporting Countries Forum (GECF) clearly refer to a possible cartelization (Massol and Tchung-Ming, 2009). Thirdly, the recent supply interruptions observed in a number of OECD regions (IEA, 2007) clearly suggest that, whatever the causes (international tensions, terrorism or technical hazards impacting unreliable infrastructures), low but positive probabilities of interruption have to be considered as likely risks. And, last but not least, natural gas plays an ever increasing role: in most OECD countries, natural gas is the fastest growing fuel in the power generation mixes. Given the rigidities of power generation in the short-run, this growing interdependence between gas and electricity also raises concerns about both the security and the reliability of electricity supplies (IEA, 2007).

Before going further, we show how the downstream part of the gas industry usually manages the possible shortfall in upstream gas. Past interruptions suggest that the durations of these episodes are usually brief. Short-run remedies have thus to be discussed. Given the dynamic features of the gas industry (e.g. the unavailability of real time metering services), we notice that an appropriate demand response cannot be timely stimulated by short-term adjustments in pricing policies (IEA, 2002). On the supply side, both a poor ressource endowment and the rigid nature of the gas supply chains strongly limit the possibility of finding efficient responses in the short-run (e.g. a significant increase in local production). Moreover, strategic stockpilling, a well-known measure implemented to increase the security of oil supplies (Nichols and Zeckhauser, 1977; Teisberg, 1981; Wright and Williams, 1982; Murphy et al., 1987; Murphy et al., 1989), is not viewed as a workable solution in the case of natural gas supplies[3] (IEA, 2007, pp. 67-83). As a result, it seems that there are not so many remedies available to deal with short-run disruptions of natural gas imports. Therefore -the shortfall in upstream gas is usually passed along to the end-user through selective interruptions. To minimize those interruptions, many importing countries in both Europe and Asia have tried to diversify their imports sources and diversification remains a priority in the gas policies of these countries.

Because of this perceived vulnerability, the security of gas supplies has inspired a huge amount of literature that can be roughly divided in two categories. The first one is by far the largest and gathers all the contributions dominated by purely geopolicy concerns[4]. The second category uses a microeconomic framework to analyze energy security. Apart some rare contributions (e.g. Manne et al. 1986; Hoel and Strøm, 1987; Markandya and Pemberton, 2010), the literature dedicated to the particular case of the gas industry is not tremendously developed. Moreover, most of these contributions clearly refer to a now outdated institutional context. Until the 1990s, the European natural gas industry was subject to government regulations and controls. In most countries, regulated state-owned or state-controlled corporations were responsible for most of the purchase, transport and sale of natural gas to the distributors[5]. As far as economic analysis is concerned, the decisions of those firms regarding supply security were elegantly captured in Manne and al. (1986) or Hoel and Strøm (1987). From an economic policy perspective, this previous organization was suspected to provide a "cosy arrangement": import contracts did not

[3]Moreover, there is still a considerable debate on the real impact of this policy on world oil prices (Considine, 2006).

[4]For example, several recent articles propose measures of energy security (Percebois, 2006; Lefèvre, 2010; Kruyt et al., 2009).

[5]In some countries (France, for example), a legal import monopoly was even granted to one particular firm.

matter because the rate-of-return regulation provided a guarantor that costs would be met and, hence, the guarantor would not be potentially stranded (Helm, 2002).

Following the UK's liberalization and privatization reforms of the late 1980 (e.g. Vickers and Yarrow, 1988; Newbery, 2000), a complete transformation of the regulatory regime started in Continental Europe in the early 2000's. Non discriminatory access provisions to the gas infrastructures (transportation, storage and LNG terminals) were introduced so as to guarantee equal opportunities to all players (IEA, 2002). As a result, competition emerged among importers, now privately-owned firms. These firms, named retailers, purchase various inputs (gas from local and foreign upstream producers, transport services and services necessary to meet fluctuations in demand) and sell gas to end-users. Customers are no longer committed to any particular supplier and, hence, any contracts out of the market are potentially exposed. This reform suggests a stimulating research agenda: does competition among gas retailers have an influence in their choices of inputs? Framed differently, it simply asks for an investigation of the ability of the current institutional arrangement to provide a suitable level of diversification.

In this paper, we provide an extension of the models developed by Manne and al. (1986) and Hoel and Strøm (1987). In these contributions, the authors studied the decisions taken by a representative central gas buyer whose objective was to maximize the expected utility of gas consumption net of the purchaser cost of buying gas. The objective functions used here explicitly takes into account possible interruptions whose occurrences are captured thanks to subjective probabilities. Both long- and short-run issues are jointly considered. The costs attached to each of these disruption states were cleverly valued thanks to short-run consumers surplus concepts while both energy purchases and consumptions under normal conditions were related to the long-run demand curve. Both papers provided a very elegant formulation but captured the essence of a now outdated institutional arrangement. Compared to these early papers, we explicitly model retailers as profit-maximizing firms engaged in a Cournot competition. Section 2 clearly presents and justifies the framework developped for analyzing their import diversification strategies. To illustrate the possibilities offered by this model, two empirical illustrations based on real cases studies are successively presented and commented in sections 3 and 4. In the former, a historical analysis of the German situation in the early 1980 is provided. In the latter, the case of South Eastern Europe is studied to analyze the possible disruptions of the Russian imports and the consequences on the importer's behavior. The last section concludes the paper.

# 2 Formulation of the problem

## 2.1 Preliminary remarks and notations

As this paper explicitly addresses the particularities of the Continental European gas industry, some definitude is needed to justify the assumptions chosen in our theoretical model. In this work, we assume a Cournot competition among the natural gas retailers of a given country and we study a hypothetical long-run equilibrium. To be more specific, the model corresponds to a static long-run equilibrium in which costs reflect a typical year.

Moreover, our analysis is focussed on long-run aspects. Thus, it seems legitimate to neglect bottlenecks in the infrastructures (transmission networks, for example). Infrastructure capacities are assumed to be both sufficient and available and there are ideal access provisions to the infrastructures so that all infrastructure-related services are offered at regulated and uniform rates which reflect total long-run unit costs, i.e. the owners of the facilities obtain a normal rate of return. Thus, these infrastructure costs correspond to constant return to scale technologies that are common to all retailers. As the infrastructure related issues play no strategic role in the Cournot competition at hand, these infrastructure marginal costs are simply normalized to zero in order to keep the model as simple as possible. Thus, the retailer's costs can be summarized as the total cost of the natural gas purchased from the different upstream producers.

We will use these notations:

| | |
|---|---|
| $i$ | index for retail firms in the country under study, |
| $I$ | the set of active retailers in the country under study, |
| $j$ | index for upstream gas producers, |
| $J$ | the set of upstream gas producers. |

Here- we assume that all possible supply disruptions states can be enumerated and we simply note $\Omega$ the (finite) set of all these random events named $\omega$. For simplicity, the particular state $\omega$ of no-disruption is named 0. Whatever the disruption state $\omega$, its occurrence can be appraised thanks to a subjective probability $\theta(\omega)$. Obviously, we have $\sum_{\omega\in\Omega}\theta(\omega) = 1$. We also assume that a consensus exists in the country on both the definition of the discrete set $\Omega$ and on the value of the probability of all the different events. Thus, those probabilities constitute common knowledge for the retailers. This assumption seems reasonable as a consensus is generally observed in most importing countries regarding the disruptive nature of the various importing schemes. From a practical perspective, applied procedures like the one presented in Bunn and Mustafaoglu (1978) can be used to evaluate those subjective probabilities.

We now have to exact how a retailer $i \in I$ acquires its gas. We assume that there are no wholesale markets and the volumes purchased are supposedly entirely obtained thanks to pre-existing bilateral contracts. At first sight, this assumption might look surprising since the pro-competitive move of the early 2000's was expected to be accompanied by the rapid development of wholesale spot markets in Continental Europe (IEA, 2002). But, this emergence has been far slower than expected and long-term bilateral arrangement are still dominant. The need for a transition period to phase out pre-existing oil products indexed long-term contracts is not a sufficient ground to explain the continuing pre-eminence of these long-term contracts and industrial observations suggest that retailers are still ready to engage in long-term bilateral trade. Despite early barriers to entry concerns that motivated an in-depth sectoral analysis by the European Commission (DG COMP, 2007), those long-term arrangements are now fully admitted by the European authorities and all juridicial actions against long-term contracts have been withdrawn[6].

The upstream side of the industry is not modeled in this study. Our assumptions are based on the results of the sectoral enquiry led by the European Commission (DG COMP, 2007). Firstly, we assume that the upstream prices of natural gas are set exogeneously[7]. Secondly, gas prices may differ across sources $j \in J$ as evidence suggests that price indexation formulas used in long-term contracts can differ from one producer to another (DG COMP, 2007, p. 103, Fig. 32). Thirdly, the European Commission noted that price indexation formulas are quite homogeneous among buyers located in a given region: either the UK, Western or Eastern Europe (DG COMP, 2007, p. 104, Fig. 33). Thus, we assume no-discriminatory pricing: the price of a given source $j \in J$ is unique and proposed to all the potential buyers $i \in I$. Lastly, this enquiry clarifies the

[6]In fact, the conclusions of this sectoral analysis were published just after the first Russo-Ukrainian dispute. Thus, they emphasize the capability of long-term contracts to provide a workable solution to the well-known "hold up" problem caused by ex post opportunism on the supply side.

[7]A complete discussion on the fixation of this contractual price can be found in the stimulating collection of papers presented in Golombek et al. (1987).

price provisions used in these bilateral long-term arrangements. In these contracts, the price of gas is settled thanks to predetermined indexation formulas that establish a direct linkage with the wholesale spot price of oil products. Given the limited short-run interactions among gas and oil products, we can assume that a disruption of gas supplies has no impact on oil products prices and hence on gas prices. Moreover, oil products price uncertainty is not modeled here. Thus, upstream prices are assumed to be constant across all the possible disruption states. In sum, upstream prices can be viewed as an exogeneously determined vector of prices $(p_j)_{j \in J}$, where each component corresponds to the price $p_j$ proposed by the producer $j$.

The amount of gas purchased by the retailers $i$ from the producer $j$ is named $x_{ij}^0$. This quantity corresponds to the volume of gas supplied by $j$ to $i$ under a no-disruption state. For a retailer, this quantity can clearly be considered as a decision variable.

Under a given disruption state $\omega \in \Omega$, the subgroup of producers whose supplies are disrupted is named $S_\omega$. The quantity of gas delivered to a retailer $i$ by a gas producer $j$ under a particular disruption state $\omega \in \Omega$ is equal to $x_{ij}^\omega = (1 - \delta_{S_\omega}(j))x_{ij}^0$ where $\delta_{S_\omega}(j)$ takes the value 1 if the gas producer $j$ belongs to the collection of disrupted producers $S_\omega$ and 0 otherwise. We observe here that the disruption state index $\delta_{S_\omega}(j)$ attached to the producer $j$ does not depend on $i$ which means that, a disruption from this producer corresponds to a total disruption of all the volumes purchased by the different retailers. Stated differently, this means that there is no discrimination among retailers: if a producer decides to cut its supplies and stop deliveries to an infrastructure then those supplies are simultaneously cut for all the retailers.

