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Department of Economics
Discussion Paper Series
No. 11/04

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Security of supply and retail competition in the European gas market. Some model-based insights

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Abstract

In this paper, we analyze the impact of uncertain disruptions in gas supply upon gas retailer contracting behavior and consequent price and welfare implications in a gas market characterized by long-term gas contracts using a static Cournot model. 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, producers in exporting countries (Russia, Algeria, etc.) to local retailers who bring gas to the consuming countries to satisfy local demands in the downstream market. Disruption costs are modeled using short-run demand functions. First we mathematically develop a 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 1980s to explain the supply choices of the German retailer, 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 dependent on the Russian gas supplies and hence very sensitive to interruption risks. Some interesting conclusions are derived concerning the necessity to economically regulate the market, by means of gas amounts control, if the disruption probability is high enough.

Keywords
Security of supply, Natural gas, Market models.

Acknowledgments
We are grateful to Vincent Briat, Steve Gabriel, Pierre-André Jouvet, Jacques Percebois and Jennifer Rontganger 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 IFP Energies nouvelles.

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1 Introduction

The security of energy supply is all but a new concern for energy importing countries. However, this concern has certainly 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 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 (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) refer to a possible cartelization (Massol and Tchung-Ming, 2009). Thirdly, the recent supply interruptions observed in a number of OECD regions (IEA, 2007) 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 the energy mix: 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 need to discuss how the downstream part of the gas industry usually manages the possible shortfall in upstream gas. Possible remedies include: large-scale commercial storage, strategic "stockpiles" (if any), re-routing of existing gas flows, increased production from other suppliers that may compensate the shortfall of others. In any case, these instruments might be unavailable. For example, local geological conditions can impede the construction of large underground gas storages (e.g. Belgium), capacity constraints on existing transmission networks can prevent the suitable re-routing of existing gas flows (e.g. South Eastern European countries), local production can be inexistent (e.g. Bulgaria). Until now, strategic stockpiling, a well-known measure implemented to increase the security of oil supplies (Nichols and Zeckhauser, 1977; Murphy et al., 1987), has not been viewed as a workable solution in the case of natural gas supplies (IEA, 2007, pp. 67-83). Now, the possibility to create some kind of precautionary storage is currently being discussed in Europe. However, given the costs of these measures, it is not certain that the stored volumes will be sufficient to fully replace the disrupted supplies. As a result of these disruptions, retailers may have no alternative but to pass along the shortfall to end-users through selective interruptions. In this paper, we analyze how these disruptions influence the retailers' contracting behavior since they can try to minimize the impact of those interruptions using diversified import sources.

Because of this perceived vulnerability, the security of gas supplies has inspired a huge amount of literature that can be roughly divided into two categories. The first one is by far the largest and gathers all the contributions dominated by purely geopolitical concerns.[1] 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 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.[2] As far as economic analysis is concerned, the decisions of those firms regarding supply security were 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 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 1980s (e.g. Vickers and Yarrow, 1988; Newbery, 2000), a complete transformation of the regulatory regime started in Continental Europe in the early 2000s. 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 retailer, creating the conditions for a competitive rivalry among these firms.

This reform suggests a thought-provoking research question: Does competition among gas retailers have an influence in their choices of inputs? Framed differently, it simply asks for an investigation of retailer's contracting behavior in a gas market dominated by long-term import contracts. How do the retailers' contracting choices influence the market outcomes (gas price, social welfare in the importing market, retailers profits, etc.) regarding the degree of supply insecurity.

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 study 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 take into account possible interruptions whose occurrences are captured thanks to perceived probabilities. Both long- and short-run issues were jointly considered. The costs attached to each of these disruption states were valued thanks to short-run consumer surplus concepts while both energy purchases and consumptions under normal conditions were related to the long-run demand curve. Both papers provided a very effective 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 presents and justifies the framework devel-

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

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

oped for analyzing their import diversification strategies. To illustrate the possibilities offered by this model, two empirical illustrations based on real case studies are successively presented and commented on sections 3 and 4. In the former, a historical analysis of the German situation in the early 1980s 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 focused on long-run aspects. The gas infrastructure required to supply gas to end-users is not explicitly modeled. This may be interpreted as assuming a fully accessible gas infrastructure without bottlenecks. This assumption may perfectly reflect European gas infrastructure conditions in the long run, when short-run regulatory and investment uncertainties are resolved. 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 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 disruption states can be enumerated and we simply note Ω the (finite) set of all these random events named ω. For simplicity, the particular state ω of no-disruption is named 0. Whatever the disruption state ω, its occurrence can be appraised thanks to a 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 Ω 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. Therefore, we do not model either the individual firms' subjective perception of the disruption risk, or the difference between real risks and risk perceptions. From a practical perspective, applied procedures like the one presented in Bunn and Mustafaoglu (1978) can be used to evaluate those probabilities.

We now have to explain 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 2000s 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 the long-term bilateral arrangements 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. 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 juridical actions against long-term contracts have been withdrawn.[3] According to gas experts, the dominance of long-term supplies is fading in Western Europe but this affirmation does not hold for Eastern Europe where the upstream market structure is much more concentrated. Hereafter, we focus on the case of Eastern European gas markets.

In this paper, we do not model the competitive interactions among suppliers who compete in both price and quality of their supplies (in this context, quality would be the security of their supplies). As a result, we assume that the upstream prices of natural gas are set exogeneously.[4] Our assumptions are based on the results of the sectoral enquiry led by the European Commission (DG COMP, 2007). Firstly, 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). Secondly, 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 that price discrimination is not an issue: 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 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 the prices of oil products 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 obviously 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_ω. 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_ω 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

[3] 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.

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

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. This assumption implies that either for technical or geopolitical reasons, all retailers are affected to the same degree by the disruption. It is important to note that our framework assumes that there is no supply-side response to a disruption: the occurrence of a disruption does not modify the behavior of the non-disrupted producers. In particular, we do not model the flexibility provisions that can partially relieve the buyers' "Take or Pay"' obligations.

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 retailer under the state ω.

Added to that, two inverse demand functions are needed. In the following, we first stick to a general formulation and denote: $f(k)$ the long-run willingness to pay for the gas where f is twice differentiable and $f'(k) < 0$, and $g(k,q)$, 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 $g(k,k) = f(k)$, $(\forall k \in \mathbb{R}^{+*})$. Indeed the short-run willingness to pay for the long-run quantity is equal to the long-run willingness. In the rest of the article k (respectively q) will denote the long (respectively short)-run quantity of gas. We also use a dumb variable t to denote the long- or short-run volume when needed in an integral. To begin with, the description of f and g is kept general. A particular specification of the inverse-demand functions will be detailed later on.

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 discussion above on the rigidities of the natural gas industry). Besides, consumers are supposed to ignore the possible occurrence of sudden disruptions. Therefore, they assume that the total contracted amount of gas x^0 will be delivered. 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 compensation has to take into consideration the limited responsiveness of the short-run demand. Thus, the corresponding consumer unease can be approximated thanks to the short-run inverse demand function. For a disruption state ω, 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 the event of a disruption, requiring the virtuous retailers to pay for the consequences of risky choices made by others would obviously create an incentive for the retailers to select 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. Formally, 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:

$$DC_i(x^0, \omega) = \frac{\sum_{j \in J} (x_{ij}^0 - x_{ij}^\omega)}{x^0 - x^\omega} \int_{x^\omega}^{x^0} g(x^0, t) dt \tag{1}$$

Besides, we assume that a retailer is not required to pay the producers involved in S_ω 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 $\sum_{j \in S_\omega} p_j x_{ij}^0$.

2.3 The model

This section presents the agents' objectives. We reiterate that we need two inverse demand functions. The first one, $f(k)$ is the long-run willingness to pay for the gas. The second, $g(k, q)$ is the short-run willingness to pay for quantity q, parametrically depending on the long-run consumption k. In the following, we use a dumb variable t to denote the long- or short-run volume when needed in an integral.

