DIW Berlin

German Institute
for Economic Research

Discussion Papers

551

Franziska Holz
Christian von Hirschhausen
Claudia Kemfert

A Strategic Model of European Gas Supply (GASMOD)

Berlin, January 2006

IMPRESSUM
© DIW Berlin, 2006
DIW Berlin
German Institute for Economic Research
Königin-Luise-Str. 5
14195 Berlin
Tel. +49 (30) 897 89-0
Fax +49 (30) 897 89-200
www.diw.de

ISSN print edition 1433-0210
ISSN electronic edition 1619-4535

DIW Berlin

Discussion Papers 551

Franziska Holz*
Christian von Hirschhausen**
Claudia Kemfert***

A Strategic Model of European Gas Supply (GASMOD)

Berlin, Januar 2006

* DIW Berlin, Department of International Economics, fholz@diw.de
** DIW Berlin, Research Professor, and Dresden University of Technology, Chair of Energy Economics and Public Sector Management, chirschhausen@diw.de
*** DIW Berlin, Department of Energy, Transport, and Environment, and Humboldt-University Berlin, ckemfert@diw.de

Abstract:
Structural changes in the European natural gas market such as liberalization, increasing demand, and growing import dependency have triggered new attempts to model this market accurately. This paper presents a model of the European natural gas supply, GASMOD, which is structured as a two-stage-game of successive natural gas exports to Europe (upstream market) and wholesale trade within Europe (downstream market), and which explicitly includes infrastructure capacities. We compare three possible market scenarios: Cournot competition on both markets, perfect competition on both markets, and perfect competition on the downstream with Cournot competition on the upstream market. We find that Cournot competition on both markets is the most realistic representation of today's European natural gas market, where suppliers at both stages generate a mark-up at the expense of the final customer (double marginalization). Our results yield a diversified supply portfolio with newly emerging (LNG) exporters gaining market shares. Enforcing perfect competition on the European downstream market would in positive welfare effects. The limited infrastructure strongly influences the results, and we identify bottlenecks mainly for intra-European trade relations whereas transport capacity on the upstream market is sufficient (with the exception of Norwegian exports) in the Cournot scenario.

Zusammenfassung:

Der europäische Erdgasmarkt erfährt derzeit tiefgreifende Veränderungen wie Liberalisierung, steigende Nachfrage und steigende Importabhängigkeit. Dies hat zu verstärkten Bemühungen geführt, den europäischen Erdgasmarkt korrekt abzubilden. Das hier vorgestellte Modell GASMOD stellt den europäischen Erdgasmarkt als ein zweistufiges Spiel dar. Auf der ersten Stufe erfolgen Exporten nach Europa, auf der zweiten Stufe wird Großhandel innerhalb Europas betrieben; Infrastrukturkapazitäten werden auf beiden Stufen explizit einbezogen. Wir vergleichen drei Szenarien: Cournot-Wettbewerb auf beiden Marktstufen, vollständiger Wettbewerb auf beiden Stufen, sowie Cournot-Wettbewerb auf der Export- und vollständigen Wettbewerb auf der Großhandelsstufe. Wir zeigen, dass zweistufiger Cournot-Wettbewerb (doppelte Marginalisierung) den heutigen europäischen Erdgasmarkt am besten abbildet. In unseren Ergebnissen erhalten wir ein diversifiziertes Importportfolio für Europa. Neu auf den Markt kommende Flüssiggas (LNG-) Exporteure gewinnen Marktanteile. Vollständiger Wettbewerb auf dem europäischen Großhandelsmarkt würde positive Wohlfahrtseffekte bringen. Die beschränkten Infrastrukturkapazitäten beeinflussen die Ergebnisse maßgeblich. Engpässe treten hauptsächlich im inner-europäischen Handel auf, allerdings nicht auf der Exportstufe; die einzige Ausnahme sind die norwegischen Exportkapazitäten.

Keywords: natural gas, strategic behavior, non-linear optimization, Europe

JEL classifications: L13, L95, C61

Acknowledgements: We would like to thank Ferdinand Pavel and Vitaly Kalashnikov for their many helpful comments and suggestions. This paper also benefited from comments by the participants of the Infratrain workshops on gas market modeling organized by TU Berlin and DIW Berlin in 2004 and 2005, the EMF 23 Modeling Workshops Washington, D.C. in December 2004 and December 2005, the 6th European IAEE Conference Bergen/Norway August 2005, and the 4th Conference on Applied Infrastructure Research Berlin October 2005. The usual disclaimer applies.

1 Introduction

The natural gas market in the European Union is undergoing considerable change. Three main challenges for the next decades can be identified: the liberalization of the industry initiated by the European Commission, an increasing demand for natural gas and, simultaneously, an increasing import dependency on gas supplied from outside the European Union. These changes and the high political stakes motivate a closer look at the gas sector. The market structure within the European Union as well as the import relations to gas producing countries are issues that need further research. The numerical simulation model developed in this paper, called "GASMOD", is a contribution to this research, taking a close look at demand and supply structures, and in particular at the infrastructure component. The static version of GASMOD presented in this paper aims at combining a realistic representation of the market structure with an analysis of required infrastructure. The remainder of the paper is structured as follows: after a survey of the literature, we outline the current state of the literature and the structure of the European gas market, with an emphasis on natural gas trade. We then explain the model and the data used. The subsequent simulation results are carried out in order to determine the "benchmark" model specification for the reference year. They will be followed by the conclusions.

2 State of the literature

The GASMOD model follows a number of other modeling attempts of the European gas sector. The apparent structure of the sector suggests modeling the market with oligopolistic competition in a game theoretic framework. Mathiesen et al. (1987) are the first in the recent literature to study market power in the European natural gas market. They are followed by Golombek et al. (1995) and Golombek et al. (1998) who analyze the effects of liberalizing the natural gas market in Western Europe, distinguishing between upstream (producers) and downstream (traders) agents on the gas market. Here, liberalization of the European gas market is defined as the situation where downstream traders can exploit arbitrage possibilities between countries as well as between market segments (industry, and local distribution companies for households). The numerical simulation of their model indicates that liberalization increases upstream competition and thus welfare. Golombek et al. (1995) have had a lasting influence on the further research in the field because they suggested marginal cost curves for several natural gas producers (Algeria, Russia/CIS, the Netherlands, Norway, and the United Kingdom) which have been widely used since.

However, analyzing energy markets with large-scale simulation models, in terms of data input, regional dis-aggregation, etc, quickly reaches computational limits. For this reason there exist a number of linear programming models of the European, the North American or the global natural gas market. The main drawback to this type of model is the underlying assumption of perfect competition which is not satisfying at least for the European market. Generally, these models optimize social welfare which seems to be an unrealistic abstraction of a market where oligopolistic firms determine supply and prices. Within the group of linear models and specifically for the European market, the EUGAS model (Perner (2002), Perner and Seeliger (2004)) is a dynamic model of long-term optimization of European gas supply, taking into account production and transport capacities, but treating gas demand exogenously. With its rich data base and its dynamic investment modeling, the EUGAS model has been the basis for several extensions, as e.g. the combination with electricity market models (Perner (2002), Bartels and Seeliger (2005)), the introduction of global gas reserves (Düweke and Hamacher (2005)), and the extension to a global model currently under way.

Besides models of partial equilibrium, there also exist general equilibrium models with a high disaggregation for the gas sector. One example is the World Gas Trade Model (Hartley and Medlock (2004)). However, these models work with the underlying assumption of perfect competition as well, which makes them less appropriate for the studying the European market.