To simplify, the total amount of gas purchased and consumed under a given disruption state $\omega \in \Omega$ is named $x^\omega = \sum_{(i,j) \in I \times J} x_{ij}^\omega$. In particular, $x^0$ is the total volume of gas purchased under a no-disruption state. Similarly, we note $x_i^\omega = \sum_{j \in J} x_{ij}^\omega$ the total amount of gas purchased by a given retailers under the sate $\omega$.

Added to that, two inverse demand functions are needed. The first one, $f(k)$ is the long-run willingness to pay for the gas where $f$ is twice differentiable and $f'(k) < 0$. The second one, $g(k, q)$ is the short-run willingness to pay for quantity $q$, parametrically depending on the long-run consumption $k$. We assume that $g(k, q)$ is twice differentiable with $\partial g / \partial k > 0$ and $g(k, k) = f(k)$, $(\forall k \in \mathbb{R}^{+*})$.

## 2.2 A formal representation of disruption costs

In this paper, we assume that gas retailers only sign firm supply contracts with their customers. Moreover, we assume that the retail price of gas cannot be adjusted in the case of a sudden short-run disruption of gas supply (cf. the previous presentation of the rigidities of the natural gas industry). As a consequence, consumers are rightly supposed to make decisions based on the firmness nature of $x^0$, the total amount of gas consumed under a no-disruption state. Should there be an interruption in deliveries, we assume that a retailer is required to make compensation payments to its disrupted customers (for example with claims). As we are dealing with brief events, the compensations have to take into consideration the limited responsiveness of the short-run demand. Thus, the corresponding consumer's unease can be approximated thanks to the short-run inverse demand function. For a disruption state $\omega$, the total disrupted quantity is $x^0 - x^\omega$ and the corresponding consumers' surplus variation is equal to: $\int_{x^\omega}^{x^0} g(x^0, t)dt$.

Of course- retailers are free to decide their upstream supply mixes. The composition of the input mix may thus vary from one retailer to another. In case of a disruption, requiring the virtuous retailers to pay for the consequences of risky choices made by others would obviously create an incentive to choose the lowest cost - higher risk choice of input. Such a mechanism is both unjustifiable and unfair. For each disruption case, each retailer's payment to consumers is thus assumed to be set in proportion to its own responsibility in the total disruption. Framed with algebra, it means that under a disruption state $\omega \in \Omega\backslash\{0\}$, a given retailer $i$ incurs a positive disruption cost $DC_i(x^0, \omega)$ equal to the payment required to its disrupted consumers:

$$DC_i(x^0, \omega) = \frac{\sum\limits_{j \in J}(x_{ij}^0 - x_{ij}^\omega)}{x^0 - x^\omega} \int_{x^\omega}^{x^0} g(x^0, t)dt.$$

Besides, we assume that a retailer is not required to pay the producers involved in $S_\omega$ for the disrupted volumes of gas observed under a state $\omega \in \Omega\backslash\{0\}$. Under that particular state, retailer $i$'s profits are thus equal to the profits earned under the no-disruption state named 0, minus the disruption costs $DC_i(x^0, \omega)$ plus $\sum\limits_{j \in S_\omega} p_j x_{ij}^0$.

### 2.3 The model

This section presents the agents' objectives.

**Consumer**: here, end-user's decisions are solely based on the retail price of gas named $P^\star$. We assume that gas end-users strive to maximize the value received from consumption minus the payments to retailers, assuming they cannot affect $P^\star$. Besides, they do not take into account the propensities of possible sudden disruptions. This assumption seems consistent with the industrial reality since most end-users completely ignore the details of the supply mix decided by the retailers and know almost nothing about the origin of the natural gas they are burning. As a result, their decisions cannot consider these disruption states. This behavior is thus represented by:

$$\begin{array}{lll} CONS(P^\star): & \underset{\{k\}}{Max} & \int_0^k f(t)dt - P^\star k \\ & \text{s.t.} & k \geq 0 \end{array}$$

If the problem has an interior solution it is characterized with levels of consumption $k$ by: $f(k) = P^\star$.

**Gas retailer**: here, we model the behavior of a risk neutral firm. Its optimization problem is to choose a purchase policy $(x_{ij}^0)_{j \in J}$ under a no-disruption state so as to maximize its expected profit across all possible disruption states:

$RETAILER_i$:

$$\begin{array}{ll} \underset{\{x_{ij}^0, j \in J\}}{Max} & \bar{\Pi}_i(x_{ij}^0, (x_{lj}^0)_{l \neq i}) = \sum\limits_{j \in J} \left(f(x^0) - p_j\right) x_{ij}^0 - \sum\limits_{\omega \in \Omega\backslash\{0\}} \theta(\omega) \left( DC_i(x^0, \omega) - \sum\limits_{j \in S_\omega} p_j x_{ij}^0 \right) \\ \text{s.t.} & x_{ij}^0 \geq 0 \quad (\forall j \in J) \end{array}$$

If the problem has an interior solution, the associated KKT is:

For $x_{ik}^0$: $\quad 0 \leq x_{ik}^0 \quad \perp \quad \frac{\partial \bar{\Pi}_i}{\partial x_{ik}^0}(x_i^0) \leq 0$

To simplify, the retailer's $i$ expected profits can hence be rewritten as follows: $\bar{\Pi}_i(x_i^0) = A+B+C$ where:

$$
\begin{aligned}
A &= \sum_{j \in J} \left( f(x^0) - p_j \right) x_{ij}^0 \\
B &= - \sum_{\omega \in \Omega \backslash \{0\}} \theta(\omega) DC_i(x^0, \omega) \\
C &= \sum_{\omega \in \Omega \backslash \{0\}} \theta(\omega) \sum_{j \in J} p_j x_{ij}^0 \delta_{S_\omega}(j)
\end{aligned}
$$

Let's calculate the partial derivative of $\bar{\Pi}_i$ with respect to the decision variable $x_{ik}^0$. This derivative is the sum of three terms: $\frac{\partial A}{\partial x_{ik}^0}, \frac{\partial B}{\partial x_{ik}^0}$ and $\frac{\partial C}{\partial x_{ik}^0}$ with:

$$
\begin{aligned}
\frac{\partial A}{\partial x_{ik}^0} &= f'(x^0) \sum_{j \in J} x_{ij}^0 + f(x^0) - p_k \\
\frac{\partial C}{\partial x_{ik}^0} &= p_k \sum_{\{\omega \in \Omega \backslash \{0\}, k \in S_\omega\}} \theta(\omega)
\end{aligned}
$$

The partial derivative of $B$ with respect to $x_{ik}^0$, is a little bit more subtle to calculate. In fact, the collection of events $\omega$ has to be separated in two subsets depending on whether the particular producer $k$ cuts its supplies under the state $\omega$ or not. Framed with algebra, we can write:

$$
\frac{\partial B}{\partial x_{ik}^0} = - \sum_{\{\omega \in \Omega \backslash \{0\}, k \notin S_\omega\}} \theta(\omega) \frac{\partial DC_i(x^0, \omega)}{\partial x_{ik}^0} - \sum_{\{\omega \in \Omega \backslash \{0\}, k \in S_\omega\}} \theta(\omega) \frac{\partial DC_i(x^0, \omega)}{\partial x_{ik}^0}
$$

This distinction among the two cases is important since the partial derivative of $DC_i(x^0, \omega)$ with respect to $x_{ik}^0$ takes a different litteral expression in the two cases. If under a given state $\omega \in \Omega \backslash \{0\}$, the particular producer $k$ cuts its supplies (i.e. $k \in S_\omega$), then the amount $x_{ik}^0$ is both present in the overall disrupted volumes $(x^0 - x^\omega)$ as well as in $i$'s disrupted purchases $\sum_{j \in J}(x_{ij}^0 - x_{ij}^\omega)$. In the other case (when $k$ does not cut its production), both the overall disrupted quantities $(x^0 - x^\omega)$ and $\sum_{j \in J}(x_{ij}^0 - x_{ij}^\omega)$ become independent of the variable $x_{ik}^0$. Moreover, in the latter case, the integral boundaries can be manipulated so as to avoid any dependence on $x_{ik}^0$.

If $k \in S_\omega$, $\frac{\partial DC_i(x^0, \omega)}{\partial x_{ik}^0} =$

$$
\frac{\sum_{\substack{(l,j) \in I \times J \\ l \neq i}} \left( x_{lj}^0 - x_{lj}^\omega \right)}{(x^0 - x^\omega)^2} \int_{x^\omega}^{x^0} g(x^0, t) dt + \frac{\sum_{j \in J} (x_{ij}^0 - x_{ij}^\omega)}{x^0 - x^\omega} \left( \int_{x^\omega}^{x^0} \frac{\partial g}{\partial k}(x^0, t) dt + f(x^0) \right).
$$

Whereas if $k \notin S_\omega$, we have a simpler expression:

$$
\frac{\partial DC_i(x^0, \omega)}{\partial x_{ik}^0} = \frac{\sum_{j \in J} (x_{ij}^0 - x_{ij}^\omega)}{x^0 - x^\omega} \left( \int_{x^\omega - x^0}^{0} \frac{\partial g}{\partial k}(x^0, t + x^0) dt \right).
$$

## 3 Some illustrations based on an iso-elasticity assumption

The framework at hand seems suitable to capture the key elements of some of the situations observed in the European natural gas industry. To illustrate this capability, it is worthwhile to choose a particular functional form for the long- and short-term inverse demands. In this section, we present some illustrations based on an iso-elasticity assumption for both the short-run and the long-run inverse demand functions. The long-run (respectively short-run) price elasticity is named $\epsilon_0$ (respectively $\epsilon_1$).

### 3.1 The model at hand

Here we suppose that $f(x) = ax^{-\frac{1}{\epsilon_0}}$ where $a$ is a constant parameter and $g(x,t) = ax^{\frac{1}{\epsilon}}t^{-\frac{1}{\epsilon_1}}$ where $\epsilon$ is a parameter defined so that

$$\forall x \in \mathbb{R} \quad g(x,x) = f(x)$$

Thus, we have

$$\frac{1}{\epsilon} = \frac{1}{\epsilon_1} - \frac{1}{\epsilon_0}$$

We also assume that the long-run inverse demand is more elastic than the short-run one, i.e. $\epsilon_0 > \epsilon_1$.