Consumer: here, the decisions of the end-users are based solely 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:

$$CONS(P^\star): \quad \underset{\{k\}}{Max} \quad \int_0^k f(t)dt - P^\star k$$
$$k \geq 0$$

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 contracting behavior of a risk-neutral firm. To keep the model simple, we will not consider the case of a risk-averse firm. Thus, 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. Since we do not model possible recourse actions in case of disruption, the only decision variables are the contractual long-term volumes decided by the retailers.

$RETAILER_i$:

$$\underset{\{x^0_{ij},\, j\in J\}}{Max} \qquad \bar{\Pi}_i(x^0_{ij},(x^0_{lj})_{l\neq i}) = \sum_{j\in J}\left(f(x^0)-p_j\right)x^0_{ij} - \sum_{\omega\in\Omega\setminus\{0\}}\theta(\omega)\left(DC_i(x^0,\omega)-\sum_{j\in S_\omega}p_j x^0_{ij}\right)$$

$$x^0_{ij}\geq 0 \quad (\forall j\in J)$$

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

$$A = \sum_{j\in J}\left(f(x^0)-p_j\right)x^0_{ij} \tag{2}$$

$$B = -\sum_{\omega\in\Omega\setminus\{0\}}\theta(\omega)DC_i(x^0,\omega) \tag{3}$$

$$C = \sum_{\omega\in\Omega\setminus\{0\}}\theta(\omega)\sum_{j\in J}p_j x^0_{ij}\delta_{S_\omega}(j) \tag{4}$$

The partial derivative of $\bar{\Pi}_i$ with respect to the decision variable x^0_{ik} is given in Appendix 1.

If the problem has an interior solution, the associated KKT conditions are:

$$\text{For } x^0_{ik}\text{:} \quad 0\leq x^0_{ik} \quad \perp \quad \frac{\partial\bar{\Pi}_i}{\partial x^0_{ik}}(x^0_i)\leq 0 \tag{5}$$

where the derivative $\dfrac{\partial\bar{\Pi}_i}{\partial x^0_{ik}}(x^0_i)$ is given in Appendix 1. Once the KKT conditions are written, it is possible to solve the model and find the traders' strategic import choices.

3 Model application in two cases

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 absolute value of the long-run (respectively short-run) price elasticity is named ϵ_0 (respectively ϵ_1).

3.1 The iso-elasticity assumption

Here we follow Manne and al. (1986) and Hoel and Strøm (1987) and assume that, in the long-run, the inverse demand function is $f(k) = ak^{-\frac{1}{\epsilon_0}}$ where a is a non-negative parameter and k represents the long-run consumption amount. As a result, the short-run demand function associated with this particular long-run consumption k is given by $g(k,q) = ak^{\frac{1}{\epsilon}}q^{-\frac{1}{\epsilon_1}}$ where q is the amount of natural gas effectively consumed in the short-run and ϵ is a parameter defined so that:

$$\forall k\in\mathbb{R} \quad g(k,k) = f(k). \tag{6}$$

Thus, we have:

$$\frac{1}{\epsilon} = \frac{1}{\epsilon_1} - \frac{1}{\epsilon_0} \tag{7}$$

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:

$$\forall k \in J, \quad 0 \leq x_{ik}^0 \perp (\alpha + \beta + \gamma + \eta) \leq 0 \tag{8}$$

where

$$\alpha = x^0 - \frac{1}{\epsilon_0} x_i^0 \tag{9}$$

$$\beta = -p_k \left(1 - \Theta(k)\right) \frac{x0^{\left(1+\frac{1}{\epsilon_0}\right)}}{a} \tag{10}$$

$$\begin{aligned} \gamma = \quad & -x0^{\left(\frac{1}{\epsilon_1}\right)} \frac{\epsilon_1}{\epsilon_1 - 1} \frac{1}{\epsilon} \sum_{\omega \in \Omega} \theta(\omega) \frac{x_i^0 - x_i^\omega}{x^0 - x^\omega} \left(x0^{\left(-\frac{1}{\epsilon_1}+1\right)} - x\omega^{\left(-\frac{1}{\epsilon_1}+1\right)} \right) \\ & -x0^{\left(\frac{1}{\epsilon_1}+1\right)} \sum_{\omega \in \Omega \backslash k \notin S_\omega} \theta(\omega) \frac{x_i^0 - x_i^\omega}{x^0 - x^\omega} \left(x0^{\left(-\frac{1}{\epsilon_1}\right)} - x\omega^{\left(-\frac{1}{\epsilon_1}\right)} \right) \end{aligned} \tag{11}$$

$$\begin{aligned} \eta = \quad & -x0^{\left(\frac{1}{\epsilon_1}+1\right)} \frac{\epsilon_1}{\epsilon_1 - 1} \sum_{\omega \in \Omega \backslash k \in S_\omega} \theta(\omega) \frac{(x^0 - x^\omega) - (x_i^0 - x_i^\omega)}{(x^0 - x^\omega)^2} \left(x0^{\left(-\frac{1}{\epsilon_1}+1\right)} - x\omega^{\left(-\frac{1}{\epsilon_1}+1\right)} \right) \\ & -x_0 \sum_{\omega \in \Omega \backslash k \in S_\omega} \theta(\omega) \frac{x_i^0 - x_i^\omega}{x^0 - x^\omega}. \end{aligned} \tag{12}$$

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 Case 1: The German situation in the 1980s

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-1980s, 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 reasonable for countries where price regulation consciously limited the profitability of monopoly importers. As 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.[5]

[5] 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).

As mentioned above, these early models posited a quasi-virtuous behavior for the importer; an assumption that hardly captures Ruhrgas's past behavior.[6] 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-1970s regarding future imports planned for the 1980s. At that time, Ruhrgas 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 insufficient to serve the future demand. Those volumes had already been purchased under pre-existing long-term bilateral agreements and were considered as both known and fixed in the coming decade. Thus, imports from two resource-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 1980s.

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 θ_1 (respectively θ_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:

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

where

$$\begin{aligned} \bar{\Pi}(x_1, x_2) = \quad & f(x_0 + l)(x_0 + l) - p_1 x_1 - p_2 x_2 - \theta_1(1 - \theta_2) \int_{x_2+l}^{x_0+l} g(x_0, t)dt \\ & -\theta_2(1 - \theta_1) \int_{x_1+l}^{x_0+l} g(x_0, t)dt - \theta_1\theta_2 \int_{l}^{x_0+l} g(x_0, t)dt \\ & +\theta_1(1 - \theta_2)p_1 x_1 + \theta_2(1 - \theta_1)p_2 x_2 + \theta_1\theta_2(p_1 x_1 + p_2 x_2) \end{aligned} \tag{13}$$

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 level is assumed to be well-known. Hence, the variable l is not a decision variable. With an iso-elastic demand, we can calculate easily $\Pi(x_1, x_2)$.

