August 2003 ECN-R--03-001

GASTALE: An oligopolistic model of production and trade in the European gas market

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Preface

In this report, the empirical model GASTALE is described and used to analyse the European natural gas market. The analyses focus primarily on the role of the downstream trading companies and their interaction with oligopolistic gas producers. A condensed version of this report was submitted to *The Energy Journal* (without knowing in this stage if it will finally be accepted for publication). This report contains more detailed information than the version sent to *The Energy Journal*. The authors would like to have this study - including its details - published, in order to be able to refer to it in their ongoing work.

The research described in this report was conducted under ECN project number 77450.03 in 2002. This research was funded by the Ministry of Economic Affairs, Government of the Netherlands. In addition, partial support for B. Hobbs was provided by the US National Science Foundation, grant ECS-00-80577. The authors would like to thank B. Daniëls for his contribution in the modelling process.

Abstract

In this paper, the empirical model GASTALE is described and used to analyse the European natural gas market. These analyses focus primarily on the role of the downstream trading companies and their interaction with gas producers. By default, producers of natural gas are assumed to form an oligopoly in the paper. Meanwhile, downstream within-country traders of gas are represented in different versions of the model as local oligopolists or perfect competitors. The model therefore has a two-level structure, in which producers engage in competition a la Cournot, and each producer is a Stackelberg leader with respect to traders, who may be Cournot oligopolists or perfect competitors. The case of Cournot traders results in a new form of energy model, that of successive oligopoly. The model is formulated as a complementarity problem, and is solved by nonlinear programming.

Considering this oligopolistic market structure, several tentative conclusions emerge. First, our model results show that successive oligopoly (so-called ‘double marginalisation’) yields significantly higher prices and lower consumer welfare than if oligopoly exists only on one level. Second, oligopoly in the trading market (because of the high concentration of traders) results in more distortion than oligopoly in production. Third, the level of traders’ profits depends on the possibilities of discrimination on the border prices. If price discrimination by producers is allowed, these producers collect a greater share of the margins on end-use prices. Fourth, when the number of traders increases and assuming an oligopolistic downstream structure, end-use prices converge to prices corresponding with perfect competition. Thus, it is important to prevent (or abolish) monopolistic structures in the downstream gas market. In the case where oligopolistic competition among downstream gas companies cannot be prevented, vertical integration should be supported (or at least not be discouraged), especially if it would result in a greater number of traders.

CONTENTS

1. INTRODUCTION

European natural gas markets are undergoing dramatic changes (Stern, 1998, Radetzki, 1999). In August 2000, most EU Member States implemented the Gas Directive concerning the internal European market for natural gas. The Directive specifies common rules for the trade, distribution, supply, and storage of natural gas. Liberalisation of the European gas market is imposed at the demand side, by gradually allowing consumers to choose their supplier. Member States have specified eligible customers, i.e., those customers that have the legal capacity to contract for natural gas. As a first step, all gas-fired power generators, irrespective of their annual consumption, are designated as eligible customers, as are final customers who consume more than 25 million cubic meters per year. This definition of eligible customers ensures that at least 20 percent of the total annual consumption of each national gas market is opened for competition. Further market opening (at least 33 percent) and customer eligibility is gradually being introduced. For the organisation of access to the network, Member States can choose between negotiated and regulated access. Natural gas companies are required to keep separate accounts for their gas trade, distribution, and storage activities (administrative unbundling).

The EU Gas Directive defines the minimum actions to be taken by the Member States. However, the ensuing development of gas markets not only depends on this institutional framework, but also on the reaction of market players, i.e., gas companies as well as their customers, to these institutions (see also Ellis, Bowitz and Roland, 2000). In this paper, the institutional framework presented in the EU Gas Directive is taken as a starting point for an analysis of possible developments in the natural gas market. We then make a range of assumptions regarding the behaviour of market players: upstream producers, downstream traders, and end users.

The main purpose of this paper is to analyse the role of downstream trade companies in the European gas market. Therefore, a quantitative model of the market for natural gas in the European Union has been developed. The model allows us to vary the behaviour of the traders and producers and to analyse the effects of this behaviour on, e.g., end-use prices of natural gas. The model can also be used to analyse the general effects of gas market liberalisation upon prices (see also European Commission, 1999). Here, we focus on complete market opening by letting all consumers free to choose their supplier.