After some algebraic developments, we derive the KKT conditions for each retailer $i$:

$$\forall k \in J, \quad 0 \leq x^0_{ik} \perp (\alpha + \beta + \gamma + \eta) \leq 0$$

where

$$\alpha = x^0 - \frac{1}{\epsilon_0} x^0_i$$

$$\beta = -p_k \left(1 - \Theta(k)\right) \frac{x^{0\left(1+\frac{1}{\epsilon_0}\right)}}{a}$$

$$\begin{aligned}
\gamma = \quad & -x^{0\left(\frac{1}{\epsilon_1}\right)} \tfrac{\epsilon_1}{\epsilon_1 - 1} \tfrac{1}{\epsilon} \sum_{\omega \in \Omega} \theta(\omega) \frac{x^0_i - x^\omega_i}{x^0 - x^\omega} \left( x^{0\left(-\frac{1}{\epsilon_1}+1\right)} - x^{\omega\left(-\frac{1}{\epsilon_1}+1\right)} \right) \\
& -x^{0\left(\frac{1}{\epsilon_1}+1\right)} \sum_{\omega \in \Omega \setminus k \notin S_\omega} \theta(\omega) \frac{x^0_i - x^\omega_i}{x^0 - x^\omega} \left( x^{0\left(-\frac{1}{\epsilon_1}\right)} - x^{\omega\left(-\frac{1}{\epsilon_1}\right)} \right) \\
\eta = \quad & -x^{0\left(\frac{1}{\epsilon_1}+1\right)} \tfrac{\epsilon_1}{\epsilon_1 - 1} \sum_{\omega \in \Omega \setminus k \in S_\omega} \theta(\omega) \frac{(x^0 - x^\omega) - (x^0_i - x^\omega_i)}{(x^0 - x^\omega)^2} \left( x^{0\left(-\frac{1}{\epsilon_1}+1\right)} - x^{\omega\left(-\frac{1}{\epsilon_1}+1\right)} \right) \\
& -x_0 \sum_{\omega \in \Omega \setminus k \in S_\omega} \theta(\omega) \frac{x^0_i - x^\omega_i}{x^0 - x^\omega}.
\end{aligned}$$

Here, $\Theta(k)$ is simply $\sum_{\{\omega \in \Omega, k \in S_\omega\}} \theta(\omega)$, the overall probability that producer $k$ cuts its supplies.

This setting allows us to study some interesting situations observed in the European natural gas industry. The coming subsections present some of these simple case studies.

### 3.2 Example 1: The German situation

Hoel and Strøm (1987) were the first to analyze the diversification issue in Continental Europe before the liberalization reforms described earlier. But even if we limit ourselves to the situation observed during the mid-1980, there could be some doubt of the ability of this model to fully represent the situation observed in the Federal Republic of Germany (FRG) - the largest gas importing country in Europe at that time. In Hoel and Strøm (1987), a representative gas buyer decides jointly its purchase of gas and its long-run capacity level so as to maximize the expected utility of gas consumption net of the purchaser cost of buying gas. Such an argument seemed reasonnable for countries where price regulation consciously limited the profitability of monopoly importers. And it was the case for Distrigaz in Belgium or Gaz de France (Radetzki,1992, p.99). But in the FRG, Ruhrgas AG - a privately-owned firm - was not explicitly regulated and earned comfortable profits[8]. As mentioned above, these early models posited a quasi-virtuous behavior for the importer; an assumption that hardly captures Ruhrgas's past behavior[9]. A profit-maximizing behavior looks more appropriate to model Ruhrgas at that time.

In the following, we study the decisions made by Ruhrgas in the early-1970 regarding future imports planned for the 1980. At that time, Rurhgas knew that the small volumes of natural gas produced in the FRG and the much larger volumes of gas imported from the Netherlands would be unsufficient to serve the future demand. Those volumes had already been purchased under pre-existing long-term bilateral aggreements and were considered as both known and fixed in the coming decade. Thus, imports from two ressource-rich countries - Norway and the USSR - had to be considered to serve this future demand. Here, we assume perfect foresight and apply the previous model to analyze Ruhrgas's decision. Ruhrgas's objective was to select its import policy so as to maximize its expected profit for a typical year in the 1980.

We assume that there is only one large retailer, $I = \{1\}$. For simplicity, the index $i = 1$ is dropped in the following formulas. The volumes coming from either the Netherlands or the local FRG production are assumed to be kept constant whatever the circumstances and are simply named $l$. The supplies from these two sources located within the EEC were perceived as secure. Both are thus characterized by a zero probability of a disruption. Hence, the Ruhrgas decision can be simplified as choosing the imported volumes $(x_j)_{j\in J}$ from a set of two sources $J = \{1, 2\}$ where Norway is indexed 1 and the USSR is indexed 2. We assume that both for Norway and the USSR, there is a non-negligible risk of disruptive behavior. We denote by $\theta_1$ (respectively $\theta_2$) the disruption probability of Norway (respectively the USSR) and $p_1$, $p_2$ the prices charged by these producers. For Ruhrgas, the optimization problem is:

$$\begin{array}{ll} \text{Max} & \bar{\Pi}(x_1, x_2) \\ \text{s.t.} & x_1 \geq 0 \quad x_2 \geq 0 \end{array}$$

where

[8] Ruhrgas returned a net profit of between 16% and 19% of its own capital between 1984 and 1988. Those profit levels were particularly comfortable compared to those exhibited by both Distrigas and Gaz de France (Radetzki, 1992, p.99).

[9] Ruhrgas's prices were so high at that time that BASF - the largest gas user in Germany - decided to actively search alternative supplies to bypass the monopoly. This situation led BASF to create an alternative gas retailer, Wingas (established as a joint-venture with the Russian Gazprom), and led them to play a major role in the construction of an import infrastructure between Russia and Germany (Victor and Victor, 2006).

$$
\begin{aligned}
\bar{\Pi}(x_1,x_2) = \quad & f(x_0+l)(x_0+l) - p_1x_1 - p_2x_2 - \theta_1(1-\theta_2)\int_{x_2+l}^{x_0+l} g(x_0,t)dt \\
& -\theta_2(1-\theta_1)\int_{x_1+l}^{x_0+l} g(x_0,t)dt - \theta_1\theta_2\int_{l}^{x_0+l} g(x_0,t)dt \\
& +\theta_1(1-\theta_2)p_1x_1 + \theta_2(1-\theta_1)p_2x_2 + \theta_1\theta_2(p_1x_1+p_2x_2)
\end{aligned}
$$

$x_1$ (resp. $x_2$) is the quantity bought by the retailer from Norway (resp. the USSR) and $x_0 = x_1 + x_2$. The local production costs are assumed to be well-known. Hence, the variable $l$ is not a decision variable. In the iso-elasticity context, we can calculate easily $\Pi(x_1, x_2)$.

$$
\begin{aligned}
\bar{\Pi}(x_1,x_2) = \quad & \mu(x_0+l)^{-\frac{1}{\epsilon_0}+1} \\
& +\nu(x_0+l)^{\frac{1}{\epsilon}}\left(\theta_1(1-\theta_2)(x_2+l)^{-\frac{1}{\epsilon_1}+1} + \theta_2(1-\theta_1)(x_1+l)^{-\frac{1}{\epsilon_1}+1} + \theta_1\theta_2 l^{-\frac{1}{\epsilon_1}+1}\right) \\
& -(1-\theta_1)p_1x_1 - (1-\theta_2)p_2x_2
\end{aligned} \tag{1}
$$

where

$$
\mu = a\left(1 - (\theta_1+\theta_2-\theta_1\theta_2)\frac{\epsilon_1}{\epsilon_1-1}\right)
$$

$$
\nu = a\frac{\epsilon_1}{\epsilon_1-1}.
$$

We can demonstrate that the profit is a concave function of the variables $x_1$ and $x_2$. **Hence the existence and uniqueness of the solution is guaranteed.**
The profit's gradient depends on the variables as follows:

$$
\begin{aligned}
\frac{\partial\bar{\Pi}}{\partial x_1}(x_1,x_2) = \quad & \left(1-\frac{1}{\epsilon_0}\right)\mu(x_0+l)^{-\frac{1}{\epsilon_0}} \\
& +\frac{\nu}{\epsilon}(x_0+l)^{\frac{1}{\epsilon}-1}\left(\theta_1(1-\theta_2)(x_2+l)^{-\frac{1}{\epsilon_1}+1} + \theta_2(1-\theta_1)(x_1+l)^{-\frac{1}{\epsilon_1}+1} + \theta_1\theta_2 l^{-\frac{1}{\epsilon_1}+1}\right) \\
& +\nu(x_0+l)^{\frac{1}{\epsilon}}\left(1-\frac{1}{\epsilon_1}\right)\theta_2(1-\theta_1)(x_1+l)^{-\frac{1}{\epsilon_1}} - (1-\theta_1)p_1 \\
\frac{\partial\bar{\Pi}}{\partial x_2}(x_1,x_2) = \quad & \left(1-\frac{1}{\epsilon_0}\right)\mu(x_0+l)^{-\frac{1}{\epsilon_0}} \\
& +\frac{\nu}{\epsilon}(x_0+l)^{\frac{1}{\epsilon}-1}\left(\theta_1(1-\theta_2)(x_2+l)^{-\frac{1}{\epsilon_1}+1} + \theta_2(1-\theta_1)(x_1+l)^{-\frac{1}{\epsilon_1}+1} + \theta_1\theta_2 l^{-\frac{1}{\epsilon_1}+1}\right) \\
& +\nu(x_0+l)^{\frac{1}{\epsilon}}\left(1-\frac{1}{\epsilon_1}\right)\theta_1(1-\theta_2)(x_2+l)^{-\frac{1}{\epsilon_1}} - (1-\theta_2)p_2.
\end{aligned}
$$

We cannot find simple analytical expressions of the optimal imports $x_1$ and $x_2$ to guarantee a maximum benefit for the German company. Hence, we have to use numerical means to solve our two dimensional problem. Let's assume for instance that $\theta_1 = 0$, which is to say that the Norwegian supply is secure and $\theta_2 > 0$. We can derive in this situation simple conditions that ensure the equilibrium gas amount to be $x_1^{eq} > 0$ and $x_2^{eq} = 0$. In that situation, using the KKT theorem, we can derive that:

$$
\begin{aligned}
&(x_0+l)^{eq} = (x_1+l)^{eq} \\
&\frac{\partial\bar{\Pi}}{\partial x_1}(x_1^{eq}, x_2^{eq}) = 0 \\
&\frac{\partial\bar{\Pi}}{\partial x_2}(x_1^{eq}, x_2^{eq}) \leq 0.
\end{aligned}
$$

Hence, we can calculate $x_1^{eq}$ and find conditions on the parameters $\theta_2$, $p_1$ and $p_2$ so that $x_2^{eq} = 0$:

$$x_1^{eq} + l = \left(\frac{p_1}{a\left(1-\frac{1}{\epsilon_0}\right)}\right)^{-\epsilon_0}$$
$$l \leq \left(\frac{p_1}{a\left(1-\frac{1}{\epsilon_0}\right)}\right)^{-\epsilon_0}$$
$$(1-\theta_2)\left(p_1 - p_2\left(1-\frac{1}{\epsilon_0}\right)\right) \leq \frac{p_1}{\epsilon_0}$$

Therefore, if the Norwegian supply is assumed to be secure and the local demand such as $l \leq \left(\frac{p_1}{a\left(1-\frac{1}{\epsilon_0}\right)}\right)^{-\epsilon_0}$, no Soviet gas is to be brought to FRG if (and only if)

$p_2 > \frac{p_1}{1-\frac{1}{\epsilon_0}}$ the Soviet Gas is too expensive or

$p_2 \leq \frac{p_1}{1-\frac{1}{\epsilon_0}}$ and $\theta_2 > \theta_2^{lim} = 1 - \frac{p_1}{\epsilon_0\left(p_1 - p_2\left(1-\frac{1}{\epsilon_0}\right)\right)}$ the Soviet supply is too risky.