As highlighted by the first modeling attempts of the 1990s, the European natural gas market is characterized by an oligopolistic market structure with a small number of producers with access to Europe, as well as a small number of wholesale traders on the European market. The NATGAS model (Mulder and Zwart (2005)) therefore chooses the representation of an oligopolistic producer market where a small number of strategic natural gas producers are facing price-taking arbitragers (traders) on the downstream market. A similar market setting is applied in Egging and Gabriel (forthcoming) where the strategic producers bid with conjectured supply functions, as in several electricity market models.

provide an extensive survey of strategic models for restructured natural gas markets, insisting on the fact that single stage models are generally easy to formulate, but that two stage models are more appropriate to capture the intricate reality of (European and other) natural gas markets; however, they are also more complex leading to possible avenues for future mathematical programming research. The GASTALE model (Boots et al. (2004)) is the first attempt to apply the structure of successive oligopoly in gas production and trading in a large-scale simulation model. This model is similar to ours in that its underlying structure is a two-stage game. However, a number of simplifying assumptions, such as symmetry of traders, diminish the generality of this approach of double marginalization. Moreover, Boots et al. (2004)assume the domestic production to be an exogenous value instead of including it in the optimization. Another difference with GASMOD (see details in section 3) is the use of cost functions and linear demand functions from Golombek et al. (1995). Whereas the static GASTALE model does not consider infrastructure capacity limitations, its recent dynamic version includes investments in scarce transport and production infrastructure (Lise et al. (2005)).

3 Structure and Dynamics of the European Natural Gas Sector

There are currently changes ongoing on the demand as well as on the supply side of the European natural gas sector. These changes do not only have an impact on the natural gas market within Europe but also on the supply relations between Europe and other gas producing countries. Hence, the gas sector has been identified as a strategic sector by the European Commission (European Commission (2001)) and by the International Energy Agency (IEA). Let us briefly examine the three main challenges for the sector:

- First, the European Commission has pushed for a progressive liberalization of the European natural gas sector, a process that is still ongoing.[1] Ownership unbundling, third party access to gas transport infrastructure, end of the destination clause are some of the keywords in this process. Liberalization of the downstream wholesale market and of gas distribution has led to a reduction of the part of long-term contracts in the supply relationships. Previous liberalization experiences in the US and the UK have shown that the share of long-term contracts diminishes, although it always remains (well) above 50% (IEA (2004c)).[2] However, the natural gas sector in many European countries still is characterized by *de facto* national monopolies of wholesale trading (e.g. Gaz de France in France, ENI in Italy, ENAGAS in Spain), or by a very limited number of active companies (e.g. E.ON-Ruhrgas, RWE and Wintershall in Germany) which leaves considerable space for strategic behavior to these companies.
- Second, European demand of natural gas is likely to rise further over the next decades. Natural gas is expected to play an increasing role in the energy mix, mainly because of its relatively low carbon dioxide emissions within the context of growing climate concerns and political climate measures. Thus, the share of natural gas in the total primary energy demand in the European Union (EU-25) is expected to increase from 23% at present to a projected 32% in 2020. This goes hand in hand with an increase of the absolute level of gas consumption from approximately 430 billion cubic meters (bcm) per year today to a projected 790 bcm per year in 2020 (IEA (2004d)). The rise in demand will mainly be driven by an increasing utilization for power generation; the share of natural gas in power generation is expected to rise from 15% in 2002 to over 35% in 2030 (IEA (2004d), p. 154).
- Third, since Europe can only partly satisfy its gas demand with indigenous production, rising demand also implies increasing import dependency. Indigenous production in the European Union is concentrated in the United Kingdom and the Netherlands which account for three quarters of the European production.[3] However, production in these countries will at best remain at the current level but will probably decrease because the fields in the North Sea are running

[1] Cf. "Acceleration Directive" 2003/55/EC, which followed Directive 98/30/EC. Also see the Benchmarking Reports annually issued by the European Commission (e.g. European Communities (2005)).

[2] Also see Neumann and Hirschhausen (2004) for a study of the evolution of long-term contracts in continental Europe.

[3] In our model, we do not consider Norway as a part of Europe since it is one of the big producers from outside the European Union. However we do not define Europe exclusively as the European Union since we have included a number of non-EU gas importing countries such as Romania, Bulgaria, and Turkey.

out of gas.[4] Especially the UK is becoming a net importer of natural gas soon; most analysts expect the turning point to be reached within the next decade (e.g. IEA (2004d)). So, in different scenarios, the gas import dependency of the EU-25 is estimated by the International Energy Agency to increase from the current 49% (233 bcm in 2002) to over 80% (639 bcm) in 2020.

A crucial question is where the future gas supplies will come from. Russia, the country with the largest gas reserves in the world[5], currently is the most important gas supplying country to the European Union (see Table 1) and is expected to expand this role. Its market share is projected to increase from the current 40% of EU imports to around two-thirds (European Commission (2001)). However, this forecast ignores the high investment costs that are needed to bring gas from new fields on stream, the large investments required to modernize and expand the transport infrastructure, and a certain political cautiousness in the EU not to rely to heavily on gas imports from Russia. North Africa, and especially Algeria, Egypt and Libya, have made significant efforts to improve their status as reliable, large-scale suppliers to Europe. However, the region has yet to conquer a market share in European supply that corresponds to its low-cost reserves, be it via pipeline or as Liquefied Natural Gas (LNG). Additional gas supplies will also come from new areas such as the Middle East, where 40% of the proven global gas reserves are located and where LNG export terminals have been constructed for about a decade now.

Table 1: Natural gas supplies to Europe from major exporters in bcm per year (2004)

	Norway		Netherlands		Russia		Algeria		Middle East		Nigeria		Total imports
	bcm	%	bcm	%	bcm	%	bcm	%	bcm	%	bcm	%	
Belgium /Luxemburg	7	35%	8	37%	0	1%	3		–		–		21
Germany	26	29%	22	24%	38	41%	–		–		–		92
Finland / Sweden	–		–		5	81%	–		–		–		6
France	15	33%	–		12	26%	7	15%	0,1	0,2%	1	2%	45
Greece	–		–		2	80%	1	20%	–		–		3
UK	9	80%	1	4%	–		–		–		–		11
Italy	7	10%	10	14%	21	30%	26	37%	–		4	5%	70
Netherlands	4	32%			3	20%	–		–		–		14
Austria	1	10%	–		6	77%	–		–		–		8
Spain / Portugal	2	7%	–		–		16	53%	5	17%	6	20%	31
Baltic*	–		–		5	100%	–		–		–		5
Poland	1	5%	–		8	87%	–		–		–		9
Czech / Slovak Rep. / Hungary	3	9%	–		24	85%	–		–		–		28
Slovenia/Croatia (FY)	–		–		2	73%	0	20%	–		–		2
Bulgaria / Romania	–		–		8	85%	–		–		–		9
Turkey	–		–		14	65%	3	15%	–		1	5%	22
Total Exports to Europe	**75**		**40**		**146**		**56**		**5**		**12**		**374**

Source: BP (2005),
* Estonia from IEA (2004b) for 2003

[4] This is reflected by the reserves-production ratio, which was equal to 6.1 and 21.7 at end 2004 for the UK and the Netherlands, respectively (BP (2005)).

[5] 48000 bcm, i.e. 26.7 % of the global proved natural gas reserves (BP (2005)).