[6] Ruhrgas's prices were so high at that time that BASF, the largest gas user in Germany, decided to actively search for 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).

$$
\begin{aligned}
\bar{\Pi}(x_1, x_2) = \quad & \mu(x_0+l)^{-\frac{1}{\epsilon_0}+1} \\
& +\nu(x_0+l)^{\frac{1}{\epsilon}}\left(\theta_1(1-\theta_2)(x_2+l)^{-\frac{1}{\epsilon_1}+1}+\theta_2(1-\theta_1)(x_1+l)^{-\frac{1}{\epsilon_1}+1}+\theta_1\theta_2 l^{-\frac{1}{\epsilon_1}+1}\right) \\
& -(1-\theta_1)p_1x_1-(1-\theta_2)p_2x_2
\end{aligned}
\tag{14}
$$

where

$$
\mu = a\left(1-(\theta_1+\theta_2-\theta_1\theta_2)\frac{\epsilon_1}{\epsilon_1-1}\right) \tag{15}
$$

$$
\nu = a\frac{\epsilon_1}{\epsilon_1-1}. \tag{16}
$$

We can show 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:

$$
\begin{aligned}
\frac{\partial\bar{\Pi}}{\partial x_1}(x_1, x_2) = \quad & \left(1-\frac{1}{\epsilon_0}\right)\mu(x_0+l)^{-\frac{1}{\epsilon_0}} \\
& +\frac{\nu}{\epsilon}(x_0+l)^{\frac{1}{\epsilon}-1}\left(\theta_1(1-\theta_2)(x_2+l)^{-\frac{1}{\epsilon_1}+1}+\theta_2(1-\theta_1)(x_1+l)^{-\frac{1}{\epsilon_1}+1}+\theta_1\theta_2 l^{-\frac{1}{\epsilon_1}+1}\right) \\
& +\nu(x_0+l)^{\frac{1}{\epsilon}}\left(1-\frac{1}{\epsilon_1}\right)\theta_2(1-\theta_1)(x_1+l)^{-\frac{1}{\epsilon_1}}-(1-\theta_1)p_1
\end{aligned}
\tag{17}
$$

$$
\begin{aligned}
\frac{\partial\bar{\Pi}}{\partial x_2}(x_1, x_2) = \quad & \left(1-\frac{1}{\epsilon_0}\right)\mu(x_0+l)^{-\frac{1}{\epsilon_0}} \\
& +\frac{\nu}{\epsilon}(x_0+l)^{\frac{1}{\epsilon}-1}\left(\theta_1(1-\theta_2)(x_2+l)^{-\frac{1}{\epsilon_1}+1}+\theta_2(1-\theta_1)(x_1+l)^{-\frac{1}{\epsilon_1}+1}+\theta_1\theta_2 l^{-\frac{1}{\epsilon_1}+1}\right) \\
& +\nu(x_0+l)^{\frac{1}{\epsilon}}\left(1-\frac{1}{\epsilon_1}\right)\theta_1(1-\theta_2)(x_2+l)^{-\frac{1}{\epsilon_1}}-(1-\theta_2)p_2.
\end{aligned}
\tag{18}
$$

We cannot find simple analytical expressions of the optimal imports x_1 and x_2 that guarantee a maximum profit for the German company. Hence, we have to use numerical means to solve our two-dimensional problem. Let us assume for instance that $\theta_1 = 0$, which is to say that the Norwegian supply is secure and $\theta_2 > 0$. It would be interesting to study the economic conditions that make the German retailer choose its supplies exclusively from the secure supplier. These conditions obviously take into account the relative gas prices and the disruption probability. 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:

$$
\begin{aligned}
& (x_0+l)^{eq} = (x_1+l)^{eq} \\
& \frac{\partial\bar{\Pi}}{\partial x_1}(x_1^{eq}, x_2^{eq}) = 0 \\
& \frac{\partial\bar{\Pi}}{\partial x_2}(x_1^{eq}, x_2^{eq}) \leq 0.
\end{aligned}
\tag{19}
$$

Hence, we can calculate x_1^{eq} and find conditions on the parameters θ_2, p_1 and p_2 so that $x_2^{eq} = 0$:

$$
\begin{aligned}
&x_1^{eq} + l = \left(\frac{p_1}{a\left(1-\frac{1}{\epsilon_0}\right)}\right)^{-\epsilon_0} \\
&l \leq \left(\frac{p_1}{a\left(1-\frac{1}{\epsilon_0}\right)}\right)^{-\epsilon_0} \\
&(1-\theta_2)\left(p_1 - p_2\left(1-\frac{1}{\epsilon_0}\right)\right) \leq \frac{p_1}{\epsilon_0}
\end{aligned}
\tag{20}
$$

Therefore, if the Norwegian supply is assumed to be secure and the local supply is 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):

$$
\begin{array}{ll}
p_2 > \frac{p_1}{1-\frac{1}{\epsilon_0}} & \text{the Soviet Gas is too expensive or} \\
p_2 \leq \frac{p_1}{1-\frac{1}{\epsilon_0}} \text{ and } \theta_2 > \theta_2^{lim} = 1 - \frac{p_1}{\epsilon_0\left(p_1 - p_2\left(1-\frac{1}{\epsilon_0}\right)\right)} & \text{the Soviet supply is too risky.}
\end{array}
\tag{21}
$$

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).
To keep the discussion general, this numerical study has been conducted using arbitrary units for the prices and volumes.
Figure 1 gives the evolution of θ_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 option becomes very expensive.

Figure 2 gives the evolution of the amounts x_1^{eq} and x_2^{eq} over θ_2 for $p_1 = 6$, $p_2 = 2$, in arbitrary units. θ_1 takes the value 0. It is reasonable to assume that the secure gas is more expensive than the insecure one. Otherwise Germany would not have any incentive to purchase the riskiest gas.[7]

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 strictly positive 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 bought from Norway no longer depends on the disruption probability θ_2.

Figure 3 represents the dependence of the gas price in the FRG market on the disruption probability of the Soviet gas θ_2 for $\theta_1 = 0$, $p_1 = 6$, and $p_2 = 2$.

Obviously, the price charged by the retailer increases with θ_2 to balance the possible impact of any gas disruption and reduce its inherent costs. Besides, for $\theta_2 > 0.12$, the retailer does not buy anymore gas from the USSR and there is, in that case, no risk of disruption.

[7] Obviously, the validity of this assertion is subject to the availability of an appropriate transmission infrastructure. This point lies beyond the scope of this article that assumes no infrastructure constraints.

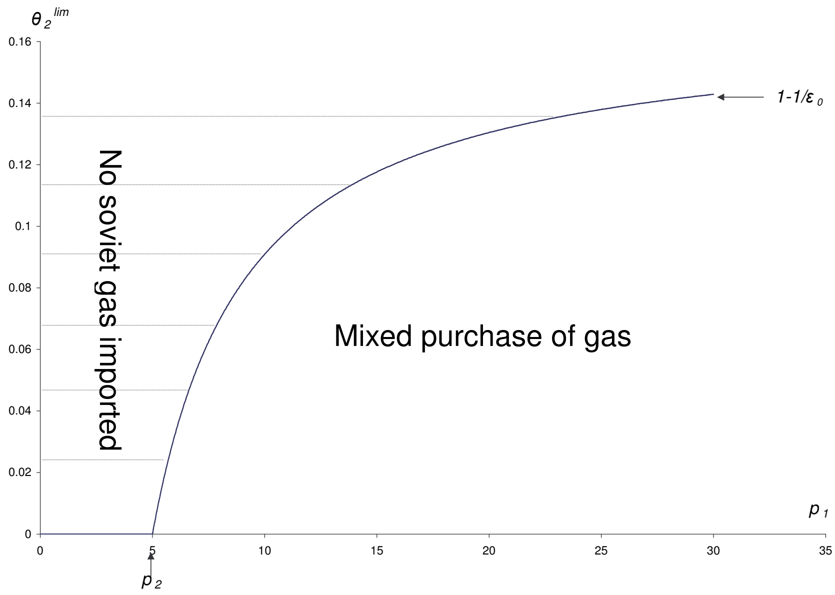

Figure 1:
Evolution of θ_2^{lim} over p_1 (arbitrary unit). $p_2 = 5$ (arbitrary unit), $\theta_1 = 0$.