We can now run some numerical simulations for a given set of values for the problem's parameters. Here, the following values were used: $\epsilon_0 = 1.2$, $\epsilon_1 = 0.3$, $a = 10$ and $l = 0.04$ in arbitrary units. The values of the long- and short-run elasticities are those used in Manne et al. (1986).
Figure 1 gives the evolution of $\theta_2^{lim}$ over the Norwegian gas price $p_1$ for $p_2 = 5$ in arbitrary units. This function increases with the price $p_1$, for it may become interesting to buy risky gas if the secure one becomes very expensive.

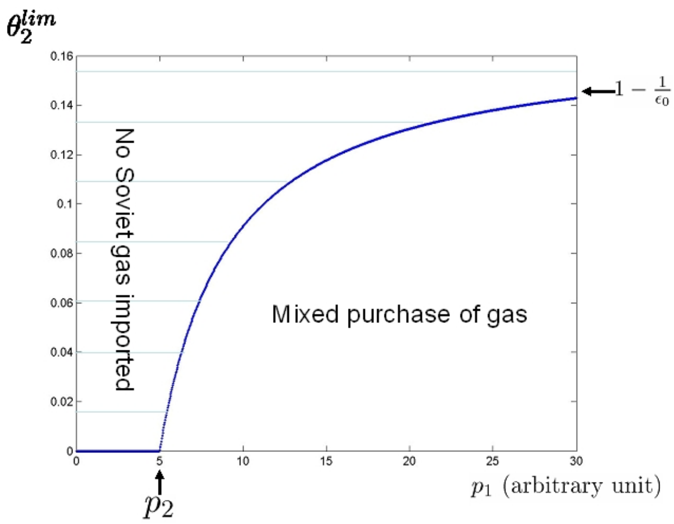


Figure 1:
*Evolution of $\theta_2^{lim}$ over $p_1$ (arbitrary unit). $p_2 = 5$ (arbitrary unit), $\theta_1 = 0$.*

Figure 2 gives the evolution of the amounts $x_1^{eq}$ and $x_2^{eq}$ over $\theta_2$ for $p_1 = 6$, $p_2 = 2$, in arbitrary units. $\theta_1$ takes the value 0.

For $\theta_1 = 0$, we notice that if the probability of a Soviet disruption remains moderate ($\theta_2 < 0.12$), then the Soviet gas becomes attractive and has a higher share in the Ruhrgas supply mix. Whereas, if $\theta_2 > 0.12$, the cost of the possible disruptions induces a relative shift towards the Norwegian gas and the Soviet gas becomes too risky ($x_2^{eq} = 0$). In that situation, the amount

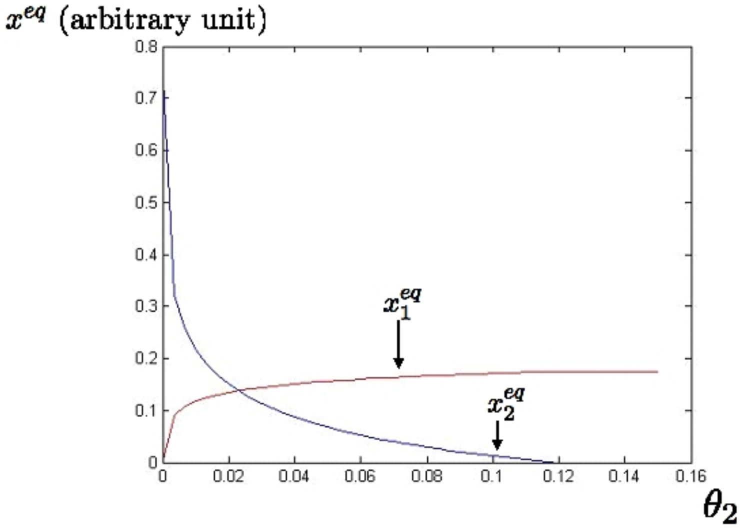


Figure 2:
*Evolution of* $x_{1,2}^{eq}$ *over* $\theta_2$ *(arbitrary unit).* $p_1 = 6$, $p_2 = 2$, $\theta_1 = 0$ *or* $0.1$.

bought from Norway no longer depends on the disruption probability $\theta_2$.

Figure 3 represents the dependance of the gas price in the FRG market on the disruption probability of the Soviet gas $\theta_2$ for $\theta_1 = 0$, $p_1 = 6$, and $p_2 = 2$.

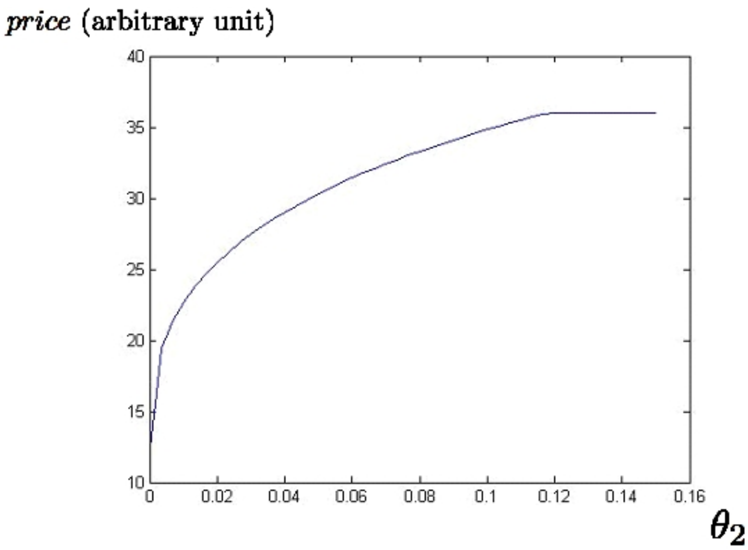


Figure 3:
*Evolution of the price over* $\theta_2$ *(arbitrary units).* $p_1 = 6$, $p_2 = 2$, $\theta_1 = 0$.

Obviously, the price charged by the retailer increases with $\theta_2$ to balance the possible impact of any gas disruption and reduce its inherent costs. Besides, for $\theta_2 > 0.12$, the retailer buys no more gas from the USSR and there is in that case, no risk of disruption. Hence, the price in the market no longer depends on $\theta_2$. However, one can wonder whether it would be better for Ruhrgas to deal with risky producers if their selling price is low. Therefore, it may be interesting to study the impact of disruption on the retailer's profit and on the social welfare observed in the FRG. The social welfare obtained in West Germany $W_{FRG}$ can be measured as the sum of the surplus obtained by the German consumers $S_c$ and the profit obtained by the sole retailer:

$$W_{FRG}(x_1, x_2) = S_c(x_1, x_2) + \bar{\Pi}(x_1, x_2)$$

where the consumers surplus is :

$$S_c(x_1, x_2) \quad = \int_0^{x_0+l} f(t)dt - f(x_0 + l)(x_0 + l) \tag{2}$$

Therefore:

$$W_{FRG}(x_1, x_2) = a\frac{1}{\epsilon_0 - 1}(x_0 + l)^{1-\frac{1}{\epsilon_0}} + \bar{\Pi}(x_1, x_2).$$

The shipper's profit is given by expression (1).
Figure 4 shows how the trader's profit and the social welfare evolve with $\theta_2$ when $p_1 = 6$, $p_2 = 2$ (arbitrary units) and $\theta_1 = 0$.

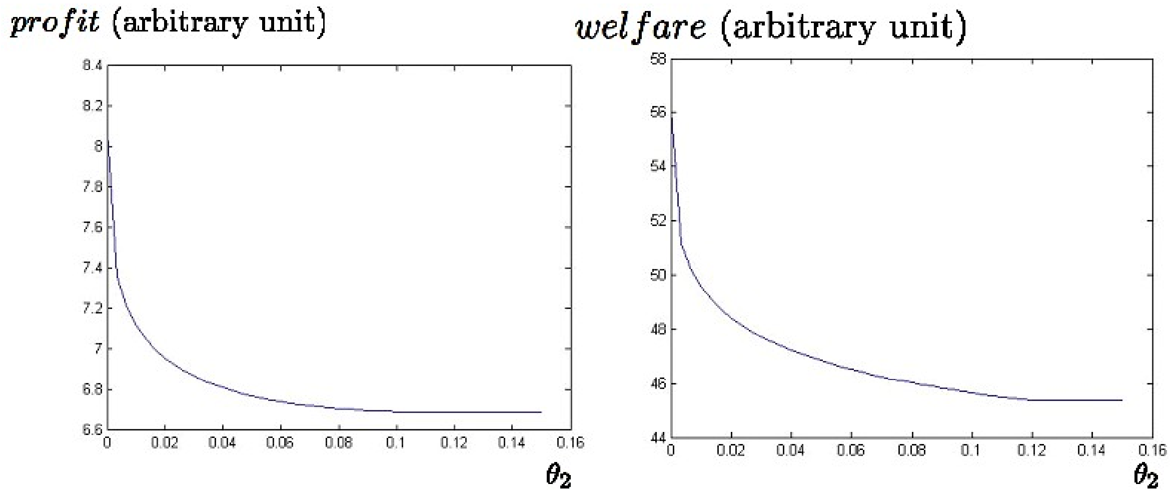


Figure 4:
*Evolution of the profit and social welfare over $\theta_2$ (arbitrary unit). $p_1 = 6$, $p_2 = 2$ (arbitrary units), $\theta_1 = 0$.*

The profit decreases with the disruption probability which suggests that it is better for the trader to deal with secure gas suppliers. This preference is also suitable for the consumer: the social welfare decreases with the disruption probability.