LNG is a form of supply with a growing importance for Europe. European LNG imports are currently bound by regasification capacity. More and more regasification terminals are built in Europe. LNG shipments mainly come from North Africa, Nigeria and the Middle East. Contrary to pipeline trade, there is an element of competition on the LNG market, because Europe is in direct price competition with the North American market, and prospectively with the Asian market as well. The higher flexibility is one of the main differences of LNG with pipeline supply which is bound by asset-specific infrastructure availability.

4 Data and Model Description

4.1 Data

We aim at an exhaustive representation of all relevant players on the European natural gas market. Table 2 summarizes the exporting and importing regions included in the model. We include Iraq and Venezuela although they have no gas export capacity yet because we want to be able to compute forecasts of their exports in other versions of the model. We assume here that there is one gas company per country or region, which is justified by still existing gas companies in several countries such as GdF in France, Gazprom in Russia etc.[6]

Table 2: Regions in the GASMOD model

Exporting Regions	Importing Regions
Algeria	United Kingdom
Libya	Netherlands
Egypt	Spain / Portugal
Iraq	France
Iran	Italy / Switzerland
Middle East (Qatar, UAE, Oman, Yemen)	Belgium / Luxemburg
Russia	Germany
Norway	Denmark
Netherlands	Sweden / Finland
United Kingdom	Austria
Nigeria	Poland
Trinidad	Czech Rep. / Slovak Rep. / Hungary
Venezuela	Former Yugoslavia / Albania
	Romania / Bulgaria
	Baltic States (Estonia, Latvia, Lithuania)
	Greece
	Turkey

We use data for the base year 2003. We focus on the trade relations so we do not distinguish intra-year seasons. Data on reference trade flows, consumption and prices for the base year come from the International Energy Agency (IEA (2004a), IEA (2004b)) and from BP (2004). Data on production

[6] This assumption is not uncommon in the literature, see for instance Egging and Gabriel (forthcoming). However, the model formulation allows to include more than one player per country which would be more realistic when modeling the future European natural gas market.

capacity in the European regions is based on IEA (2004b) and own estimations. Transport capacity data comes from GTE[7], the European organization of the national TSOs (transmission system operators) for intra-European capacities, and from OME (2001) for exporter capacities.

Production and transport cost data ("border prices") are taken from OME (2001). This is long-run marginal cost data, including likely investments on existing infrastructure. We add transport costs within Europe as unit costs per unit of gas and km of average distance between countries as assumed by Oostvoorn (2003); they include transport costs (e.g. gas used for compression), losses and possible transit fees. The cost data is a crucial input to the model with an important influence on the results. Given the long distance to the market, Russian gas is among the expensive suppliers in Europe. In the OME (2001) data, LNG is still a high-cost supplier with costs of around 3 US-$ per Mbtu (million British Thermal unit) to the EU border for typical LNG exporters as Nigeria, Venezuela and the Middle East (Table 3). Norway is a producer at fairly high costs, whereas Algeria and the European producers (United Kingdom and the Netherlands) can export at relatively low costs to Europe. Political and other "soft" considerations (e.g. the reliability of an exporter) do not enter the cost data and are not taken into account in this model.. The same is true for reserves which do not enter in the calculation of the production capacity of the producers.

Table 3: Cost data (border prices) of selected producer countries

Producer country	Border price in US-$ per Mbtu	Border price in US-$ per tcm
Netherlands	1.65	52.15
Norway (to Germany)	2.10	82.06
Russia via Ukraine*	2.55	79.92
Algeria to Italy**/ Spain**	2.07 / 2.15	84.41 / 85.63
Middle East (LNG)**	2.91	104.75

Source: OME (2001), and own calculations
* unweighted average border price at the Slovak border
** average border price weighted by export capacity

4.2 Model

We structure the European natural gas market as a two-stage-game of successive imports to Europe (first stage, upstream) and trade within Europe (second stage, downstream). First, gas producing companies decide on their exports, mostly from countries outside Europe, to European countries. Simultaneously, indigenous producers in Europe, for instance in Germany, Italy, Austria, etc. decide about their production quantities. Thus, indigenous producers and exporters are directly competing with each other. Note that the endogenous determination of indigenous production quantities is a novelty compared to other gas market models where indigenous production usually is entered as an exogenous, pre-determined value.

[7] www.gte.be

On the second stage, gas trading companies in Europe which have imported gas and which have bought indigenously produced gas sell this gas in the European countries, including their own country. We implicitly assume a liberalized, but oligopolistic market in Europe: TPA (Third Party Access) to the gas network is ensured for each exporter and each European trading company. There is no destination clause which means that consumers are free to choose their supplier which may well come from abroad (e.g. French consumers can purchase from the German trader). Since the focus of our model is on the strategic relations between the producers on the first stage, and between the traders on the second stage, we do not distinguish several market segments (such as industry, power generation, residential sector). Furthermore, we implicitly assume that there is no vertical integration between the two stages; this assumption goes hand in hand with the aggregation of one player per country that we use. Although some players along the LNG chain and to a lesser extent the pipeline gas chain have started to integrate vertically from the producer to the downstream trader, we believe that overall this aggregation reflects the trade relations in the natural gas market reasonably well.

GASMOD can be characterized as a game theoretic model assuming perfect information. The producers on the first stage have perfect information about the demand situation on the second stage and decide on their production quantities by taking into account the downstream market situation. According to standard game theory the appropriate method of determining equilibrium prices and quantities is backwards induction. We assume the exporters to be Stackelberg leaders over the traders, that is the traders on the second stage are price-takers of the equilibrium prices determined on the first stage.

On each stage, the players play a non-cooperative game and maximize their individual payoffs. Following the literature of energy market modeling, we model the oligopolistic markets on both stages with Cournot (quantity) competition instead of Bertrand (price) competition.[8] By assuming an oligopolistic market structure on both stages the problem of double marginalization is represented: upstream and downstream markets are imperfectly competitive and suppliers on both markets exert market power, i.e. their price includes a margin. The downstream oligopoly leads to an additional price distortion and hence to an even less efficient allocation compared to the situation of a single oligopoly (cf. Spengler (1950)).

The equilibrium on each stage is the solution of the non-linear profit optimization program of each player. On each stage, each player maximizes his profits (under certain capacity constraints, see below). For the upstream exporter f this gives us:

$$\underset{x_{f,r}}{Max.}\Pi\left(x_{f,r}\right)=\left(pe_r-c_f-t_{f,r}\right)*x_{f,r} \tag{1}$$

[8] This seems to be suitable in a market where many relations are still based on long-term take-or-pay (ToP) contracts. In ToP contracts the quantities can be chosen in the short run given the demand and price developments; however a minimum quantity must always be paid to the seller. Also, Bertrand competition generally yields lower price margins and even prices equal to marginal cost (i.e. the perfect competition equilibrium) which would be unrealistic for a highly concentrated market as the natural gas market in Europe.

$x_{f,r}$ is the supply by exporter f to wholesale trader r, pe_r is the inverse demand function (see below), c_r is the production cost function of producer f, and $t_{f,r}$ his transport costs for delivering to trader r. In line with the literature we suppose unit production and transport costs. We neglect transport costs within each European country / region by setting them at a low level because we focus on the international trade relationship.

Taking into account the behavioral assumptions of Cournot competition and the standard definitions of own-price elasticity and market share, we derive the first order condition (FOC) of the profit maximization program. In a pure Cournot-Nash equilibrium no player must have an incentive to move; in other words the conjectured variation of the other players must be 0. Thus:

$$\frac{\partial X_r}{\partial x_{f,r}} = \frac{\partial\left(\sum_f x_{f,r}\right)}{\partial x_{f,r}} = 1 = \alpha \tag{2}$$

In the case of prefect competition, in contrast, each player is price taker of the market equilibrium (assumption of atomic agents), which gives:

$$\frac{\partial X_r}{\partial x_{f,r}} = \frac{\partial\left(\sum_f x_{f,r}\right)}{\partial x_{f,r}} = \alpha = 0$$

We use this property (the parameter α) to define different model settings of either Cournot competition or perfect competition on one or both stages.