Our model builds on earlier modelling work in this field. In a thorough review article, Smeers (1997) discussed the potential of combining Industrial Economics and computation of economic equilibria in order to analyse the restructuring of European electricity and gas markets. In the context of the European gas market, most recent models represent the market as being either purely competitive (e.g., Capros et al, 2000) or, equivalently, based on cost-minimisation principles (e.g., Parcebois and Valette, 1996). In reality, however, the gas market is highly concentrated, and if unregulated, it is reasonable to expect that prices will deviate from the marginal cost ideal. When imperfect competition has been simulated in the European gas market, Cournot paradigms have been applied. Mathiesen et al (1987) concluded that the gas market is best described by the Cournot game (i.e., as a game in quantities). Competition can be expected to take place through quantities, since long-term take-or-pay contracts still prevail in the natural gas market. Some potential effects of liberalisation were analysed by Golombek et al (1995, 1998). In their 1995 article, they focused on the effects of price discrimination and arbitrage possibilities. They concluded that as gas traders will exploit arbitrage possibilities, the development of market power could be prevented. Using the same model, their 1998 article studied the optimal organisational structure of gas production. However, unlike the model in this paper, theirs did not consider the effects of imperfect competition among traders, or the results of oligopoly in both trading and production. [1]

Golombek et al allowed us to use their model as a basis to develop GASTALE (*G*as m*A*rket *S*ystem for *T*rade *A*nalysis in a *L*iberalising *E*urope). GASTALE was initially developed to analyse the effects of gradual gas market liberalisation on end-use prices and market shares of producers (Oostvoorn and Boots, 1999; European Commission, 1999). In this paper, GASTALE is elaborated in order to analyse the role of gas trading companies in the European gas market.

GASTALE describes the European gas market in terms of two layers of companies on the supply side along with consumers in three basic sectors on the demand side of the market. The market structure is assumed to consist of an oligopoly of upstream gas producers and a layer of downstream gas traders, all of whom are profit maximisers. However, the position of traders is up to the modeler and can vary from a national monopoly to perfect competition between traders. The case of imperfectly competitive traders results in a model structure that is new in the energy modelling literature: that of successive oligopolists. In equilibrium, total gas demand equals total supply in each market sector in each country. This equilibrium is driven by production costs, third party transmission tariffs, demand elasticities of the consumers, and the intensity of competition among producers and traders.

Previous theoretical studies have addressed the properties of successive oligopoly models, and a few applications have focussed on the effects of vertical integration within particular markets. Greenhut and Ohta (1976) consider an abstract single market in which there is an upstream monopolist producer and either a monopoly or duopoly downstream. Later, they generalise their model to allow oligopolists in both levels (Greenhut and Ohta, 1979). They derive optimal pricing strategies for the upstream firms, who are Stackelberg leaders with respect to the downstream firms. They found that successive oligopoly results in higher consumer prices, lower output, and lower total profits than vertical integration, results that are largely confirmed here. Sherali and Lelano (1988) study the existence and computation of a more general case in which vertically integrated oligopolists compete side-by-side with unintegrated upstream and downstream firms. Our model can be viewed as an extension and application of the successive oligopolist model of Greenhut and Ohta (1979) to a situation in which, first, multiple consumer markets are separated in space and, second, producers have nonlinear production costs. A contribution of this paper is the presentation of a practical computational approach for large successive oligopoly models based on nonlinear programming.

In the next Chapter, an overview of the theoretical economic model describing the behaviour in the European gas market is given. In Chapter 3, empirical assumptions regarding consumer demand, production costs, and costs of international transport and third party access (TPA) to within-country transmission systems are described. Then, Chapter 4 presents two market equilibrium models, one allowing border price discrimination among consuming sectors and the other assuming no discrimination. The models are formulated as complementarity problems,