It is now time to make a comparison between our model and the situation studied in Manne and al. (1986). In their paper, they described Ruhrgas as a social welfare-maximizing firm. We can easily study this situation in our iso-elasticity framework: the retailer optimization program is given as follows:

$$\begin{aligned} \text{Max} \quad & W_{FRG}(x_1, x_2) = \tfrac{a}{\epsilon_0 - 1}(x_0 + l)^{1-\frac{1}{\epsilon_0}} + \bar{\Pi}(x_1, x_2) \\ \text{s.t.} \quad & x_1 \geq 0, \; x_2 \geq 0 \\ & \bar{\Pi}(x_1, x_2) \geq 0. \end{aligned}$$

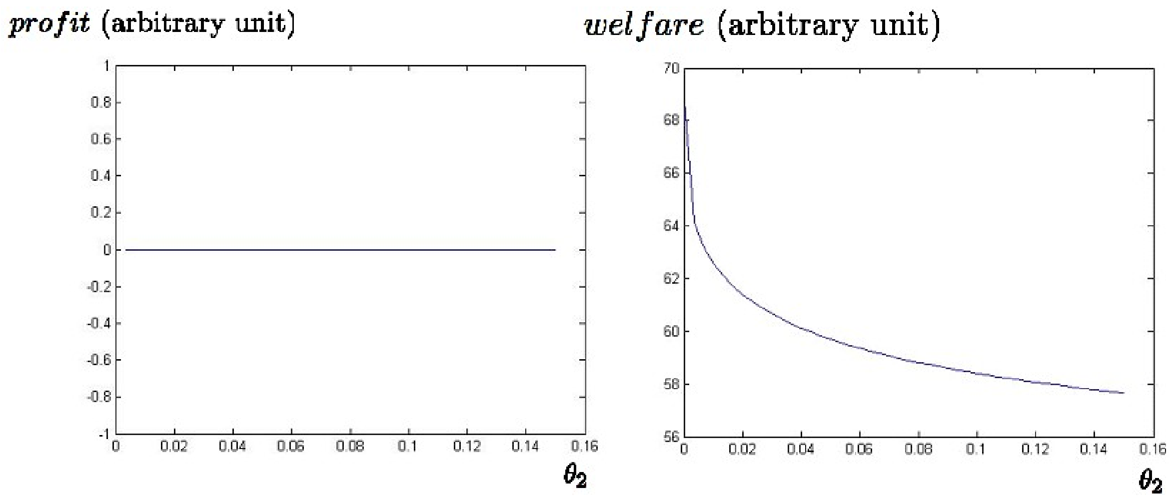


Figure 5:
*Evolution of the profit and social welfare over $\theta_2$ (arbitrary unit). $p_1 = 6$, $p_2 = 2$ (arbitrary units), $\theta_1 = 0$, welfare-maximizing agent.*

Figure 5 gives the evolution of Ruhrgas's profit $\bar{\Pi}$ and the social welfare $W_{FRG}$ over the Russian disruption probability $\theta_2$. Here, we notice that the retailer's profit is always equal to 0 and social welfare decreases with the disruption probability. Therefore, since it is known that Ruhrgas earned a significant profit in the 80s (Radetzki, 1992), it is more reasonable to model its behavior as a profit-maximizing firm, as we did thanks to our study.
Figure 6 gives the evolutions of the equilibrium quantities $x_1^{eq}$ and $x_2^{eq}$ over the disruption probability $\theta_2$ in the social welfare maximizer framework. The main difference one can notice in comparison to the profit-maximizing situation is that there is no threshold effect. Indeed, there is always some risky gas which is imported even if the disruption probability is high. However $x_2^{eq}$ decreases with $\theta_2$.

An interesting lesson can be derived from this analysis: the import behavior of a tightly regulated monopoly significantly differs from the one chosen by a profit-maximizing one.

### 3.3 Example 2: The Bulgarian situation

During the Russo-Ukrainian gas dispute of January 2009, the transit of Russian gas to Europe was cut for nearly two weeks. By far the most serious consequences were observed in the Balkans where some countries experienced an emergency situation, with parts of the populations unable to heat their homes[10]. On top of the intense emotion created by this quasi humanitarian crisis, this event reactivated a debate on the regulatory reforms needed for those countries.
In the Balkans, the regulatory framework of the natural gas industry is undergoing radical reforms with the aim of implementing the EU legislation on energy and competition[11]. A separation between regulated infrastructure-related activities and retail activities similar to the one currently at work in Western Europe is expected.

[10] An early description of these consequences can be found in Pirani et al. (2009, p. 53-56)
[11] This is the explicit goal of the Southeast Europe Energy Community Treaty that came into force on July 1, 2006.

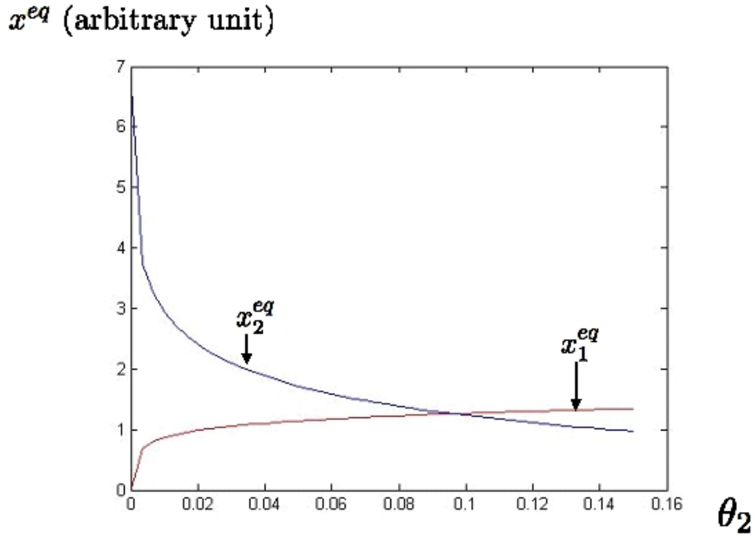


Figure 6:
*Evolution of the* $x_1^{eq}$ *and* $x_2^{eq}$ *over* $\theta_2$ *(arbitrary unit).* $p_1 = 6$, $p_2 = 2$ *(arbitrary units),* $\theta_1 = 0$, *welfare-maximizing agent.*

Some pertinent insights for the natural gas market can be obtained from our model. Until now, the Bulgarian gas industry was dominated by Bulgargaz Plc, the state-owned gas company, which holds a monopoly on the transmission and distribution of natural gas throughout the country.
There is currently an increasing concern about potential threats to the security of gas supply for this country in the coming decade. In fact, Bulgaria is characterized by a huge dependence upon imports from a single large supplier (Russia) and the country's gas demand is expected to grow strongly alongside its economic transition. As a result, there is a sound debate about the possibility of creating new imports infrastructures that would connect Bulgaria and other Southeast European countries to new sources of gas located either in the Caspian area or in Western Europe (e.g. Lise and al., 2008). Given the huge uncertainties attached to these projects, it is worthwhile to consider a benchmark scenario based on a continuing total dependence on Russian imports.
Thanks to the previous model, this case is relatively easy to analyze as follows. Here, we assume that $n$ retailers are competing to serve the Bulgarian gas market. These firms have a reduced choice and can only purchase their gas from a unique producer: Gazprom, the Russian gas company. Hence, with our notations, the sets $I$ and $J$ are $I = \{1, 2, ..., n\}$ and $J = \{1\}$. Let's denote by $x_i$ the amount of natural gas bought by the firm $i$. $x^0$ denotes also the total quantity sold by the producer $x^0 = \sum_{i=1}^{n} x_i$ and $\theta$ the probability that Russia cuts its production, either for technical, economical or political reasons. The price charged by the producer is $p$, the elasticities values for the short and long-run demands are respectively $\epsilon_1 = 0.3$ and $\epsilon_0 = 1.2$ [12]. Besides, we give arbitrary values for the other exogeneous parameters: $a = 1$ and $p = 1$ in arbitrary units. We assume that in case of disruption, there are some "force majeure" provisions that allow the import of gas from neighboring countries. We will denote by $c$ this minimum gas quantity in Bulgaria in case of disruption. The maximization problem can thus be written for each firm $i$:

[12] The review of empirical studies presented in Hoel and Strøm (1987) supports this assumption of an elasticity value greater than one for the long-run price elasticity of the natural gas demand in a European country.

$$\begin{aligned} &\text{Max} \quad (f(x_0)-p)x_i - \theta \tfrac{x_i}{x_0}\int_c^{x_0} g(x_0,t)dt + \theta p x_i \\ &\text{s.t.} \quad\ \ x_i \geq 0 \end{aligned} \tag{3}$$

We denote by $\Pi$ each firm's profit: $\Pi(x_i) = (f(x_0)-p)x_i - \theta \frac{x_i}{x_0}\int_c^{x_0} g(x_0,t)dt + \theta p x_i$.
Assuming that the natural gas demand takes an isoelastic functional form, we have

$$\Pi(x_i) = a x_0^{-\frac{1}{\epsilon_0}} x_i \left(1 - \theta\frac{\epsilon_1}{\epsilon_1 - 1}\right) + \theta a \frac{\epsilon_1}{\epsilon_1-1} c^{-\frac{1}{\epsilon_1}+1} x_i x_0^{\frac{1}{\epsilon}-1} - p(1-\theta)x_i$$

We can demonstrate that the function $\Pi(x_i, x_j, j \neq i)$ where the variable is $x_i$ and $x_j$, $j \neq i$ are considered constant is concave. **The existence and uniqueness of an optimum for each firm is thus guaranteed.**
To simplify our expressions, we call

$$\alpha = a\left(1 - \theta\frac{\epsilon_1}{\epsilon_1-1}\right)$$

$$\beta = \theta a \frac{\epsilon_1}{\epsilon_1 - 1} c^{-\frac{1}{\epsilon_1}+1}$$

The first order calculations give:

$$\frac{\partial \Pi}{\partial x_i}(x_i) = \alpha x_0^{-\frac{1}{\epsilon_0}-1}\left(x_0 - \frac{x_i}{\epsilon_0}\right) + \beta x_0^{\frac{1}{\epsilon}-2}\left(x_0 + \left(\frac{1}{\epsilon}-1\right)x_i\right) - p(1-\theta) \tag{4}$$

Market transparency is an inherent assumption to our model (i.e. we assume that the $n$ retailers have the same knowledge of the market in terms of prices and probability of disruption). Furthermore, mathematically speaking, we notice that the optimization problem 3 is symmetric for all the retailers. Consequently, we can already predict that the Nash-Cournot equilibrium is reached when all the amounts $x_i$ are equal. Hence, let's call $x_{eq}$ the equilibrium quantity bought by each retailer and use the first order condition to find it. We can deduce an implicit equation that gives $x_{eq}$ from expression 4:

$$\alpha n^{-1-\frac{1}{\epsilon_0}}\left(n - \frac{1}{\epsilon_0}\right) x_{eq}^{-\frac{1}{\epsilon_0}} + \beta n^{\frac{1}{\epsilon}-2}\left(\frac{1}{\epsilon} - 1 + n\right) x_{eq}^{\frac{1}{\epsilon}-1} - (1-\theta)p = 0 \tag{5}$$

Actually, it is not possible to find general analytical expressions of the solution for 5. We will use numerical means to solve it. However, we can already predict that equation 5 has a unique solution. Indeed, $\forall n \in \mathbb{N}^*$ the function

$$g_n : x \longrightarrow \alpha n^{-1-\frac{1}{\epsilon_0}}\left(n - \frac{1}{\epsilon_0}\right) x^{-\frac{1}{\epsilon_0}} + \beta n^{\frac{1}{\epsilon}-2}\left(\frac{1}{\epsilon} - 1 + n\right) x^{\frac{1}{\epsilon}-1} - (1-\theta)p$$

is strictly decreasing on $\mathbb{R}_+^*$ and realizes a bijection from $\mathbb{R}_+^*$ to $\mathbb{R}$.
If we assume that an equilibrium is possible, we can calculate the price of the product in the market and study its dependence on the disruption probability $\theta$ and the number of retailers $n$.

$$price = a(nx_{eq})^{-\frac{1}{\epsilon_0}}$$

Figure 7 gives the evolution of the natural gas price in the market, over the number of retailers $n$, for $\theta = 0.15$ and $c = 0.4$ in arbitrary units.