Price elasticity σ_r on the market r, and market share $\theta_{f,r}$ of player f on the market r are:

$$\sigma_r = \frac{\partial X_r}{\partial pe_r} \cdot \frac{pe_r}{X_r} \tag{3}$$

$$\theta_{f,r} = \frac{x_{f,r}}{X_r} \tag{4}$$

FOC: $x_{f,r} : pe_r - mc_f - t_{f,r} + pe_r{}' \cdot x_{f,r} = pe_r - mc_{f,r} - t_{f,r} + \frac{\partial pe_r}{\partial x_{f,r}} \cdot \frac{\partial X_r}{\partial X_r} \cdot \frac{pe_r}{pe_r} \cdot \frac{X_r}{X_r} \cdot x_{f,r} = 0$

which yields by taking into account (2), (3), and (4):

$$mc_f + t_{f,r} = pe_r * \left(1 + \alpha * \frac{\theta_{f,r}}{\sigma_r}\right) \tag{5}$$

where mc_f are marginal costs and $\frac{\theta_{f,r}}{\sigma_r}$ is the price margin obtained by the oligopolistic supplier. In other words, suppliers can exert market power with respect to their competitors. The margin is equal to zero in the case of perfect competition. With this formulation we follow Kemfert and Tol (2000) and Kemfert and Kalashnikov (undated) who use a similar optimization program in a model of the German respectively the European electricity market.

Each player is restricted by capacity limitations such as transport infrastructure constraints (export, import capacities in terms of pipelines and LNG terminals), and production capacities. On the first stage of exports to Europe, gas trade is restricted by the export infrastructure of each producer and the import capacity of each wholesale trader. In addition, the indigenous (domestic) production capacity in each European country is limited. On the second stage, the supply by each trader is restricted by the transport capacity of the pipeline grid between him and each end-user market. We introduce these restrictions of the exports, imports and domestic production with shadow prices (Lagrangian multipliers) in the respective first order conditions where the shadow price represents the valuation of an additional available capacity unit. Hence, the FOC (5) is completed by the shadow prices and for the exporter f this is equal to:

$$mc_f + t_{f,r} = pe_r * \left(1 + \alpha * \frac{\theta_{f,r}}{\sigma_r}\right) - \lambda \exp_f - \lambda imp_r \tag{6}$$

where $\lambda \exp_f$ and λimp_r are the shadow prices for export capacity of the exporter f and the import capacity of importer r, respectively.

Since we consider market relations we do not restrict bilateral trade relations to adjacent countries (as e.g. Egging and Gabriel (forthcoming)). An exporter can supply each European region but not more than can physically be transported through the natural gas grid (or via the LNG terminals) connecting them. This way we can represent trade flows as observed in reality where for instance the Czech Republic has imported 2.62 bcm of natural gas from Norway (BP (2005)).

For the natural gas consumption on the end-market m, we assume an iso-elastic demand function of the form:

$$y_m = d0_m \cdot \left[\frac{p_m}{p0_m}\right]^{-\sigma_m} \tag{7}$$

y_m and p_m are the quantities and prices, $d0_m$ and $p0_m$ are the reference demand and the reference price on the market m in the base year, and σ_m is the price elasticity of the final demand. We prefer an iso-elastic demand function instead of a linear demand function (as suggested by Golombek et al. (1995)) because this allows to have a non-negative demand for every price. We assume the demand elasticities σ_r and σ_m to be rather low in absolute terms (-0.7 for Western Europe, -0.6 for Eastern

Europe)[9] which reflects a certain inelasticity of the natural gas demand.[10] Shifting from natural gas to another fuel would require changes in the technical installations, which are costly and time-demanding. The right choice of the elasticities is crucial in a model with an iso-elastic demand function; we have carried out (but not reported) several sensitivity analyses which confirm the correctness of our choice.

Equilibrium is reached at the intersection of demand and supply. The demand coming from the downstream (end consumer) market is addressed to the traders who forward it to the exporters. The combination of the individual Karush-Kuhn-Tucker conditions (FOC) and the market balance gives us the following non-linear equilibrium model:

FOC upstream:
$$mc_f + t_{f,r} = pe_r * \left(1 + \frac{\theta_{f,r}}{\sigma_r}\right) - \lambda \exp_f - \lambda imp_r \tag{6}$$

FOC domestic producers:
$$mcdom_r = pe_r * \left(1 + \frac{\theta dom_r}{\sigma_r}\right) - \lambda dom_r \tag{8}$$

FOC downstream:
$$pe_r + t2_{r,m} = p0_m * \left(1 + \frac{\theta_{r,m}}{\sigma_m}\right) * \sqrt[\sigma_m]{\frac{Y_m}{d0_m}} \tag{9}$$

Market balance:
$$\sum_m y_{r,m} = \sum_f x_{f,r} + domprod_r \tag{10}$$

This model is programmed in the MCP (mixed complementarity problem) format in GAMS, and solve with a standard algorithm for MCP, PATH.[11]

5 Simulation Results

The model is run for different market scenarios. We would like to assess which market scenario fits the current (2003) reality of the European natural gas market best. From our sector description we have already drawn the preliminary conclusion that the European natural gas market is an imperfect market, with a double marginalization structure. Therefore, in addition to the scenario of double marginalization, we also simulate the scenarios of perfect competition on both markets or of the downstream market only. Whereas the scenario of perfect competition on both market stages seems very unrealistic, the liberalization of the European gas sector is supposed to lead to competitive downstream market in the future.

[9] We assume the price elasticity to be higher (in absolute values) by 0.05 for countries where natural gas does not have a large share in energy consumption, i.e. Spain/Portugal, Sweden/Finland, Poland, Balkan, and Greece. Thus we assume that switching to alternative fuels is easier for countries where dependency on natural gas is lower.

[10] Liu (2004)finds long-run own price elasticities for natural gas between –0.774 and 0.075 for OECD countries. Earlier estimations find higher elasticities (in absolute values), see e.g. Estrada and Fugleberg (1989), Al-Sahlawi (1989). Boots et al. (2004) use elasticities from Pindyck (1979) which are considerably higher (between 1.17 and 2.23).

[11] For more details about programmation in the MCP format see Rutherford (1995) and Ferris and Munson (2000).

We recall that GASMOD in its version presented here is a quasi-static model to the extent that it only regards one time period. This means that we reproduce the base year 2003 and the results must be interpreted as market outcomes if the upstream and downstream markets corresponded perfectly to the characteristics of Cournot oligopoly or perfect competition. Thus from the proximity of our results to the original data we can derive conclusions about the actual market structure on the European natural gas market. In the following, we highlight the general results for the endogenous variables, thereby concluding about the currently prevailing market structure and effects of alternative market scenarios.