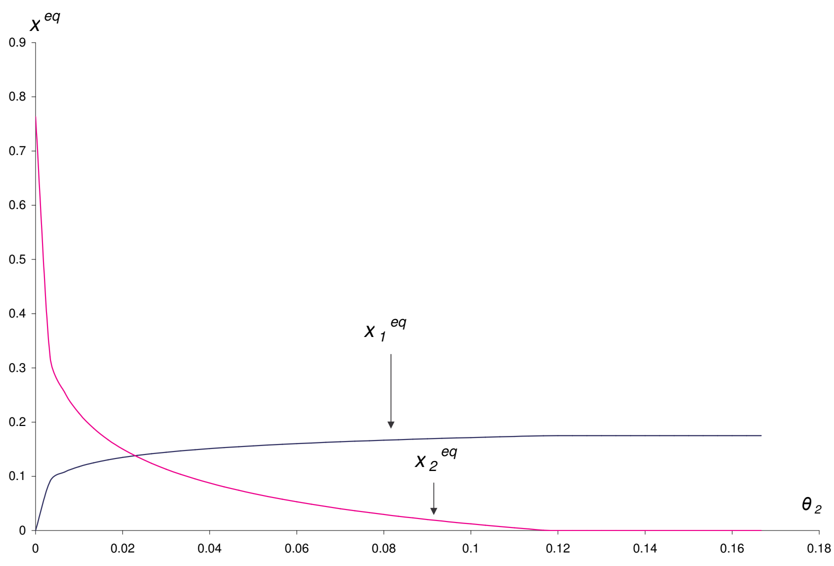

Figure 2:
Evolution of $x_{1,2}^{eq}$ over θ_2 (arbitrary unit). $p_1 = 6$, $p_2 = 2$, $\theta_1 = 0$.

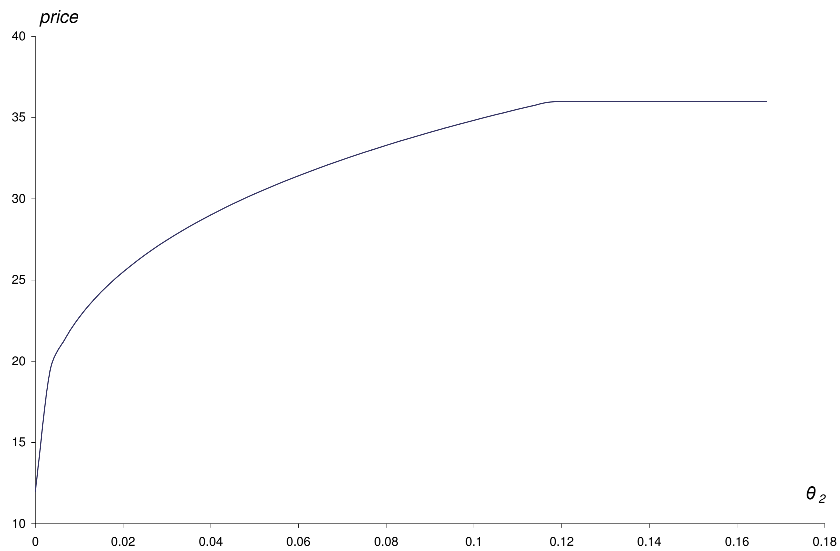

Figure 3:
Evolution of the price over θ_2 *(arbitrary units).* $p_1 = 6$, $p_2 = 2$, $\theta_1 = 0$.

Hence, the price in the market no longer depends on θ_2.

From a social welfare perspective, one can wonder whether it would be better 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 expected 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 expected profit obtained by the sole retailer:

$$W_{FRG}(x_1, x_2) = S_c(x_1, x_2) + \bar{\Pi}(x_1, x_2) \tag{22}$$

where the consumer surplus is :

$$S_c(x_1, x_2) \quad = \int_0^{x_0+l} f(t)dt - f(x_0 + l)(x_0 + l) \tag{23}$$

Therefore:

$$W_{FRG}(x_1, x_2) = a\frac{1}{\epsilon_0 - 1}(x_0 + l)^{1-\frac{1}{\epsilon_0}} + \bar{\Pi}(x_1, x_2). \tag{24}$$

The retailer's profit is given by expression (14).
Figure 4 shows how the retailer's profit and the social welfare evolve with θ_2 when $p_1 = 6$, $p_2 = 2$ (arbitrary units) and $\theta_1 = 0$.

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

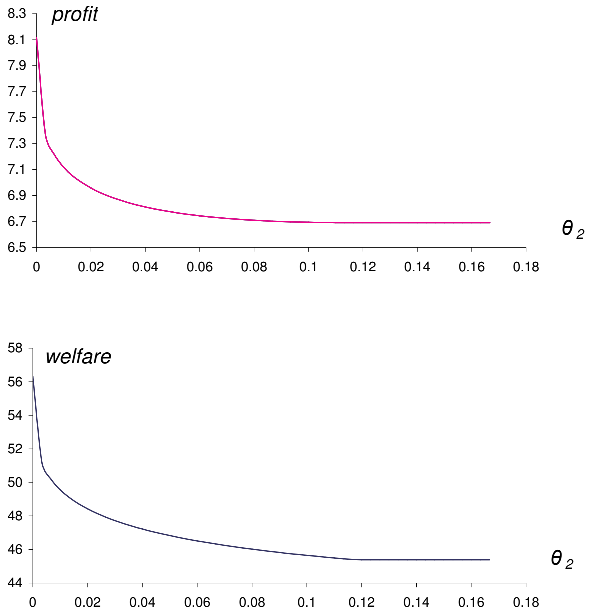

Figure 4:
Evolution of the profit and social welfare over θ_2 *(arbitrary unit).* $p_1 = 6$, $p_2 = 2$ *(arbitrary units),* $\theta_1 = 0$.

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:

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

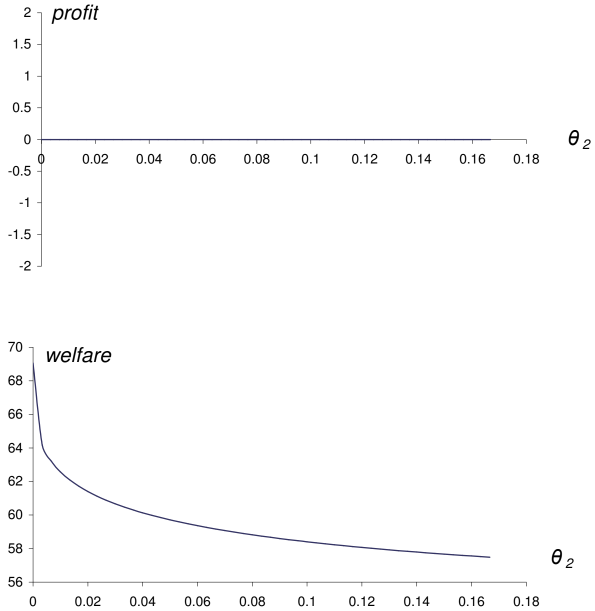

Figure 5:
Evolution of the profit and social welfare over θ_2 (arbitrary unit). $p_1 = 6$, $p_2 = 2$ (arbitrary units), $\theta_1 = 0$, welfare-maximizing agent.

Figure 5 gives the evolution of Ruhrgas's profit $\bar{\Pi}$ and the social welfare W_{FRG} over the Russian disruption probability θ_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 1980s (Radetzki, 1992), we think that it is more reasonable to model its behavior using a profit-maximizing perspective.
Figure 6 gives the evolutions of the equilibrium quantities x_1^{eq} and x_2^{eq} over the disruption probability θ_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 θ_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.