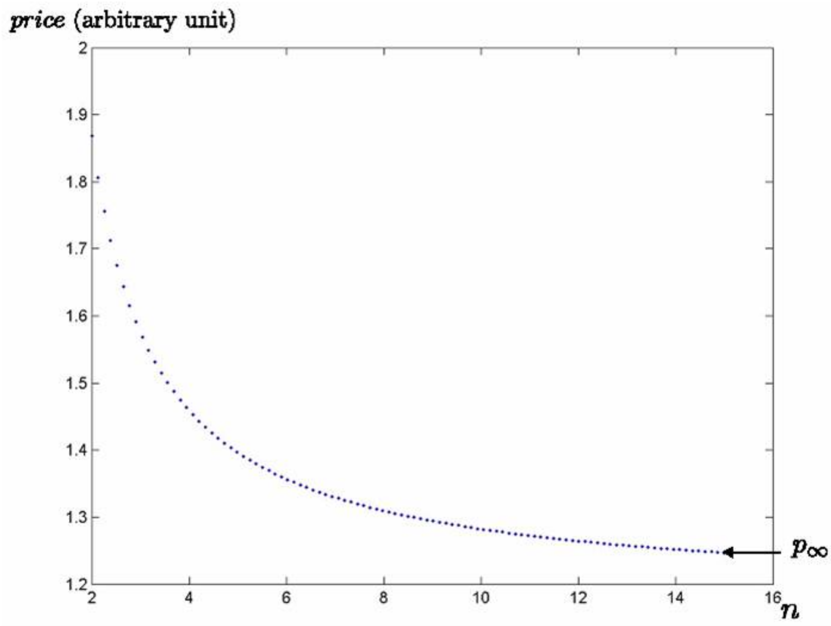


Figure 7:
*Evolution of the gas price in the market over n. $\theta = 0.15$, and $c = 0.4$ in an arbitrary unit.*

As expected, the price decreases with the number of retailers as stringent competition leads to cheaper products and smaller profits. We notice that the price converges towards a finite value $p_\infty$, that can be calculated. For this purpose, we need to study the convergence of the sequence $nx_{eq}(n)$ when $n \longrightarrow \infty$. Let's denote $\rho_n = nx_{eq}(n)$. Using equation 5 we deduce that $\rho_n$ is the unique solution of

$$f_n(\rho_n) = \alpha\left(1 - \frac{1}{n\epsilon_0}\right)\rho_n^{-\frac{1}{\epsilon_0}} + \beta\left(\frac{\frac{1}{\epsilon}-1}{n}+1\right)\rho_n^{\frac{1}{\epsilon}-1} - (1-\theta)p = 0$$

Let's call $f$ the function: $\mathbb{R}_+^* \longrightarrow R$

$$f : x \longrightarrow \alpha x^{-\frac{1}{\epsilon_0}} + \beta x^{\frac{1}{\epsilon}-1} - (1-\theta)p$$

$f$ is a decreasing function and realizes a bijection from $\mathbb{R}_+^*$ to $\mathbb{R}$. Let's call $\rho = f^{-1}(0)$ the unique solution of the equation $f(x) = 0$ and let's demonstrate that $\rho_n \longrightarrow \rho$. Indeed, we have $f_n(\rho_n) - f(\rho) = 0$. Hence $\forall n \in \mathbb{N}^*$:

$$\alpha\left(\rho_n^{-\frac{1}{\epsilon_0}} - \rho^{-\frac{1}{\epsilon_0}}\right) + \beta\left(\rho_n^{\frac{1}{\epsilon}-1} - \rho^{\frac{1}{\epsilon}-1}\right) = \frac{1}{n}\left(\frac{\alpha}{\epsilon_0}\rho_n^{-\frac{1}{\epsilon_0}} + \beta\left(\frac{1}{\epsilon}-1\right)\rho_n^{\frac{1}{\epsilon}-1}\right) \tag{6}$$

We can demonstrate easily that $\exists M \in \mathbb{R}_+^*$ such as $\forall n \in \mathbb{N}^*$ $|\rho_n| < M$ (that is to say the sequence $\rho_n$ is boundned). Using equation 6, we conclude that $\alpha\left(\rho_n^{-\frac{1}{\epsilon_0}} - \rho^{-\frac{1}{\epsilon_0}}\right) + \beta\left(\rho_n^{\frac{1}{\epsilon}-1} - \rho^{\frac{1}{\epsilon}-1}\right) \longrightarrow 0$ when $n \longrightarrow \infty$. Hence:

$$f(\rho_n) \longrightarrow f(\rho)$$

$f$ being a continuous bijective function, $f^{-1}$ is also a bijective continuous function and we conclude that $\rho_n = f^{-1}(f(\rho_n)) \longrightarrow f^{-1}(f(\rho)) = \rho$.
Finally, we can write the price limit $p_\infty$:

$$p_\infty = a\rho^{-\frac{1}{\epsilon_0}}$$

Using relation $\alpha\rho^{-\frac{1}{\epsilon_0}} + \beta\rho^{\frac{1}{\epsilon}-1} = (1-\theta)p$, we can calculate

$$\frac{\mathrm{d}\rho}{\mathrm{d}\theta}(\theta) = \frac{-p + \frac{\epsilon_1}{\epsilon_1 - 1} a\rho^{-\frac{1}{\epsilon_0}} - \frac{\epsilon_1}{\epsilon_1 - 1} a c^{1-\frac{1}{\epsilon_1}} \rho^{-\frac{1}{\epsilon}-1}}{-\frac{1}{\epsilon_0}\alpha\rho^{-\frac{1}{\epsilon_0}-1} + \beta\left(\frac{1}{\epsilon}-1\right)\rho^{\frac{1}{\epsilon}-1}} = \frac{-1}{\theta} \frac{1}{-\frac{1}{\epsilon_0}\alpha\rho^{-\frac{1}{\epsilon_0}-1} + \beta\left(\frac{1}{\epsilon}-1\right)\rho^{\frac{1}{\epsilon}-1}} \left(p - a\rho^{-\frac{1}{\epsilon_0}}\right). \quad (7)$$

If we assume that the force majeure imports capacity $c$ is low enough, such as $c < \left(\frac{p}{a}\right)^{-\epsilon_0} \epsilon_1^{\frac{\epsilon_1}{1-\epsilon_1}} = 1.67 \left(\frac{p}{a}\right)^{-\epsilon_0}$, we can demonstrate (see appendix) that

$$\forall\theta \in [0,1] \;\; p \leq a\rho(\theta)^{-\frac{1}{\epsilon_0}}.$$

Hence, in this situation we conclude that $\forall\theta \in [0,1] \; \frac{\mathrm{d}\rho}{\mathrm{d}\theta}(\theta) \leq 0$, or

$$\forall\theta \in [0,1] \quad \frac{\mathrm{d}p_\infty}{\mathrm{d}\theta}(\theta) \geq 0.$$

On the contrary, if $c > \left(\frac{p}{a}\right)^{-\epsilon_0} \epsilon_1^{\frac{\epsilon_1}{1-\epsilon_1}}$, we demonstrate that (see appendix):

$$\forall\theta \in [0,1] \quad \frac{\mathrm{d}p_\infty}{\mathrm{d}\theta}(\theta) \leq 0.$$

Figure 8 shows how $p_\infty$ evolves with $\theta$ for $c = 0.4$ (arbitrary unit). We already know that in the case of completely secure supply (i.e. $\theta = 0$), the standard pure and perfect competition study allows us to assert that the market price converges towards the producer's price $p$ when $n$ is large enough. Our model arrives at the same conclusion: indeed, when $\theta = 0$, we can easily calculate $\rho(0)$ and we find $\rho(0) = \left(\frac{p}{a}\right)^{-\epsilon_0}$ or $p_\infty(0) = p$.

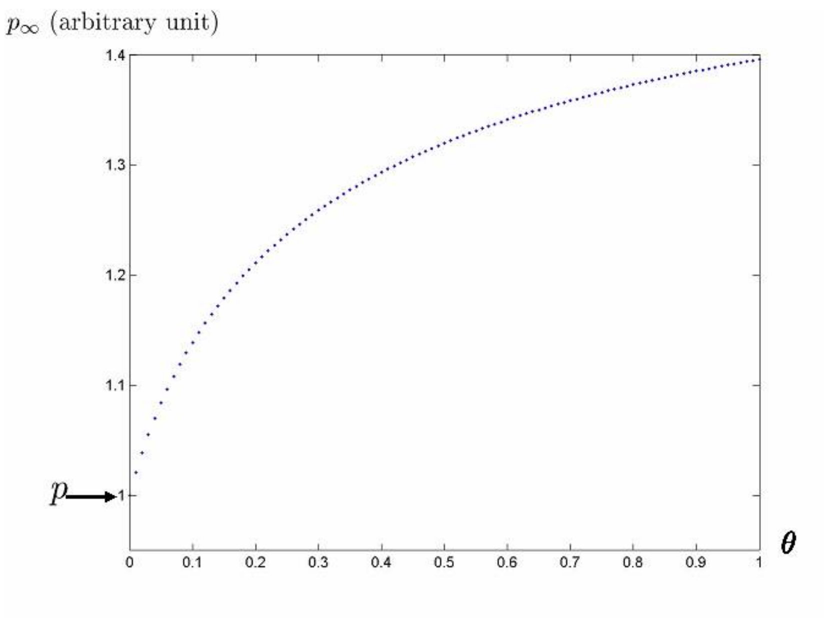


Figure 8:
*Evolution of $p_\infty$ (arbitrary unit) over $\theta$. $c = 0.4$ in an arbitrary unit.*

The conclusion we can draw from the pure and perfect concurrence situation is quite interesting: if the alternative imports capacity is low enough (which is quite realistic for the current Bulgarian situation) and the number of trading firms is large, insecure supplies make the gas retail price higher than the import price, which obviously decreases the consumers' utility, even if they are compensated if disruption occurs.

Figure 9 gives the evolution of the price over the disruption probability $\theta$ for $n = 6$ and $c = 0.4$ in arbitrary units.

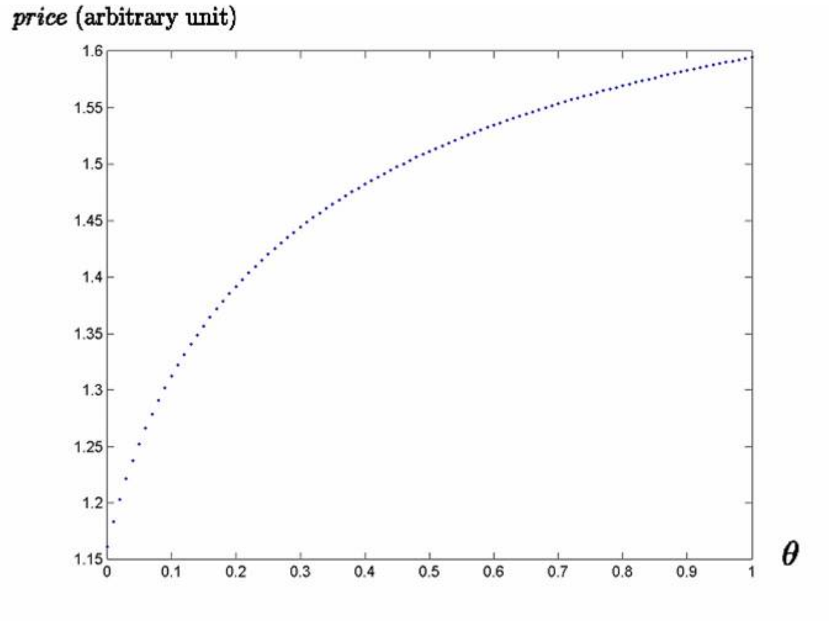


Figure 9:
*Evolution of the gas price in the market (arbitrary unit) over $\theta$. $n = 6$ and $c = 0.4$ in an arbitrary unit.*

The price increases with the probability $\theta$ because if the supplier is not secure, the retailers need to charge a high natural gas price in order to ensure their long-run profit, so that they can compensate the loss due to any disruption, which can occur quite frequently.