5.1 Upstream market: Exports to Europe and Domestic Production

5.1.1 Exports

Table 4 reports the results for the exports on the first stage. Compared to the reference data for 2003 (also see Section 3, Table 1), in the Cournot scenario, exports from some traditional suppliers to Europe (Russia, Algeria) decrease while newly emerging exporters (Middle East, Nigeria) gain market shares. Among the large traditional exporters only Norway, the Netherlands and UK remain at a significant level in this static scenario. Most strikingly, Russia loses a considerable market share in Europe, partly because of its relatively high production and especially transport costs due to the long distance to the European market. This is also due to the model formulation where large players like Russia have the same strategic "weight" as smaller players like Nigeria, Trinidad etc.[12] In the Cournot scenario, LNG exporters like the Middle East, Nigeria and Trinidad gain some market share. For LNG we may expect an even greater increase of exports to Europe in the future since costs of LNG shipments are projected to decrease further in the coming years.

The comparison with the perfect competition scenario confirms that there is strategic withholding of quantities in the Cournot scenario in order to increase the price above marginal cost levels (also see Section 4.2.2. for the prices). In perfect competition, the greater demand because of lower prices allows market entry and increased market share of higher cost producers such as Russia and Egypt. LNG and other non-traditional exporters supply even more natural gas to Europe than in the Cournot scenario. The demand increase compared to the benchmark scenario is such that even higher cost producers are bound by their transport capacity (see Section 4.3.1). Since demand on the markets prefers the lowest-cost supplier, exporters first serve the markets which are the closest to them (in terms of combined production and transport costs); in a context of high demand this explains why the UK and the Netherlands do not export but supply only local traders in the perfect competition scenario.

[12] Considering firms instead of countries, including multinational firms which are typical for the global natural gas market, would most likely resolve this uncertainty in the results.

Table 4: Export quantities and market share (as percentage of total exports to Europe)[13]

Exporter	Cournot Competition		Perfect Competition		EU liberalization		Reference exports to Europe 2003*	*Reference market share 2003*
	Exports (bcm/year)	*Market share*	Exports (bcm/year)	*Market share*	Exports (bcm/year)	*Market share*		
Algeria	14,7	*4,4%*	66,0	*14,6%*	66,0	*11,9%*	57,77	*17,6%*
Libya	4,8	*1,4%*	14,5	*3,2%*	14,5	*2,6%*	0,75	*0,2%*
Egypt	5,0	*1,5%*	11,9	*2,6%*	11,9	*2,2%*	0	*0,0%*
Iran	0,0	*0,0%*	10,0	*2,2%*	10,0	*1,8%*	3,52	*1,1%*
Middle East	13,3	*4,0%*	26,6	*5,9%*	26,6	*4,8%*	2,43	*0,7%*
Russia	58,8	*17,7%*	196,0	*43,3%*	134,4	*24,3%*	131,77	*40,1%*
Norway	86,0	*25,8%*	86,0	*19,0%*	86,0	*15,6%*	68,37	*20,8%*
Netherlands**	66,6	*20,0%*	0,0	*0,0%*	80,4	*14,6%*	42,17	*12,8%*
UK**	59,4	*17,8%*	0,0	*0,0%*	81,5	*14,7%*	11,5	*3,5%*
Nigeria	12,6	*3,8%*	22,7	*5,0%*	22,7	*4,1%*	10,37	*3,2%*
Trinidad	12,0	*3,6%*	18,7	*4,1%*	18,7	*3,4%*	0	*0,0%*
Total	333,1	*100,0%*	452,4**	*100,0%*	552,6**	*100,0%*	328,65	*100,0%*

* **Source: BP (2004).**
** Excluding own domestic consumption in UK and the Netherlands. If domestic consumption is included, total "exports" are higher in the Perfect Competition than in the Competition " scenario as intuition suggests.

Finally, we see that a perfectly competitive downstream market (scenario "EU liberalization") would considerably change the outcome. Higher demand on the downstream market because of lower (competitive) prices triggers considerably higher exports. This contradicts the widespread thesis that an oligopolistic downstream market is the best response to an oligopolistic upstream market. Perfect competition on the downstream market with a given Cournot market on the export side also leads to more diversification of supplies.

5.1.2 Domestic Production

Table 6 reports the quantities and market shares of domestic production. We recall that domestic production is endogenously determined by the profit maximizing behavior of the producers. We observe that the higher demand due to lower prices in perfect competition and EU liberalization leads to domestic production as part of the natural gas supplies in more countries than in the Cournot competition scenario. This completes the picture of a more diversified supply that we also derive for exports under the perfect competition assumption. In both scenarios with perfect competition, domestic production is generally higher than observed in the reference data. Often domestic production serves the demand when trade capacities to a country are congested (see 4.3). This is especially true in the perfect competition scenarios where higher quantities would have been traded if physically possible and where the share of domestic production in the supply is high in many countries.

[13] The Netherlands and UK are considered as exporters and as importers. In this table we have removed the exports to the traders in the Netherlands and UK. However these quantities are available for re-export (including domestic consumption) on the 2nd stage.

Table 5: Domestic production quantities and market shares of the domestic producers on the upstream market

Domestic producer	Cournot competition		Perfect competition		EU liberalization		Domestic production 2003 in bcm (IEA (2004b))
	Domestic production (bcm/year)	*Part of the supply in the same country*	Domestic production (bcm/year)	*Part of the supply in the same country*	Domestic production (bcm/year)	*Part of the supply in the same country*	
UK*	27,4	*35,9%*	120,0	*100,0%*	38,5	*42,2%*	108,4*
Netherlands*	23,4	*42,1%*	90,0	*80,7%*	9,6	*32,9%*	73,1*
Spain/Port.			0,3	*0,7%*	0,3	*0,7%*	0,2
France			1,9	*3,2%*	1,9	*2,9%*	1,6
Italy/Switz.			16,3	*19,4%*	16,3	*13,4%*	13,6
Belgium/Lux.							0
Germany			13,2	*21,5%*	26,7	*21,1%*	22,2
Denmark	1,0	*44,7%*	8,5	*100,0%*	9,6	*86,4%*	8,0
Swed./Fin.							0
Austria							2,1
Poland	6,0	*27,8%*	6,8	*38,3%*	6,8	*32,7%*	5,6
CSH	3,9	*14,7%*	3,9	*3,5%*	3,9	*15,3%*	3,3
Balkan			4,1	*100,0%*	4,1	*28,9%*	3,4
Rom./Bulg.			17,5	*49,8%*	17,5	*69,3%*	14,6
Baltic							0
Greece					0,03	*0,9%*	0,03
Turkey							0,6

* Here we report exports from the UK or the Netherlands to the trader in the same country.

5.2 Downstream market: Intra-European Wholesale Market

5.2.1 Intra-European Trade

Although we separate them in the presentation of results, the first and second stage are solved simultaneously. Thus the model is complex and the results on the second stage inherently depend on the first stage and vice versa. Although the results of the first stage for the Cournot scenario may be somewhat surprising, the results of the second stage, and especially the final consumption, indicate a proximity to the real world situation. Indeed, as is shown in Table 7 we generally obtain results for this case that are close to actual final consumption in 2003. Clearly, this gives an indication to consider the Cournot case as the most realistic representation of the today's European natural gas market. The consumption figures in the perfect competition and the EU liberalization scenario generally are much higher than real world data. The notable exception of the UK can be explained by the observed competitive market structure in this country in contrast to the rest of Europe.

Looking at particular regions, some interesting features can be discovered (Appendix, Table 9). For instance, direct exports to Germany (1st stage trade) only come from Northern Europe, especially Norway. This result is confirmed by several sensitivity analyses. However, Germany is still consuming Russian gas, as in reality, but which is indirectly supplied via Eastern European (Czech and Polish) and Austrian traders. Reciprocally, Russia is not directly exporting to Western Europe, but mainly to Eastern Europe. This is due to the production and transport cost structure. Hence, the results in GASMOD are more cost-driven than trade relations are in today's reality where they are often the consequence of geo-political considerations and the existence of destination clauses. However, the results of our model point to an increased diversity of supply which is also a political objective in Europe.