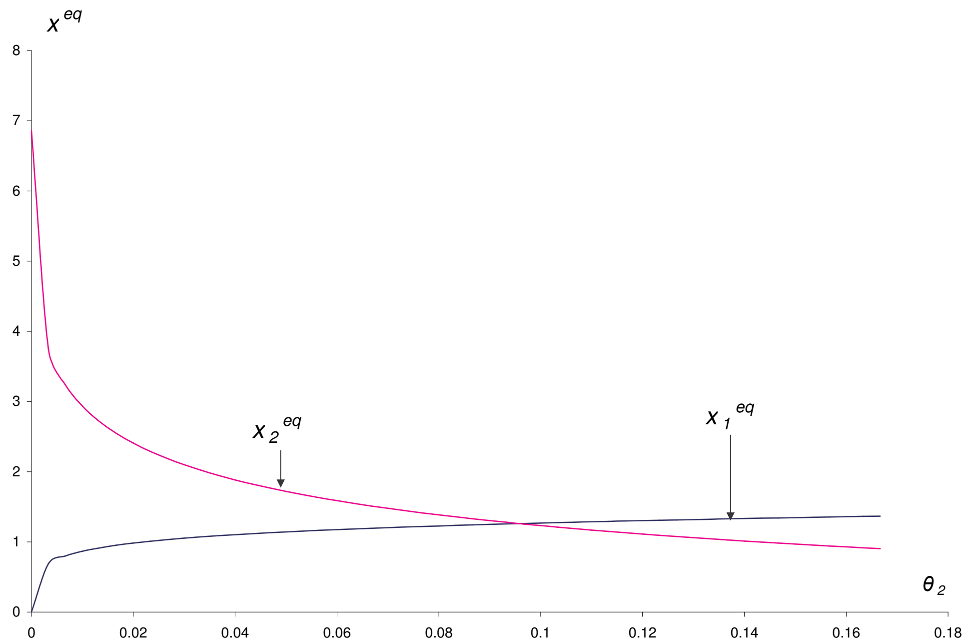

Figure 6:
Evolution of the x_1^{eq} *and* x_2^{eq} *over* θ_2 *(arbitrary unit).* $p_1 = 6$, $p_2 = 2$ *(arbitrary units),* $\theta_1 = 0$, *welfare-maximizing agent.*

3.3 Case 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 population unable to heat their homes.[8] 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.[9] A

[8] An early description of these consequences can be found in Pirani et al. (2009, p. 53-56)

[9] This is the explicit goal of the Southeast Europe Energy Community Treaty that came into force on July 1, 2006.

separation between regulated infrastructure-related activities and retail activities similar to the one currently at work in Western Europe is expected.
Some pertinent insights for the natural gas market can be obtained from our model. Until now, the Bulgarian gas industry has been 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 import 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. 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 us 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 θ the probability that Russia cuts its production, either for technical, economical or political reasons. The price charged by the producer is p, the elasticity values for the short- and long-run demands are respectively $\epsilon_1 = 0.3$ and $\epsilon_0 = 1.2$.[10] 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 the event of disruption. The maximization problem can thus be written for each firm i:

$$\begin{aligned} \text{Max} \quad & (f(x_0) - p)x_i - \theta \tfrac{x_i}{x_0} \int_c^{x_0} g(x_0, t)dt + \theta p x_i \\ & x_i \geq 0 \end{aligned} \tag{25}$$

We denote by Π 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 iso-elastic functional form, we have

$$\Pi(x_i) = a x_0^{-\frac{1}{\epsilon_0}} x_i \left(1 - \theta \frac{\epsilon_1}{\epsilon_1 - 1}\right) + \theta a \frac{\epsilon_1}{\epsilon_1 - 1} c^{-\frac{1}{\epsilon_1}+1} x_i x_0^{\frac{1}{\epsilon}-1} - p(1-\theta)x_i \tag{26}$$

We can show 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

$$\alpha = a \left(1 - \theta \frac{\epsilon_1}{\epsilon_1 - 1}\right) \tag{27}$$

[10] 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.

$$\beta = \theta a \frac{\epsilon_1}{\epsilon_1 - 1} c^{-\frac{1}{\epsilon_1}+1} \tag{28}$$

The first-order conditions calculation gives:

$$\frac{\partial \Pi}{\partial x_i}(x_i) = \alpha x_0^{-\frac{1}{\epsilon_0}-1}\left(x_0 - \frac{x_i}{\epsilon_0}\right) + \beta x_0^{\frac{1}{\epsilon}-2}\left(x_0 + \left(\frac{1}{\epsilon} - 1\right) x_i\right) - p(1-\theta) \tag{29}$$

Appendix 2 gives the technical study of the dependence of the gas volume and price in the Bulgarian market over the problem's parameters.
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.

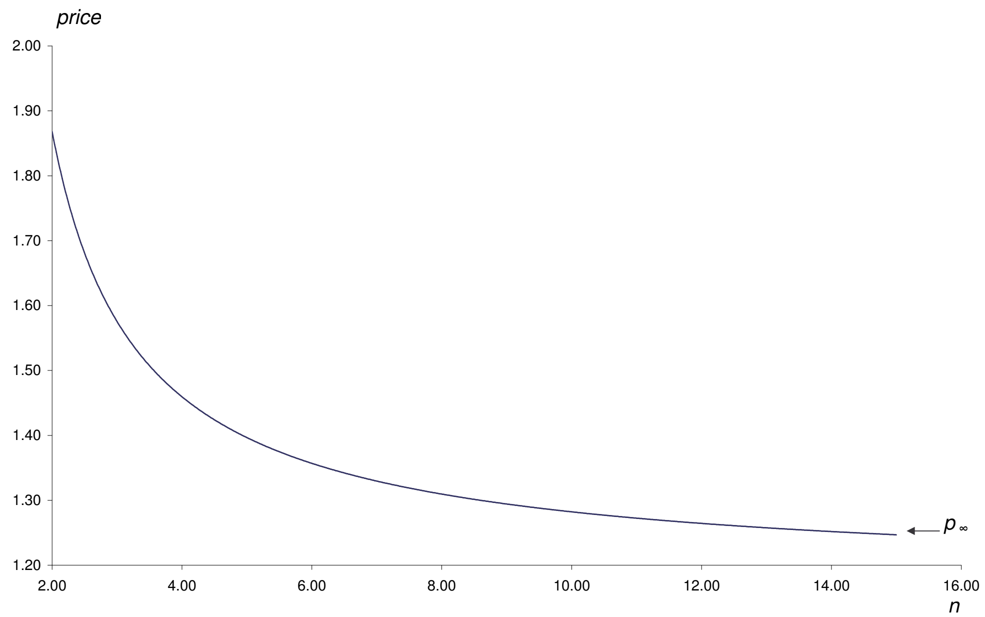

Figure 7:
Evolution of the gas price in the market over n. $\theta = 0.15$, and $c = 0.4$ in an arbitrary unit.

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_∞, that can be calculated. For this purpose, we need to study the convergence of the sequence $nx_{eq}(n)$ when $n \longrightarrow \infty$. This study is carried out in Appendix 3.

Figure 8 shows how p_∞ evolves with θ 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 $p_\infty(0) = p$.

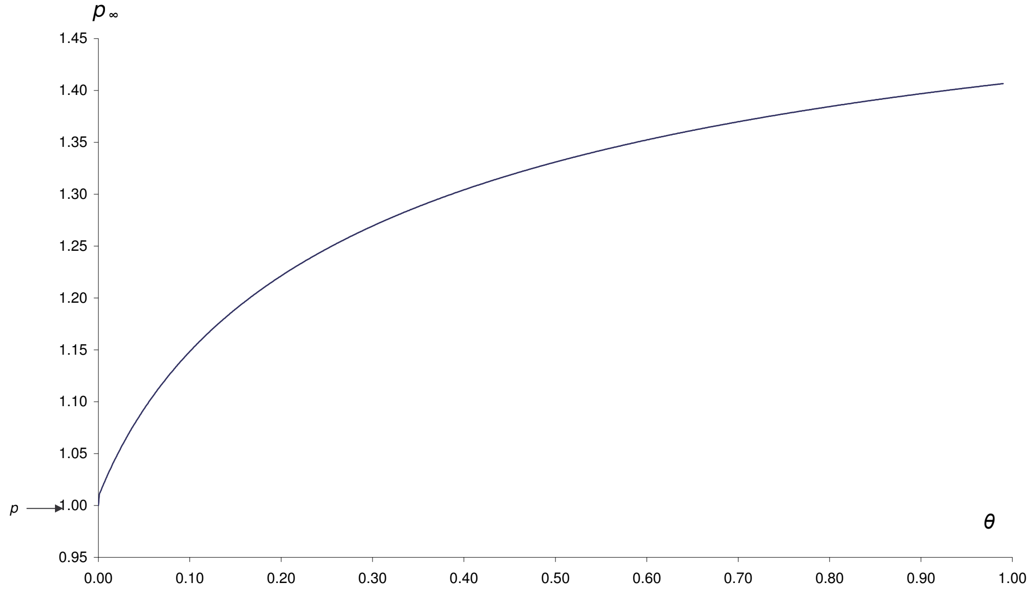

Figure 8:
Evolution of p_∞ (arbitrary unit) over θ. $c = 0.4$ in an arbitrary unit.