[1] There exist a number of other solution concepts that can be used for energy market games, such as Bertrand (price) competition, supply function equilibria, and tacit collusion (Tirole, 1988; Day et al, 2002). Bertrand competition is sometimes used as a lower bound for imperfectly competitive prices. Bertrand competition under some assumptions yields the pure competition solution; however, under other assumptions, Bertrand games can give prices above marginal cost, but well below Cournot levels. In our model, Bertrand competition among two or more traders would result in the pure competition solutions presented in the tables, and can be viewed as a lower bound to prices under trader oligopoly. However, we believe that this optimistic outcome is relatively unlikely when the trading sector is highly concentrated in a country (e.g., monopoly or duopoly). Supply function equilibria (Klemperer and Meyer, 1989) are most appropriate when demand is highly variable or uncertain, and there is little storage; thus it has found wide use in electricity market models (especially in auction-based markets), but not in the gas sector. Tacit collusion models are theoretically attractive in concentrated markets characterised by frequent interaction (*e.g.*, as in daily power auctions). However, they have not been used in detailed energy sector models for several reasons, including the absence of models for nonsymmetric firms and the lack of computational methods for markets with complex cost and demand structures, as in the EU gas market. For these reasons, characterization of the gas market as a game in quantities is a reasonable point of departure for analysing strategic interactions among producers and traders.

and are solved by nonlinear programming. Chapter 5 describes the cases regarding downstream trade behaviour and analyses the results. In Chapter 6 the number of traders is varied, while Chapter 7 illustrates the modelling of various degrees of market opening and their effects. The paper ends with a set of conclusions. Appendices summarise sensitivity analyses with regard to price elasticities of demand, along with international transmission tariff assumptions.

2. SUCCESSIVE UPSTREAM AND DOWNSTREAM BEHAVIOUR

The end-use markets are distinguished by country, denoted by n=1,..,N, and by market segments, denoted by g=1,..,G. End-user markets are supplied by trading companies r=1,..,R, where each trader r is linked to one or more markets ng. That is, traders have a predetermined supply region. The producers supply the traders with gas. A distinction is made between i=1,..,I major producers and a group of remaining regulated providers for whom we assume that production and sales are exogenous (exogenous sales to market ng are denoted by the constant $exog_{ng}$).

2.1 Downstream

Traders are assumed to be either perfectly competitive or Cournot players in end-use markets. The maximisation problem for trader r is given by:

$$\pi_r = \max_{rng} \sum_{n,g} (p_{ng} - bp_{ng} - dc_{ng}) \cdot y_{rng} \tag{1}$$

where p_{ng} is the retail price of natural gas in consumer market ng, while y_{rng} is gas delivered to market ng by trader r. Retail price is endogenous to the market, being a function of total gas delivered by all traders, including r, but is exogenous to traders if they are competitive. The trader has to purchase gas from producers at the border price bp_{ng} and subsequently pays transmission tariff dc_{ng} for transporting gas to consumers; we assume the tariff is the same for all r.[2] We also assume that traders are price-takers with respect to the border price of gas; however, this may not be strictly true for very large traders or consumers (such as power companies). Another assumption is that all traders have identical costs of serving a particular market segment, and that they are price-takers with respect to the border price.

The consumer price is determined as a function of consumed quantities, i.e., the inverse demand function is $p_{ng} = D_{ng}^{-1}(x_{ng} - exog_{ng})$, where x_{ng} is the total amount consumed in market ng. Recall that $exog_{ng}$ is defined as the amount of exogenous (nonprice-responsive) gas supplied to market ng (for instance, by publicly-owned utilities); as a result, $x_{ng} = \sum_r y_{rng} + exog_{ng}$. (Note that we neglect gas losses due, for example, to leakage and fuel required to operate compressors.)

If we assume Cournot competition among traders and the above demand function, downstream profit maximisation results in the following first-order (Karush-Kuhn-Tucker) condition:

$$\tfrac{\partial \pi_i}{\partial y_{rng}} = p_{ng} - (bp_{ng} + dc_{ng}) + p'_{ng} \cdot y_{rng} \leq 0, \quad y_{rng} \geq 0, \quad \tfrac{\partial \pi_i}{\partial y_{rng}} y_{rng} = 0 \tag{2}$$

This equation depicts the individual trader's demand for gas y_{rng} given the border price bp_{ng}. The expression for the border price can then be derived from (2) as:

$$bp_{ng} \geq p_{ng} - dc_{ng} + p'_{ng} \cdot y_{rng} \tag{3}$$

[2] In calculating this tariff for each country, we assume no substantial change in present taxes and cross-subsidies by country, which can be very substantial. The tariff coefficient is also assumed to include trading costs and a normal return to capital for the traders; we assume that these are relatively small compared to within-country transmission costs.