Table 6: Final consumption of natural gas in bcm per year

Markets	Cournot Competition	Perfect Competition	EU liberalization	Consumption 2003
UK	49,5	113,3	95,9	95,4
Netherlands	38,9	69,6	56,9	40,3
Spain/Portugal	27,5	39,8	39,4	26,6
France	50,7	60,2	63,3	43,3
Italy/Switzerland	96,0	115,9	121,1	73,6
Belgium/Luxembourg	16,1	21,3	21,4	16,0
Germany	100,7	147,4	138,3	85,5
Denmark	0	6,2	5,7	5,4
Sweden/Finland	2,0	6,3	2,2	5,3
Austria	11,9	15,5	14,6	9,4
Poland	12,6	17,6	16,2	11,2
Czech/Slovak/Hungary	26,3	41,8	36,4	28,8
Balkan	9,7	10,0	10,5	7,7
Bulgaria/Romania	13,3	29,2	28,9	20,9
Baltic	0	3,3	5,7	5,0
Greece	2,3	3,7	3,6	2,3
Turkey	0	33,6	33,1	20,9
TOTAL	457,6	734,7	693,4	497,6

5.2.2 Prices

Figure 1 reports the prices on the upstream market and the downstream market for some selected countries. One clearly recognizes the effect of market power in the Cournot scenario where strategic withholding of production increases prices. However, prices are not only influenced by the market situation but also by the availability of import capacity for a market. Markets like the UK or Sweden/Finland for instance which benefit from the proximity to an exporter (own production or Russia, respectively) on the first stage cannot be supplied on the second stage due to missing infrastructure and therefore have to pay a high-mark-up to their local wholesale trader. This explains the heterogeneity of prices in the Cournot scenario. Clearly, this is a model effect which has to be removed for a more realistic representation of the European natural gas market, by modeling countries with this characteristics as competitive markets.

Indeed, the picture is different in two aspects in the scenarios with perfect competition. Prices are distributed homogenously between the countries, and the prices generally are lower. For both scenarios, the premium added on the import price is equal to the transport costs of the marginal trader; very often there is only intra-country trade so that the difference between prices on the upstream and the downstream market equals the assumed intra-country transport costs (2 US-$ per tcm). Although exporters behave strategic in the EU liberalization scenario the prices are considerably lower than in the Cournot scenario and only about 20% higher than in the Perfect competition scenarios. This confirms the finding that enforcing competition on the European market would lead to increased welfare because it allows higher consumption of natural gas combined with lower prices.

Figure 1: Border prices of selected countries (wholesale traders) in US-$ per tcm

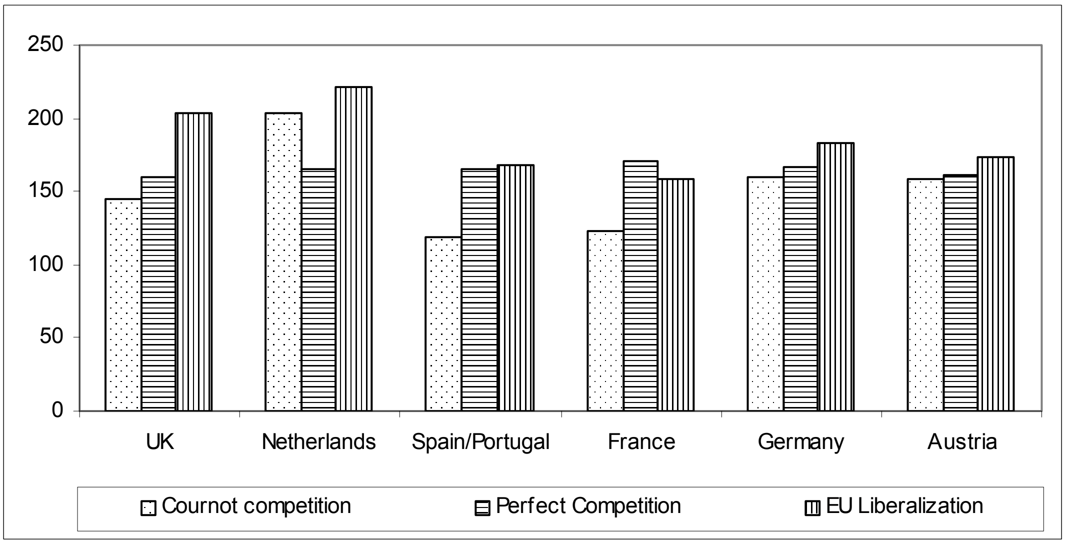
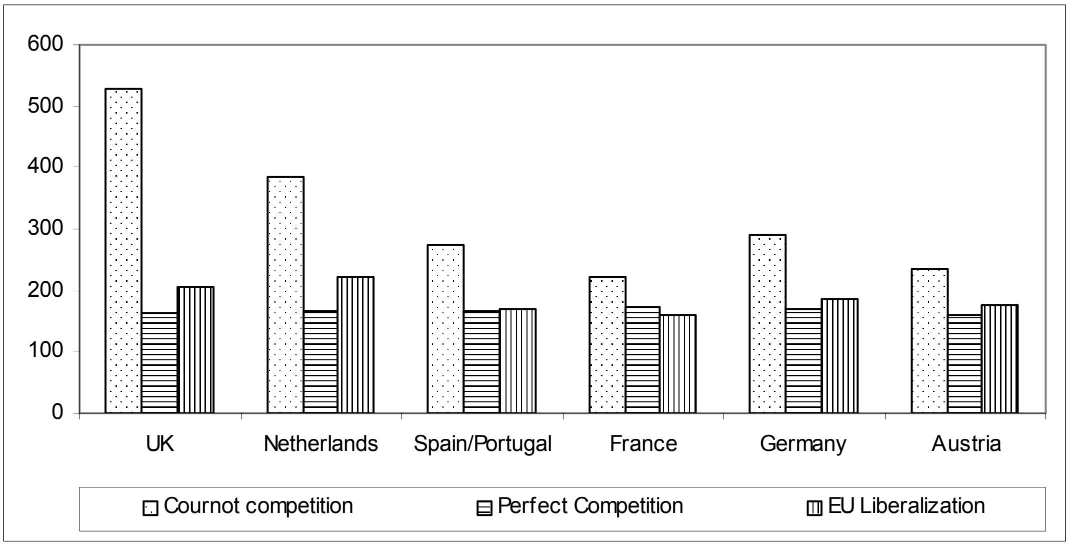