The conclusion we can draw from the pure and perfect competition 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 consumers are compensated if disruption occurs. This indicates that, added to the "oligopolistic margin", there exists a "security margin" charged by the retailers to compensate the disruption costs they have to support in case of supply failure. This "security margin" increases with the disruption risk θ. This study illustrates how the disruption costs are passed along to consumers: the consumer surplus is thus a decreasing function of the disruption risk.

As far as retailers' profit is concerned, we can prove that the industry's total expected profit is nought and does not vary with θ. A formal proof of this result is given in Appendix 5. Therefore, the total revenue derived from the non-negative difference between import and retail price is exactly equal to the expected total disruption cost. As a result, the national welfare of this importing country is a decreasing function of the disruption probability θ.

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

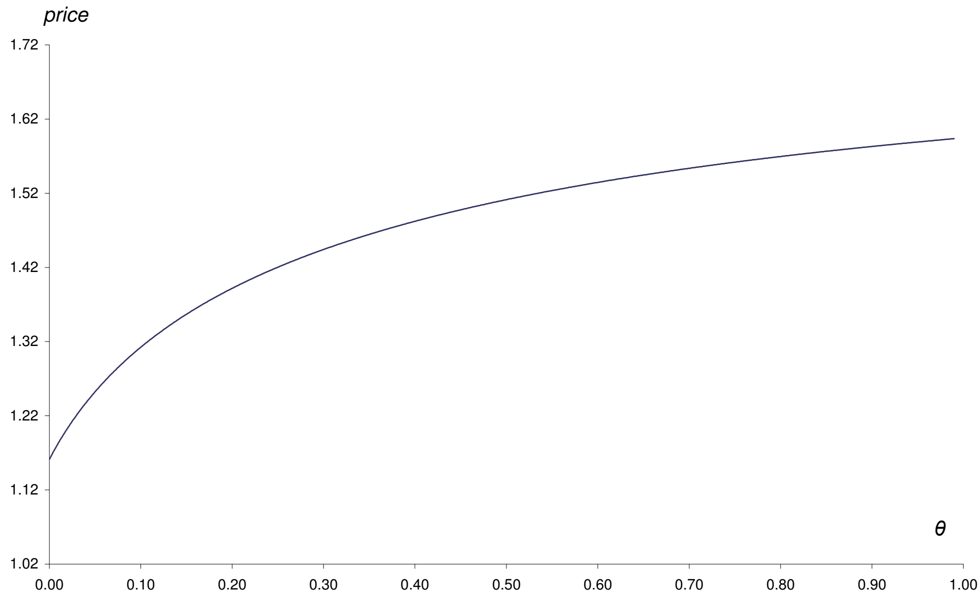

Figure 9:
Evolution of the gas price in the market (arbitrary unit) over θ. $n = 6$ and $c = 0.4$ in an arbitrary unit.

The price increases with the probability θ 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 us study now the impact of any disruptive behavior on the gas amount imported to the Bulgarian market. We also study the possibility of controlling the market by a national gas regulator. In this paper, we assume the existence of an efficient social welfare maximizing regulator that has a perfect information on contract prices, disruption probabilities and disruption costs.[11] Among the large set of possible regulatory instruments (e.g. imposing the firms to hold some precautionary storage), we focus on a possible regulatory intervention on the firms' contracting decisions. More specifically, let us 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).

[11] Thus, we do not model the principal-agent interactions between the regulator and the regulated firms.

We denote by W the total social welfare:

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

where

$$\begin{aligned} W_{consumers} &= \int_0^{x_0} f(t)dt - f(x_0)x_0 && \text{Consumer surplus} \\ W_{retailers} &= \sum_{i=1}^{n} \left((f(x_0) - p)x_i - \theta \frac{x_i}{x_0} \int_c^{x_0} g(x_0, t)dt + p\theta x_i \right) && \text{Retailers' profits} \end{aligned} \tag{30}$$

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

$$W(x) = \tau n^{-\frac{1}{\epsilon_0}+1} x^{-\frac{1}{\epsilon_0}+1} + \beta n^{\frac{1}{\epsilon}} x^{\frac{1}{\epsilon}} - np(1-\theta)x \tag{31}$$

where

$$\tau = a \left(\frac{\epsilon_0}{\epsilon_0 - 1} - \theta \frac{\epsilon_1}{\epsilon_1 - 1} \right) \tag{32}$$

$$\beta = \theta a \frac{\epsilon_1}{\epsilon_1 - 1} c^{-\frac{1}{\epsilon_1}+1}. \tag{33}$$

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.

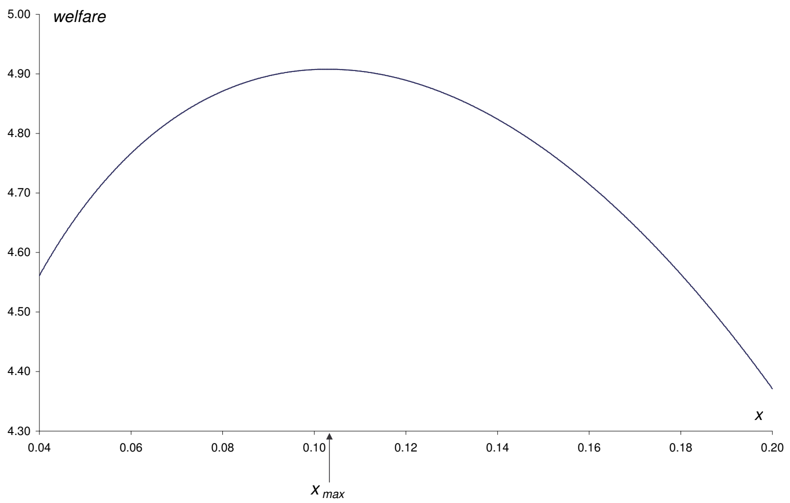

Figure 10:
Evolution of the social welfare over x (arbitrary units). $\theta = 0.15$, $n = 6$, and $c = 0.4$ (arbitrary units).

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 θ for $n = 6$ and $c = 0.4$ in arbitrary units. We notice that there is a specific disruption probability θ_{lim}, that depends only on the inner-market characteristics (i.e. ϵ_0, ϵ_1, n, c, a and p) such as:

$$\begin{array}{ll} \text{if } \theta \leq \theta_{lim} & x_{eq} \leq x_{max} \\ \text{if } \theta > \theta_{lim} & x_{eq} > x_{max} \end{array} \tag{34}$$

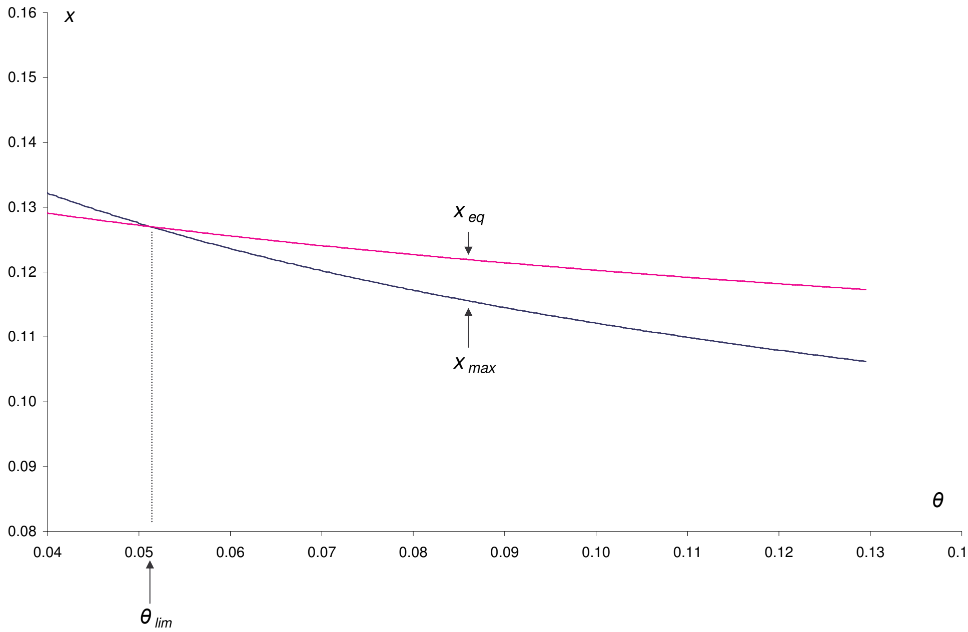

Figure 11:
Evolution of x_{eq} and x_{max} (arbitrary units) over θ. $n = 6$ and $c = 0.4$ (arbitrary unit).