If $y_{rng} > 0$, then (3) holds as an equality. If we instead assume perfect competition amongst traders, the term $p'_{ng} \cdot y_{rng}$ in equation (2), denoting the effect of an extra unit of throughput on the profitability of inframarginal sales, would be omitted. The border price would then be no less than the difference between end-user price and transmission costs:

$$bp_{ng} \geq p_{ng} - dc_{ng} \tag{4}$$

Again, this holds as an equality if $y_{rng} > 0$.

Following Golombek et al (1995), we assume a linear (affine) consumers' demand curve for natural gas. The empirical specification of the linear inverse demand function is:

$$p_{ng} = D_{ng}^{-1}(x_{ng} - exog_{ng}) \equiv \alpha_{ng} + \beta_{ng} \cdot (x_{ng} - exog_{ng}) \tag{5}$$

where $\alpha_{ng} > 0$ and $\beta_{ng} < 0$ are the parameters to be calibrated at assumed prices, consumption and elasticities for the base year (1995). This procedure ensures that all demand functions go through the actual market outcomes in that base year (Mathiesen et al, 1987). Moreover, we will assume that each consumers' quantity demanded is positive, i.e., that retail price is less than the price intercept of the demand function:

$$p_{ng} < \alpha_{ng} \tag{6}$$

Where traders are competitive, Equation (6) is equivalent to the condition that the border price $bp_{ng} < \alpha_{ng} - dc_{ng}$. In the case of Cournot traders, it can be shown that the upper bound is tighter: $bp_{ng} < \alpha_{ng} - dc_{ng} + \beta_{ng}\, y_{rng}$ for any r, where $\beta_{ng} y_{rng} < 0$. (These results can be obtained by recognizing that $p'_{ng} < 0$ in (3), and (3) and (4) hold as an equality if $y_{rng} > 0$; then (3) or (4) is substituted into (6).) An implication of the foregoing assumptions, along with the assumption that the cost of serving a particular market segment is identical for all traders, is that all throughput quantities $y_{rng} > 0$, and (3) and (4) hold as equalities.

Since symmetry of traders implies that there is no price discrimination among traders, there is no need to divide the sales variable for producer *i* into sales to individual traders. Therefore, q_{ing} can denote the total gas delivered to all traders in market *ng* by producer *i*. We assume that total sales to *ng* by producers $\sum_i q_{ing}$ equal total sales to that segment by traders $\sum_r y_{rng}$. Therefore, if traders are perfectly competitive, and (6) holds, then the effective demand curve that faces producers for market segment *ng* is:

$$bp_{ng} = \alpha_{ng} + \beta_{ng} \cdot (x_{ng} - exog_{ng}) - dc_{ng} = \alpha'_{ng} + \beta'_{ng} \cdot \sum_i q_{ing} \tag{7}$$

where $\alpha'_{ng} \equiv \alpha_{ng} - dc_{ng}$ and $\beta'_{ng} \equiv \beta_{ng}$. Equation (7) shows that in the competitive trader case, the demand facing producers is the consumer demand that traders see, but shifted downward by amount dc_{ng}. On the other hand, if traders are Cournot players, the expression for the slope of the curve changes to $\beta'_{ng} \equiv \beta_{ng}\left(\frac{R_{ng}+1}{R_{ng}}\right)$, where R_{ng} is the number of traders serving market segment *ng*. (The intercept α'_{ng} is the same as in the competitive trader case.) Thus, within-country transmission costs shift the original demand curve downwards, since $\alpha'_{ng} < \alpha_{ng}$, while market power among traders makes the demand curve steeper, as $|\beta'_{ng}| > |\beta_{ng}|$. With zero transmission costs and a large number of traders, the effective demand curve converges to the consumers' demand curve. This result is derived from the Cournot equilibrium among identical traders, given that the traders are price-takers with respect to the border price of gas.