Figure 2: Endmarket prices of selected countries in US-$ per tcm

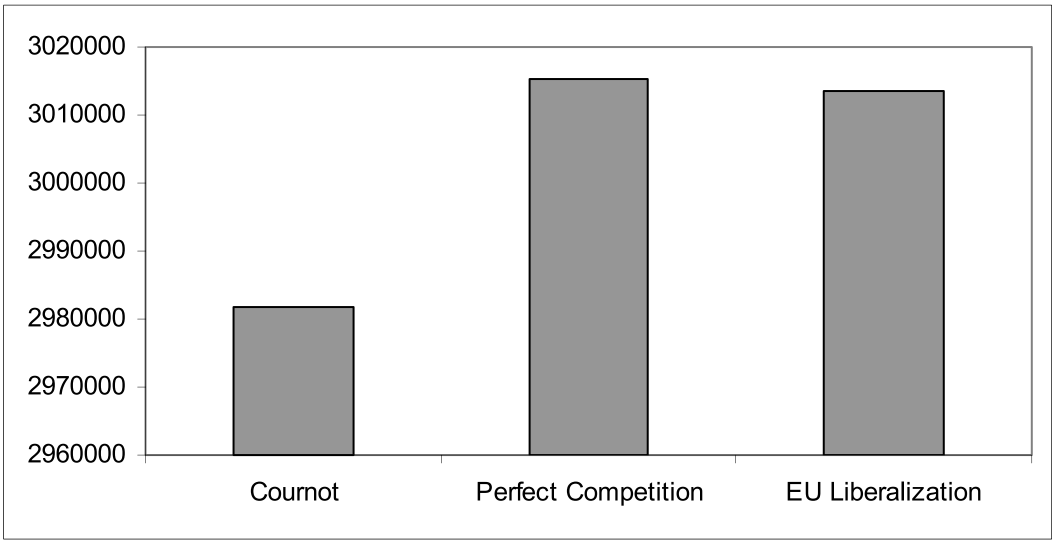


5.3 Welfare Effects in Europe

As suggested by economic theory we find larger quantities and lower prices in the market scenarios with perfect competition compared to the Cournot scenario. If this also translates in higher welfare, as we expect, our results have important implications for the market organization of the European natural gas sector, especially for the wholesale market. Indeed, the traditional argument consists in rejecting the need to reduce the market power of only one of the markets a double oligopoly because the of the market power effects of the other party. This argument is often brought forward by the European natural gas wholesale traders against regulation of their industry.

However, our findings differ from this argument. As depicted in Figure 2, in the EU liberalization scenario we find a welfare close to the case of overall perfect competition. Both welfare results are unsurprisingly higher than in the double marginalization scenario. There are large welfare gains to expect from liberalizing the European wholesale market of natural gas. In contrast, the additional welfare gain from having a liberalized export market would be minimal (about 0.06%) compared to the EU liberalization scenario, thus again making a case for enforcing competition on the European wholesale market.

Figure 3: Welfare results for all market scenarios, in US-$



5.4 Infrastructure Capacity Constraints

5.4.1 Upstream Market

On the upstream market, the only transport route which is congested in the Cournot scenario is the Norwegian access to Europe. Norway has relatively modest production costs, and it is situated closely to high demand in North-West Europe, so that transport costs are modest, too; thus, Norway is well positioned as a supplier to Europe. Our results are reflected in reality by the stable reserve situation and the increasing production capacity in Norway which make it an important exporter for the coming decades with the need to expand its export infrastructure.

In contrast, in the perfect competition case and very similar in the EU liberalization case, there are many exporters which are bound by their actual export capacities (Table 9), either pipelines or LNG liquefaction terminals. Export capacities are taken into account as the existing export infrastructure in 2003. It is striking that even an exporter with large export capacities as Russia reaches the bounds of its capacities but it gives an idea of the quantities that would be traded in a fully competitive market without capacity restrictions as compared to the actual natural gas market. This also clearly shows the necessity to take into account infrastructure capacities when modeling a network such as the natural gas market.

Table 7: Export capacity utilization of each exporter[14]

Exporters	Cournot competition	Perfect competition	EU liberalization
Algeria	22%	100%	100%
Libya	33%	100%	100%
Egypt	43%	100%	100%
Iran	0%	100%	100%
Middle East	50%	100%	100%
Russia	30%	100%	69%
Norway	100%	100%	100%
Netherlands	74%	0%	89%
UK	50%	0%	68%
Nigeria	55%	100%	100%
Trinidad	64%	100%	100%

Table 8: Congested Intra-European capacity (used at 100 %) in the Cournot competition scenario

From	To
Netherlands, Belgium, Germany	UK
UK, Germany, Belgium	Netherlands*
France	Spain / Portugal
Balkan (via Slovenia), France	Italy / Switzerland
Germany	Belgium / Luxemburg
Belgium, Austria*	Germany*
Germany	Poland
Austria	Czech / Slovak Republic / Hungary*
Italy / Switzerland	Balkan
Denmark**	Sweden / Finland**

* Note that these transport routes are also congested in the EU liberalization scenario.
** Only in the Perfect Competition and EU liberalization scenarios.

5.4.2 Downstream Market

In Table 10 we indicate the congested transport routes within Europe. We focus on the Cournot scenario as we have identified this as the most realistic representation of today's European natural gas market. The large number of bilateral transport routes that are listed seems surprising. But there clearly exist only a small number of cross-border natural gas pipelines within Europe, many of them with very limited capacity. Several studies have already pointed out that this is an important obstacle to a Single European market of natural gas (European Communities (2005), Neumann et al. (forthcoming)).

[14] Note that in addition to export capacity restrictions we have also introduced import capacity and bilateral trade restrictions. Whereas import capacity of European traders generally is not binding, bilateral trade capacity quite often is but with a structure similar to the exort capacity utilization.

Although we find many congestions in two directions, this is not a necessary result since compressor capacity at a cross-border point may be such that more gas can flow in one direction than in the other. As discussed above, we observe in the results that missing transport capacity has a clear effect on prices since the local wholesale trader can benefit from a quasi-monopoly.

6 Conclusions

In this paper, we have presented a model of the European natural gas market. GASMOD is a static model which structures the natural gas market as a two-stage game of successive i) exports to Europe, and ii) trade within Europe. In contrast to other models in the literature we have applied a two-stage structure and have incorporated an endogenous determination of domestic production. Infrastructure capacities which are an important characteristic of a network industry and which may be binding are explicitly taken into account in the model. We use GASMOD for numerical simulations with reference data for the base year 2003. We model three different market scenarios: Cournot competition on both the upstream and the downstream market, perfect competition on both markets, and Cournot competition on the upstream market with a downstream market in perfect competition.

We find that the scenario of Cournot competition is the most realistic representation of the European natural gas market with total export and consumption quantities close to the reference data. However, our results present a more diversified picture of supplies to Europe, with newly emerging (LNG) exporters gaining market shares in Europe. This indicates currently, other factors are at play determining the supply relations in the real world (e.g. long-term contracts, destination clauses, etc.). Results in the Cournot competition scenario are strongly influenced by infrastructure capacities since a limited access to a market reduces the number of players which can then exert more market power. With no surprise we find the highest prices, lowest quantities and lowest welfare in this scenario, thereby confirming the welfare-reducing effect of double marginalization.

Whereas the scenario of perfect competition is only simulated to benchmark the results of the Cournot scenario, the scenario of perfect competition on the downstream market in the presence of an oligopoly on the upstream market merits closer attention. Indeed this is a situation which could be enforced by the regulation authorities in Europe. We find that this case has an unambiguous welfare-enhancing effect compared to double marginalization. This contradicts the widespread thesis that an oligopolistic downstream market is the best response to an oligopolistic upstream market. Our results also point to more diversified supplies than in the Cournot scenario, which is another objective of European energy policy.

The comparison with real world data indicates that the current state of the European natural gas market is best represented by a scenario of Cournot competition. Deviations for some countries suggest that modeling their market with competitive behavior might be more appropriate, be it in a competitive fringe for smaller exporters or traders, or as competitive market because of limited access to the market (which leads to unrealistically high mark-ups) or in the case of the UK because of its already successful market liberalization.[15] There are several improvements which should be included in GASMOD, notably, the infrastructure bottlenecks that we have identified should be the basis for further investigation and for modeling the dynamics of the natural gas market and of investment in its infrastructure.