Let's study now the impact of any disruptive behavior on the gas amount imported to the Bulgarian market. We also study the possibility of controling the market by a gas regulator. Let's assume that a possible regulation fixes a maximum amount $X$ bought by each retailer $i$, in order to optimize the expected social welfare (shared between the retailers and the consumers). We denote by $W$ the total social welfare:

$$W = W_{consumers} + W_{retailers}$$

where

$$W_{consumers} = \int_0^{x_0} f(t)dt - f(x_0)x_0 \qquad \text{Consumer surplus}$$

$$W_{retailers} = \sum_{i=1}^{n} \left( (f(x_0) - p)x_i - \theta \frac{x_i}{x_0} \int_c^{x_0} g(x_0, t)dt + p\theta x_i \right) \qquad \text{Retailers' profits}$$

Under the iso-elasticity assumptions, we can calculate analytically welfare $W$ if the quantity of gas bought by each retailer $x_i$ is $x$:

$$W(x) = \tau n^{-\frac{1}{\epsilon_0}+1} x^{-\frac{1}{\epsilon_0}+1} + \beta n^{\frac{1}{\epsilon}} x^{\frac{1}{\epsilon}} - np(1-\theta)x$$

where

$$\tau = a\left(\frac{\epsilon_0}{\epsilon_0 - 1} - \theta\frac{\epsilon_1}{\epsilon_1 - 1}\right)$$

$$\beta = \theta a \frac{\epsilon_1}{\epsilon_1 - 1} c^{-\frac{1}{\epsilon_1}+1}.$$

Figure 10 represents the evolution of the welfare over the quantity bought by each retailer $x$ for $\theta = 0.15$, $n = 6$, and $c = 0.4$ in arbitrary units.

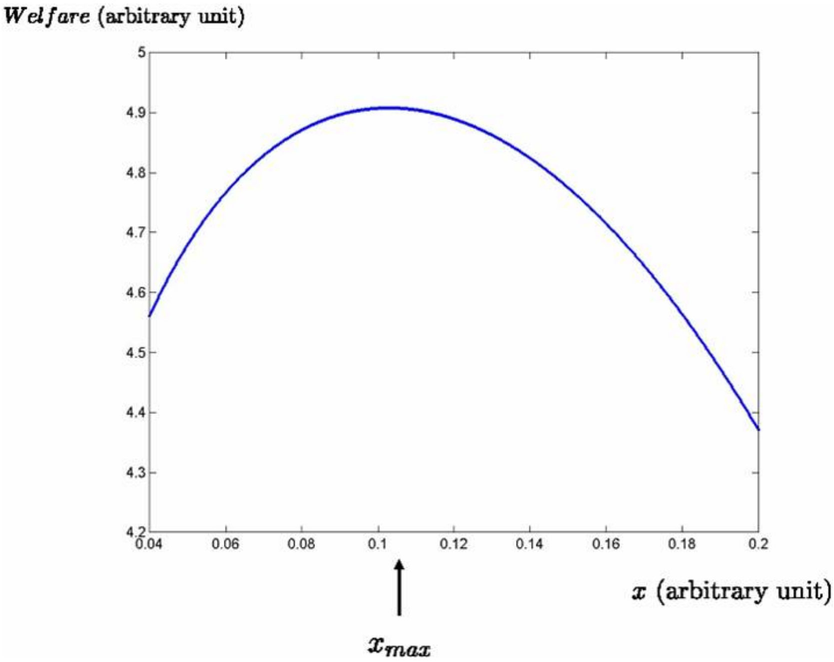


Figure 10:
*Evolution of the social welfare over $x$ (arbitrary units). $\theta = 0.15$, $n = 6$, and $c = 0.4$ (arbitrary units).*

We notice that there is an optimal amount $x_{max}$ to be bought by each retailer to ensure a maximum welfare. We will now compare this quantity to the one imported by the retailers if they were to interact freely without any regulation. Figure 11 gives the evolution of $x_{max}$ and $x_{eq}$ over $\theta$ for $n = 6$ and $c = 0.4$ in arbitrary units. We notice that there is a specific disruption probability $\theta_{lim}$, that depends only on the inner-market characteristics (i.e. $\epsilon_0$, $\epsilon_1$, $n$, $c$, $a$ and $p$) such as:

if $\theta \leq \theta_{lim}$ $\quad x_{eq} \leq x_{max}$
if $\theta > \theta_{lim}$ $\quad x_{eq} > x_{max}$

The main conclusion to draw from this study is the following: to optimize the social welfare, a regulator should fix a maximum amount $X$ sold by Gazprom to the Bulgarian retailers only if the risk of disruption is high: $\theta > \theta_{lim}$. In that case, the maximum amount $X$ must be $x_{max}(\theta)$.

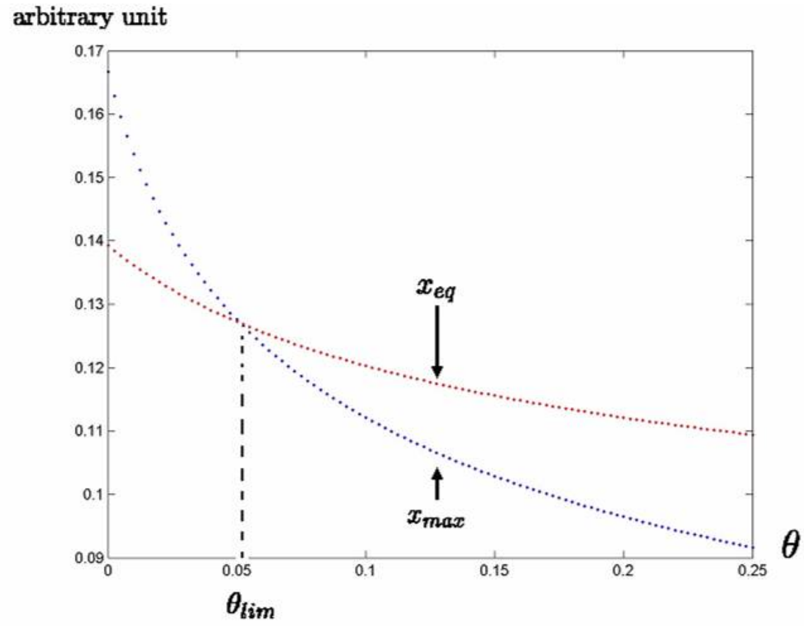


Figure 11:
*Evolution of $x_{eq}$ and $x_{max}$ (arbitrary units) over $\theta$. $n = 6$ and $c = 0.4$ (arbitrary unit).*

No regulation should be imposed if the producer is not too risky (i.e. $\theta \leq \theta_{lim}$) for any restriction on the gas amount would decrease the social welfare.

At this stage of our model, it is interesting to study the evolution of the probability $\theta_{lim}$, that is the regulation determining factor- over the minimum capacity or gas storage amount $c$. Economically speaking, it is easy to predict that this probability increases with $c$. Indeed, if the inner Bulgarian gas capacity is high in case of emergency, it is possible to tolerate frequent disruptions, without any regulation. Figure 12 represents the evolution of $\theta_{lim}$ over the capacity $c$, for $n = 6$, $p = 1$ and $a = 1$ in arbitrary units.

We notice that the probability $\theta_{lim}$ converges, for big capacities towards a finite value $\theta_\infty$ that depends only on $\epsilon_0$, $\epsilon_1$, $a$ and $p$. In our example, $\theta_\infty \approx 0.5$. The main conclusion to draw is that for very risky producers ($\theta > \theta_\infty$), a regulation policy must always be imposed in order to optimize the social welfare.

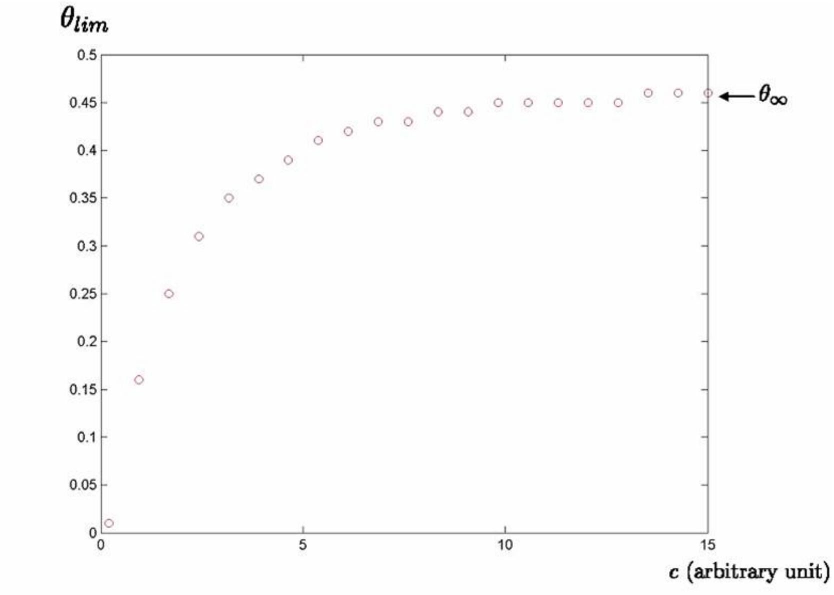


Figure 12:
*Evolution of $\theta_{lim}$ over c (arbitrary unit). $n = 6$.*

## 4 Concluding remarks

The main goal of this paper is to study the impacts on the natural gas market of supply disruption risks. For that purpose, we developed a static model (over a typical period of one year) based on a Cournot game between different retailers who buy gas from possibly risky producers and bring it onto the market. The upstream market is represented as follows: the retailers sign long-term contracts with local producers (e.g. Gazprom) that fix the selling gas price. We take into account the recent market liberalization by assuming that all the retailers have the same access to transport means. We also suppose that local producers sell their gas at the same price to all the retailers. In the downstream market, the retailers interaction is modeled by a Cournot game, with an assumption of market transparency, when all the actors maximize their expected profit, taking into consideration specific disruption costs they have to pay to the consumers' in case of supply interruption from risky producers. Disruption costs can be quantified by introducing a short-run demand function $g(k, q)$, which is the consumers willingness to pay for the gas amount $q$ in case of disruption if the long-run consumption is $k$. We were able to study in details some particular Western European markets by making an iso-elasticity assumption on the long- and short-run inverse demand functions.
The German gas market of the 80s, which is represented by the interaction between one big shipper, Ruhrgas AG, who brings gas to the end-user market and two big producers, Russia and Norway, has been described accurately by our model. We have demonstrated in particular that if the Russian gas becomes too expensive or too risky, (compared to the Norwegian gas, which is supposed to be safe) with bounds that can be precisely determinated and that depend only on the inner market characteristics, no Russian gas would be brought to Germany by Ruhrgas AG for this would decrease its profit. We also predict that the price charged by Ruhrgas in the German market would increase with the disruption probability.
The Bulgarian gas market was also a case in point of our model: we assume the existence of a certain number of retailers that buy gas mostly from one risky producer: Gazprom. The conclusions we can draw from our study are very interesting. Firstly, the gas price in the

market $p_\infty$, in case of pure and perfect competition is higher than the producer's price, which is the pure and perfect competition gas price in the market if Russia is considered to be a safe supplier. Secondly, we demonstrate that, under some specific assumptions on the local force majeure imports production, $p_\infty$ increases with the Russian disruption probability $\theta$. Finally, we demonstrate the existence of a threshold $\theta_{lim}$ such as if the disruption probability is greater than $\theta_{lim}$, it is better, for the overall social welfare to regulate the market (by means of quantities control) and not leave the actors to interact freely.