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 $x_{max}(\theta)$. 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 θ_{lim}, that is the regulation determining factor, over the alternative import capacity amount c. Economically speaking, it is easy to predict that this probability increases with c. Indeed, if the alternative gas import capacity is high in the event of an emergency, it is possible to tolerate frequent disruptions, without any regulation. Figure 12 represents the evolution of θ_{lim} over the capacity c, for $n = 6$, $p = 1$ and $a = 1$ in arbitrary units.

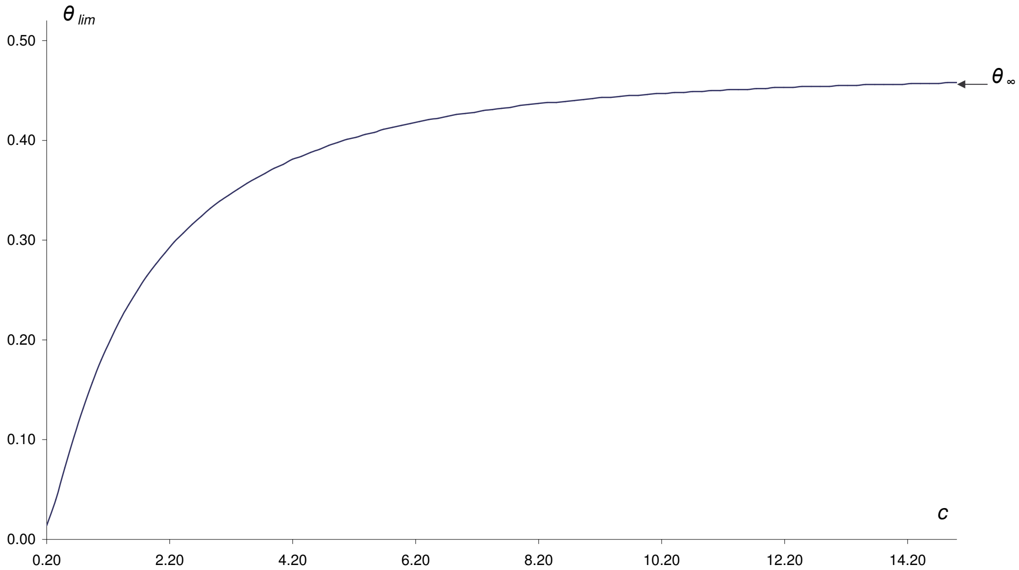

Figure 12:
Evolution of θ_{lim} over c (arbitrary unit). $n = 6$.

We notice that the probability θ_{lim} converges, for large capacities towards a finite value θ_{∞} that depends only on ϵ_0, ϵ_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 of import volumes must always be imposed in order to optimize the social welfare regardless of the alternative import amount c.

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 develop 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 previous models found in the literature do not take into account the current economic situation of the energy markets in Europe, because they assume a pure and perfect competition structure. Since their liberalization, an oligopolistic description that takes into consideration market powers exerted through the gas chain is more suitable to study the European natural gas markets. In our model, the upstream market is represented as follows: the retailers sign long-term contracts with 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 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 consumers in case of supply interruption from risky producers. Disruption costs can be quantified by introducing a short-run demand function. 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 1980s, which is represented by the interaction between one big retailer, 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 shown 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 determined and that depend only on the inner market characteristics, no Russian gas would be brought to Germany by Ruhrgas AG as this would decrease its profit. We also show that the price charged by Ruhrgas in the German market would increase with the disruption probability. The Bulgarian gas market is also a case analyzed thanks to our model: we assume the existence of a certain number of retailers that buy gas mostly from one risky producer: Gazprom. The main conclusions we can draw from our study are the following: Firstly, the gas price in the market, 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. This indicates that, added to the "oligopolistic margin", there exists a "security margin" charged by the retailers to compensate the disruption costs they have to support in the event of supply failure. This "security margin" increases with the disruption risk. Secondly, we show that, under some specific assumptions on the local force majeure supplies, the pure and perfect competition price increases with the Russian disruption probability. Finally, we show the existence of a threshold probability such as if the disruption probability is greater than the threshold, 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.
The results of this paper are obtained by assuming the predominance of disruption costs in a firms' decisions, thereby a negligible role is thus given to the alternative crisis management techniques: strategic withdrawal from existing natural gas storages, alternative short-term imports, re-routing of existing gas flows, increased production from other suppliers that may compensate the shortfall of others. Following the impressive disruptions that occurred in Eastern Europe, concerns about the security of supply are now back at

the top of the policy makers' agenda. The identification of the optimal measures to be implemented in the short-run to cope with a disruption is still an on-going issue. As a result, future research could expand the framework discussed in this paper in order to identify optimal crisis management policies.

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Appendix 1

In this appendix, we calculate the partial derivative of $\bar{\Pi}_i$ with respect to the decision variable x^0_{ik}. This derivative is the sum of three terms: $\frac{\partial A}{\partial x^0_{ik}}, \frac{\partial B}{\partial x^0_{ik}}$ and $\frac{\partial C}{\partial x^0_{ik}}$ with:

$$\frac{\partial A}{\partial x^0_{ik}} = f'(x^0)\sum_{j\in J} x^0_{ij} + f(x^0) - p_k \quad (35)$$

$$\frac{\partial C}{\partial x^0_{ik}} = p_k \sum_{\{\omega\in\Omega\backslash\{0\},k\in S_\omega\}} \theta(\omega) \quad (36)$$

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

$$\frac{\partial B}{\partial x^0_{ik}} = -\sum_{\{\omega\in\Omega\backslash\{0\},k\notin S_\omega\}} \theta(\omega)\frac{\partial DC_i(x^0,\omega)}{\partial x^0_{ik}} - \sum_{\{\omega\in\Omega\backslash\{0\},k\in S_\omega\}} \theta(\omega)\frac{\partial DC_i(x^0,\omega)}{\partial x^0_{ik}} \quad (37)$$

Let us consider a particular producer k and buyer i. The distinction among the two cases is important since the partial derivative of $DC_i(x^0,\omega)$ with respect to x^0_{ik} takes a different literal 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^0_{ik} is both present in the overall disrupted volumes $(x^0 - x^\omega)$ as well as in i's disrupted purchases $\sum_{j\in J}(x^0_{ij} - x^\omega_{ij})$. In the other case (when k does not cut its production), both the overall disrupted quantities $(x^0 - x^\omega)$ and $\sum_{j\in J}(x^0_{ij} - x^\omega_{ij})$ become independent on the variable x^0_{ik}. Moreover, in the latter case, the integral boundaries can be manipulated so as to avoid any dependence on x^0_{ik}.