7 References

Al-Sahlawi MA. The Demand for Natural Gas: A Survey of Price and Income Elasticities. Energy Journal 1989; 10, 1; 77-90.

Bartels M, Seeliger A. Interdependenzen zwischen Elektrizitätserzeugung und Erdgasversorgung unter Berücksichtigung eines europäischen CO2-Zertifikatehandels. IEWT 2005 Conference Proceedings, 2005: Vienna (Austria).

Boots MG, Rijkers FAM, Hobbs BF. Trading in the Downstream European Gas Market: A Successive Oligopoly Approach. Energy Journal 2004; 25, 3; 73-102.

BP. Energy in Focus - BP Statistical Review of World Energy June 2004. British Petroleum; 2004.

BP. Putting Energy in the Spotlight - BP Statistical Review of World Energy: London; 2005.

Düweke J, Hamacher T. Modellierung der globalen Ergasressourcen und des Erdgastransports. Conference Proceedings IEWT 2005, 2005: Vienna (Austria).

Egging RG, Gabriel SA. Examining Market Power in the European Natural Gas Market. Energy Policy forthcoming; In Press, Corrected Proof.

Estrada J, Fugleberg O. Price Elasticities of Natural Gas Demand in France and West Germany. Energy Journal 1989; 10, 3; 77-90.

European Commission. Green Paper - Towards a European Strategy for the Security of Energy Supply. European Commission, DG TREN: Brussels; 2001.

European Communities. Annual Report on the Implementation of the Gas and Electricity Internal Market. European Commission: Brussels; 2005.

Ferris MC, Munson TS. Complementarity Problems in GAMS and the PATH Solver. Journal of Economic Dynamics and Control 2000; 24, 2; 165-188.

Golombek R, Gjelsvik E, Rosendahl KE. Effects of Liberalizing the Natural Gas Markets in Western Europe. Energy Journal, 1995, 16: 85-111.

Golombek R, Gjelsvik E, Rosendahl KE. Increased Competition on the Supply Side of the Western European Natural Gas Market. Energy Journal 1998; 19, 3; 1-18.

Hartley P, Medlock KB. A Global Market for Natural Gas? Prospects to 2035. Geopolitics of Gas Working Paper Series, 2004: 1-19: Stanford (Ca., USA).

[15] See e.g. Egging and Gabriel (forthcoming) for a model with a competitive fringe), and Pavel and Holz (2005) for an application of this specification in the GASMOD model.

IEA. Energy Prices and Taxes - Quarterly Statistics - Third Quarter 2004. International Energy Agency: Paris; 2004a.

IEA. Natural Gas Information. OECD/IEA: Paris; 2004b.

IEA. Security of Gas Supply in Open Markets - LNG and Power at a Turning Point. OECD: Paris; 2004c.

IEA. World Energy Outlook 2004. OECD/IEA: Paris; 2004d.

Kemfert C, Kalashnikov V. Economic Effects of the Liberalisation of the German Electricity Market - Simulation by a Game Theoretic Modelling Tool. mimeo, undated. University of Oldenburg: Oldenburg.

Kemfert C, Tol R. The Liberalisation of the German Electricity Market - Modelling an Oligopolistic Structure by a Computational Game Theoretic Modelling Tool. Oldenburg Working Paper, 2000: Oldenburg.

Lise W, Hobbs BF, Oostvoorn Fv. Security of Supply in the Liberalised European Gas Market, Simulation Results with the Dynamic GASTALE Model. IAEE Europe 2005 Conference Proceedings, 2005: Bergen (Norway).

Liu G. Estimating Energy Demand Elasticities for OECD Countries. Discusssion Papers Statistics Norway, 2004.

Mathiesen L, Roland K, Thonstad K 1987. The European Natural Gas Market: Degrees of Market Power on the Selling Side. In: Golombek R, Hoel M, Vislie J Eds), Natural Gas Markets and Contracts. North-Holland; 1987.

Mulder M, Zwart G. Modelling Long Run Strategic Behaviour on the Liberalised European Gas Market. IAEE Europe 2005 Conference Proceedings, 2005: Bergen (Norway).

Neumann A, Hirschhausen Cv. Less Long-Term Gas to Europe? - A Quantitative Analysis of European Long-Term Gas Supply Contracts. Zeitschrift für Energiewirtschaft 2004; 28, 3; 175-182.

Neumann A, Siliverstovs B, Hirschhausen Cv. Convergence of European Spot Market Prices for Natural Gas? Applied Economics Letters forthcoming.

OME. Assessment of Internal and External Gas Supply Options for the EU - Evaluation of the Supply Costs of New Natural Gas Supply Projects to the EU and an Investigation of Related Financial Requirements and Tools. Observatoire Méditerranéen de l'Energie: Sophia-Antipolis; 2001.

Oostvoorn Fv. Long-Term Gas Supply Security in an Enlarged Europe. ECN: Petten; 2003.

Pavel F, Holz F. Will There Be Enough For Everybody? - A Simulation Analysis of the LNG Market in the Atlantic Basin. Presentation at the 4th Conference of Applied Infrastructure Research, 2005. TU Berlin: Berlin.

Perner J. Die langfristige Erdgasversorung Europas - Analysen und Simulationen mit dem Angebotsmodell EUGAS. Oldenbourg Industrieverlag: Munich; 2002.

Perner J, Seeliger A. Prospects of Gas Supplies to the European Market Until 2030—Results from the Simulation Model EUGAS. Utilities Policy 2004; 12, 4; 291-302.

Pindyck RS. The Structure of World Energy Demand. The MIT Press: Cambridge, Massachusetts and London, England; 1979.

Rutherford TF. Extension of GAMS for Complementarity Problems Arising in Applied Economic Analysis. Journal of Economic Dynamics and Control 1995; 19, 8; 1299-1324.

Spengler JJ. Vertical Integration and Anti-Trust Policy. Journal of Political Economy 1950; 58, 4; 347-352.

Appendix: **Table 9: Intra-European Trade in the Cournot (Double Marginalization) Scenario**

	UK	Netherl	Spain/Port	France	Italy/Switz	Belgium/Lux	Germany	Denmark	Swed/Finl	Austria	Poland	CSH	Balkan	Rom/Bulg	Baltic	Greece	Turkey
UK	25,1	10,0	2,2	10,2	7,1	4,4	8,1			2,5	2,2	4,2	0,3				
Netherlands	8,3	12,7	2,2	1,4	2,0	2,0	20,4			0,7	1,8	4,2					
Spain/Port			11,5										1,1				
France			2,2	15,4	7,1												
Italy/Sw					47,7								1,4				
Belgium/Lux	8,3	10,0	2,2	14,1	7,1	5,5	8,1			3,5	2,2	4,2	1,2				
Germany	1,6	1,6	2,2	8,1	7,1	1,6	31,1			2,3	2,2						
Denmark	1,6								0,6								
Swed/Finl									1,4								
Austria	1,6	1,6	1,6	1,6	17,9	1,6	7,1			2,6	2,2	4,2	0,3				
Poland	1,6	1,6	1,2			0,2	11,8				1,1	4,2					
CSH	1,6	1,6	2,0			0,7	14,0			0,2	1,1	5,5					
Balkan					0,2								1,7	6,1			
Rom/Bulg													3,9	7,2		1,3	
Baltic																	
Greece																1,0	
Turkey																	
TOTAL	49,5	38,9	27,5	50,7	96,0	16,1	100,7	0,0	2,0	11,9	12,6	26,3	9,7	13,3	0,0	2,3	