## References


[1] Bunn, D.W, and M. M. Mustafaoglu, 1978. *Forecasting Political Risk*, Management Science 24.15 (November): 1557-67.

[2] Considine, T. J., 2006. *Is the strategic petroleum reserve our ace in the hole?*, The Energy Journal, 27, 3, (2006), 91-112.

[3] Costantini, V., Gracceva, F., Markandya, A. and Vicinia, G., 2007. *Security of energy supply: Comparing scenarios from a European perspective*, Energy Policy, Vol. 35, No. 1, (January), 210-226.

[4] DG COMP, 2007. *DG Competition report on energy sector inquiry*, SEC(2006)1724, European Commission, Competition DG, 10 January, 2007, Brussels.

[5] Fouquet, R. and Pearson, P.J.G., 2006. *Long-run Trends in Energy Services: The Price and Use of Lighting in the United Kingdom, 1300-2000*, The Energy Journal, *Vol. 25, No. 1.*

[6] Golombek, R., Vislie, J. and Hoel, M., 1987 (Eds.). *Natural gas markets and contracts*, North-Holland.

[7] Helm, D., 2002. *Energy policy: security of supply, sustainability and competition*, Energy Policy 30 173-184.

[8] von Hirschhausen, C., Neumann, A., 2008. *Long-Term Contracts and Asset Specificity Revisited: An Empirical Analysis of Producer-Importer Relations in the Natural Gas Industry*, Review of Industrial Organization, Vol. 32, No. 2, pp. 131-143.

[9] Hoel, M., Strøm, S., 1987. *Supply security and Import diversification of Natural Gas*, in R. Golombek, J. Vislie and M. Hoel (Eds.): Natural gas markets and contracts, North-Holland.

[10] International Energy Agency, 2002. *Flexibility in natural gas supply and demand.* OECD/IEA, Paris.

[11] International Energy Agency, 2007. *Natural Gas Market Review.* OECD/IEA, Paris.

[12] International Energy Agency, 2008. *World Energy Outlook 2008.* OECD/IEA, Paris.

[13] Kruyt, B., van Vuuren, D.P., de Vries, H.J.M., and Groenenberg, H., 2010. *Indicators for energy security*, Energy Policy, Vol. 38, No. 4.

[14] Lefèvre, N., 2010. *Measuring the energy security implications of fossil fuel resource concentration*, Energy Policy, Vol. 38, No. 4 (April), pp. 1635-1644.

[15] Manne, A.S., Roland, K., Stephan, G., 1986. *Security of supply in the Western European market for natural gas*, Energy Policy, Vol. 14, No. 1 (February), Pages 52-64.

[16] Markandya A., Pemberton M., 2010. *Energy security, energy modelling and uncertainty*, Energy Policy, Vol. 38, No. 4 (April), pp. 1609-1613.

[17] Massol, O., and S. Tchung-Ming, 2009. *Cooperation among liquefied natural gas suppliers: is rationalization the sole objective?*, Energy Economics, Accepted manuscript.

[18] Murphy, F. H., M. A. Toman and H. J. Weiss, 1987. *A Stochastic Dynamic Nash Game Analysis of Policies for Managing the Strategic Petroleum Reserves of Consuming Nations*, Management Science, Vol. 33, No. 4 (April), pp. 484-499

[19] Newbery, D.M. (2000). *Privatization, Restructuring and Regulation of Network Utilities*, (The Walras-Pareto Lectures, 1995), MIT Press.

[20] Nichols, A. and R. Zeckhauser, 1977. *Stockpiling Strategies and Cartel Prices*, Bell Journal of Economics 8(1), Spring, 66-96.

[21] Percebois, J., 2006. *Dépendance et vulnérabilite: Deux façons connexes mais différentes d'aborder les risques énergétiques.* Cahier N° 06.03.64, Centre de Recherche en Economie et Droit de l'Énergie (CREDEN), Université de Montpellier, France.

[22] Radetzki M., 1992. *Pricing of Natural Gas in the West European Market*, Energy Studies Review, Vol. 4, No. 2.

[23] Teisberg, T. J., 1981. *A Dynamic programing Model of the U.S. Strategic Petroleum Reserve*, Bell J. Economics, 12, 2, 526-546.

[24] Vickers, J. and Yarrow G., 1988. *Regulation of privatised firms in Britain*, European Economic Review, Vol.32, No. 2-3 (March), pp. 465-472.

[25] Victor, N., and Victor, D.G., 2006. *Bypassing Ukraine: exporting Russian gas to Poland and Germany.* In Victor, D.G., Jaffe, A.M., Hayes, M. H. (Eds), Natural Gas and Geopolitics: From 1970 to 2040, Cambridge University Press.

[26] Wright, B. D. and J. C. Williams, 1982. *The Roles of Public and Private Storage in Managing Oil Import Discussions*, Bell J. Economics, 13, 2, 341-353.

# 5 Appendix

In this appendix, we demonstrate the properties stated in section 3.3:

$$\text{if} \quad c < \left(\frac{p}{a}\right)^{-\epsilon_0} \epsilon_1^{\frac{\epsilon_1}{1-\epsilon_1}} \quad \text{then} \quad \forall\theta \in [0,1] \quad p \leq a\rho(\theta)^{-\frac{1}{\epsilon_0}}$$

$$\text{and if} \quad c > \left(\frac{p}{a}\right)^{-\epsilon_0} \epsilon_1^{\frac{\epsilon_1}{1-\epsilon_1}} \quad \text{then} \quad \forall\theta \in [0,1] \quad p \geq a\rho(\theta)^{-\frac{1}{\epsilon_0}}$$

- We assume $c < \left(\frac{p}{a}\right)^{-\epsilon_0} \epsilon_1^{\frac{\epsilon_1}{1-\epsilon_1}}$
  Let's suppose that $\exists\theta_0 \in [0,1[$ such as $p \geq a\rho(\theta_0)^{-\frac{1}{\epsilon_0}}$. Using equation 7, we have $\frac{\mathrm{d}\rho}{\mathrm{d}\theta}(\theta_0) > 0$. We define $\theta_1$ as follows:

  $$\theta_1 = \sup\{\theta \in [\theta_0, 1[ \ / \ \frac{\mathrm{d}\rho}{\mathrm{d}\theta}(\theta) > 0\}$$

  and let's demonstrate that $\theta_1 = 1$. If $\theta_1 < 1$, since the function $\theta \longrightarrow \rho(\theta)$ is continuously derivable, we can conclude that $\frac{\mathrm{d}\rho}{\mathrm{d}\theta}(\theta_1) = 0$. Using equation 7 we find that $p = a\rho(\theta_0)^{-\frac{1}{\epsilon_0}}$. However, we know that $\forall\theta \in [\theta_0, \theta_1[ \quad \frac{\mathrm{d}\rho}{\mathrm{d}\theta}(\theta) > 0$. Hence, the function $\theta \longrightarrow \rho(\theta)$ is strictly increasing on the set $[\theta_0, \theta_1[$ and $\rho(\theta_1) > \rho(\theta_0)$. We already have $p \geq a\rho(\theta)^{-\frac{1}{\epsilon_0}}$. Thus we find

  $$p \geq a\rho(\theta_0)^{-\frac{1}{\epsilon_0}} > a\rho(\theta_1)^{-\frac{1}{\epsilon_0}} = p$$

  which is absurd. Then $\theta_1 = 1$ and we conclude that $\frac{\mathrm{d}\rho}{\mathrm{d}\theta}(1) > 0$ or

  $$p > a\rho(1)^{-\frac{1}{\epsilon_0}}. \tag{8}$$

  We can quite easily calculate $\rho(1)$:

  $$\rho(1) = c\epsilon_1^{\frac{\epsilon_1}{\epsilon_1 - 1}}$$

  and using the condition $c < \left(\frac{p}{a}\right)^{-\epsilon_0} \epsilon_1^{\frac{\epsilon_1}{1-\epsilon_1}}$, we find that:

  $$a\rho(1)^{-\frac{1}{\epsilon_0}} > p$$

  which is absurd, regarding equation 8.

  Hence:

  $$\forall\theta \in [0,1] \quad p \leq a\rho(\theta)^{-\frac{1}{\epsilon_0}}$$

- We assume $c > \left(\frac{p}{a}\right)^{-\epsilon_0} \epsilon_1^{\frac{\epsilon_1}{1-\epsilon_1}}$
Hence, $a\rho(1)^{-\frac{1}{\epsilon_0}} < p$ and $\frac{\mathrm{d}\rho}{\mathrm{d}\theta}(1) > 0$. We intend to demonstrate that $\forall\theta \in [0,1]$ $a\rho(\theta)^{-\frac{1}{\epsilon_0}} < p$. If we assume that $\exists\theta_0 \in [0,1[$ such as $a\rho(\theta_0)^{-\frac{1}{\epsilon_0}} \geq p$, we call $\theta_1$ the probability:

$$\theta_1 = \inf\{\theta \in [\theta_0, 1[ \;/\; \frac{\mathrm{d}\rho}{\mathrm{d}\theta}(\theta) \geq 0\}.$$

Here again, since the function $\theta \longrightarrow \rho(\theta)$ is continuously derivable, we have $\frac{\mathrm{d}\rho}{\mathrm{d}\theta}(\theta_1) = 0$. However, we know that $\forall\theta \in [\theta_0, \theta_1[$, $\frac{\mathrm{d}\rho}{\mathrm{d}\theta}(\theta) \leq 0$. Hence, $\rho(\theta_1) < \rho(\theta_0)$. However, we already have:

$$p = a\rho(\theta_1)^{-\frac{1}{\epsilon_0}} > a\rho(\theta_0)^{-\frac{1}{\epsilon_0}} \geq p$$

which is absurd. Thus our conclusion.