If $k \in S_\omega$,

$$\frac{\partial DC_i(x^0,\omega)}{\partial x^0_{ik}} = \frac{\sum_{\substack{(l,j)\in I\times J\\ l\neq i}} \left(x^0_{lj} - x^\omega_{lj}\right)}{(x^0 - x^\omega)^2}\int_{x^\omega}^{x^0} g(x^0,t)dt + \frac{\sum_{j\in J}\left(x^0_{ij} - x^\omega_{ij}\right)}{x^0 - x^\omega}\left(\int_{x^\omega}^{x^0}\frac{\partial g}{\partial k}(x^0,t)dt + f(x^0)\right) \quad (38)$$

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

$$\frac{\partial DC_i(x^0,\omega)}{\partial x^0_{ik}} = \frac{\sum_{j\in J}\left(x^0_{ij} - x^\omega_{ij}\right)}{x^0 - x^\omega}\left(\int_{x^\omega - x^0}^{0}\frac{\partial g}{\partial k}(x^0, t + x^0)dt\right). \quad (39)$$

Appendix 2

In this appendix, we theoretically solve the retailers' optimization problems given in formulation 25 of section 3.3.

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 25 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 us call x_{eq} the equilibrium quantity bought by each retailer and use the first-order condition to find it. We can deduce an implicit function that gives x_{eq} (i.e. a relation between x_{eq} and the problem's parameters) from expression 29:

$$\alpha n^{-1-\frac{1}{\epsilon_0}}\left(n-\frac{1}{\epsilon_0}\right)x_{eq}^{-\frac{1}{\epsilon_0}}+\beta n^{\frac{1}{\epsilon}-2}\left(\frac{1}{\epsilon}-1+n\right)x_{eq}^{\frac{1}{\epsilon}-1}-(1-\theta)p=0 \tag{40}$$

Actually, it is not possible to find general analytical expressions of the solution for 40. We will use numerical means to solve it. However, we can already predict that equation (40) 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 θ and the number of retailers n.

$$price = a(nx_{eq})^{-\frac{1}{\epsilon_0}} \tag{41}$$

Appendix 3

This appendix studies the price behavior in the pure and perfect competition context p_∞.

Let us denote $\rho_n = nx_{eq}(n)$. Using equation 40 we deduce that ρ_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 us call f the function: $\mathbb{R}_+^* \longrightarrow \mathbb{R}$

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

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

$$\alpha\left(\rho_n^{-\frac{1}{\epsilon_0}}-\rho^{-\frac{1}{\epsilon_0}}\right)+\beta\left(\rho_n^{\frac{1}{\epsilon}-1}-\rho^{\frac{1}{\epsilon}-1}\right)=\frac{1}{n}\left(\frac{\alpha}{\epsilon_0}\rho_n^{-\frac{1}{\epsilon_0}}+\beta\left(\frac{1}{\epsilon}-1\right)\rho_n^{\frac{1}{\epsilon}-1}\right) \tag{42}$$

We can show easily that $\exists M\in\mathbb{R}_+^*$ such as $\forall n\in\mathbb{N}^*$ $|\rho_n|<M$ (that is to say the sequence ρ_n is boundned). Using equation 42, 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_∞:

$$p_\infty = a\rho^{-\frac{1}{\epsilon_0}} \tag{43}$$

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

$$\frac{\mathrm{d}\rho}{\mathrm{d}\theta}(\theta) = \frac{-p + \frac{\epsilon_1}{\epsilon_1-1}a\rho^{-\frac{1}{\epsilon_0}} - \frac{\epsilon_1}{\epsilon_1-1}ac^{1-\frac{1}{\epsilon_1}}\rho^{-\frac{1}{\epsilon}-1}}{-\frac{1}{\epsilon_0}\alpha\rho^{-\frac{1}{\epsilon_0}-1} + \beta\left(\frac{1}{\epsilon}-1\right)\rho^{\frac{1}{\epsilon}-1}} = \frac{-1}{\theta}\frac{1}{-\frac{1}{\epsilon_0}\alpha\rho^{-\frac{1}{\epsilon_0}-1} + \beta\left(\frac{1}{\epsilon}-1\right)\rho^{\frac{1}{\epsilon}-1}}\left(p - a\rho^{-\frac{1}{\epsilon_0}}\right). \tag{44}$$

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 show (see Appendix 4) that

$$\forall\theta \in [0,1] \quad p \le a\rho(\theta)^{-\frac{1}{\epsilon_0}}. \tag{45}$$

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

$$\forall\theta \in [0,1] \quad \frac{\mathrm{d}p_\infty}{\mathrm{d}\theta}(\theta) \ge 0. \tag{46}$$

On the contrary, if $c > \left(\frac{p}{a}\right)^{-\epsilon_0}\epsilon_1^{\frac{\epsilon_1}{1-\epsilon_1}}$, we show that (see Appendix 4):

$$\forall\theta \in [0,1] \quad \frac{\mathrm{d}p_\infty}{\mathrm{d}\theta}(\theta) \le 0. \tag{47}$$

Appendix 4

In this appendix, we show the properties stated in Appendix 3:

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

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

- We assume $c < \left(\frac{p}{a}\right)^{-\epsilon_0}\epsilon_1^{\frac{\epsilon_1}{1-\epsilon_1}}$

  Let us suppose that $\exists\theta_0 \in [0,1[$ such as $p \ge a\rho(\theta_0)^{-\frac{1}{\epsilon_0}}$. Using equation 44, we have $\frac{\mathrm{d}\rho}{\mathrm{d}\theta}(\theta_0) > 0$. We define θ_1 as follows:

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

  and let us show 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 44 we find that $p = a\rho(\theta_0)^{-\frac{1}{\epsilon_0}}$. However, we know that $\forall\theta \in [\theta_0, \theta_1[$ $\frac{\mathrm{d}\rho}{\mathrm{d}\theta}(\theta) > 0$. 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 $p \ge a\rho(\theta)^{-\frac{1}{\epsilon_0}}$. Thus we find

  $$p \ge a\rho(\theta_0)^{-\frac{1}{\epsilon_0}} > a\rho(\theta_1)^{-\frac{1}{\epsilon_0}} = p \tag{48}$$

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

$$p > a\rho(1)^{-\frac{1}{\epsilon_0}}. \tag{49}$$

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

$$\rho(1) = c\epsilon_1^{\frac{\epsilon_1}{\epsilon_1 - 1}} \tag{50}$$

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

$$a\rho(1)^{-\frac{1}{\epsilon_0}} > p \tag{51}$$

which is absurd, regarding equation 49.

Hence:

$$\forall \theta \in [0, 1] \quad p \leq a\rho(\theta)^{-\frac{1}{\epsilon_0}} \tag{52}$$

- 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 show 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 θ_1 the probability:

$$\theta_1 = \inf\{\theta \in [\theta_0, 1[\;/\; \frac{\mathrm{d}\rho}{\mathrm{d}\theta}(\theta) \geq 0\}. \tag{53}$$

  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:

$$p = a\rho(\theta_1)^{-\frac{1}{\epsilon_0}} > a\rho(\theta_0)^{-\frac{1}{\epsilon_0}} \geq p \tag{54}$$

  which is absurd. Thus our conclusion.

Appendix 5

In this appendix, we show that the retailers' profit in the Bulgarian market is equal to 0, in the situation of pure and perfect competition. We will use the notation of Appendix 3. The retailer's total profit is:

$$\Pi_{tot} = \sum_i \Pi_i = n\Pi(x_i) \tag{55}$$

where the individual profit $\Pi(x_i)$ is given in equation 26. Hence:

$$\Pi_{tot} = \alpha\rho^{-\frac{1}{\epsilon_0}+1} + \beta\rho^{\frac{1}{\epsilon}} - (1-\theta)p\rho \tag{56}$$

where α and β have been defined in section 3.3 and the variable ρ in Appendix 3.
We already know (Appendix 3) that ρ is such that $f(\rho) = 0$, where the function f is defined in Appendix 3. It is easy to notice that:

$$\Pi_{tot} = \rho f(\rho) \tag{57}$$

Therefore:

$$\Pi_{tot} = 0 \tag{58}$$

Thus our conclusion.