Some further relationships can also be defined. In each market *ng*, equations (5) and (7) imply that when traders are competitive, the border price is related to the retail price as follows: $bp_{ng} = p_{ng} - dc_{ng}$. But in the Cournot situation, we have instead $bp_{ng} = p_{ng} - dc_{ng} + \beta_{ng} \sum_i q_{ing} / R_{ng}$. Because $\beta_{ng} < 0$, this shows that for a given border price bp_{ng}, Cournot traders increase the retail price (and thus increase their margin) by amount $|\beta_{ng} \sum_i q_{ing} / R_{ng}|$. Finally, in either the competitive or Cournot trader case, each trader *r* in market *ng* sells the same amount $y_{rng} = (x_{ng} - exog_{ng})/R_{ng}$, under our assumption that traders and producers included in the model do not supply the exogenous portion of consumer demand.

2.2 Upstream

Assume that the production side of the gas market forms an oligopoly. Assume also that producers choose their production and sales quantities simultaneously (one-stage game). Each producer maximises its profit given the quantities chosen by the other firms. The resulting equilibrium, if it exists, is therefore a Nash-Cournot equilibrium. As is well known, a Cournot equilibrium with a large number of firms is approximately competitive, i.e., the market price converges to marginal cost (Tirole, 1988).

The objective function of a profit-maximising gas producer *i* is given by:

$$\pi_i = \max_{q_{ing}} \sum_{n,g} (bp_{ng} - t_{in}) \cdot q_{ing} - c_i(\sum_{n,g} q_{ing}) \tag{8}$$

As explained below, the border price bp_{ng} is an endogenous function of the quantity variables in the producer's model (8), unlike the trader's model (1). Thus, the producers anticipate the reaction of traders; i.e., producers are Stackelberg leaders with respect to traders who are followers. Costs of producing quantity $\sum_{n,g} q_{ing}$ are denoted by $c_i(\cdot)$. It is assumed that the cost function is increasing and convex in production, that is, $c_i' > 0$ and $c_i'' \geq 0$. The cost of long-distance transport from producer *i* to country *n* is denoted by t_{in} per unit of gas delivered q_{ing}. Again, we neglect losses of gas during transmission; we also do not explicitly consider pipeline capacity limitations, but assume that they, along with losses, are reflected in t_{in}.

In order to link the upstream and downstream profit maximisation problems, the expression for the border price in (7) is substituted for bp_{ng}, making price endogenous:

$$\pi_i = \max_{q_{ing}} \sum_{n,g} (\alpha'_{ng} + \beta'_{ng} \cdot \sum_j q_{jng} - t_{in}) \cdot q_{ing} - c_i(\sum_{n,g} q_{ing}) \tag{9}$$

The first-order condition for maximising producer *i*'s profits is then:

$$\tfrac{\partial \pi_i}{\partial q_{irng}} = \alpha'_{ng} + \beta'_{ng}(\sum_j q_{jng}) + \beta'_{ng} \cdot q_{ing} - (t_{in} + c_i') \leq 0; \quad q_{ing} \geq 0; \quad \tfrac{\partial \pi_i}{\partial q_{irng}} q_{ing} = 0 \tag{10}$$

If $q_{ing} > 0$, the first-order condition for q_{ing} yields:

$$q_{ing} = -[bp_{ng} - (t_{in} + c_i')] / \beta'_{ng} \tag{11}$$

In general, a Cournot equilibrium among producers implies that marginal delivered costs of producers are not equalised, as would be the case in a perfectly competitive market. Too little is produced and the industry's cost of production is not minimised. Since it is assumed here that the trade companies also compete on quantities, their throughput quantities are also too little given bp_{ng} and, in general, transmission costs are not minimised (although in the symmetric cost case considered here, transmission does occur at minimum cost). As our results below show, market distortions decrease when trade companies are perfectly competitive, i.e., when the border price in equation (7) is defined using $\beta'_{ng} = \beta_{ng}$. In contrast, in the Cournot trader case, $|\beta'_{ng}| > |\beta_{ng}|$, and the q_{ing} found in equation (11) will be smaller than if traders are perfectly competitive.

3. EMPIRICAL SPECIFICATIONS

3.1 Demand

Consumption of natural gas in the European Union (EU-15) totalled 346 bcm in 1995 (IEA, 1997). However, the majority (97%) of total EU consumption occurs in just eight countries. In this study we focus on those countries that can be classified as mature gas markets. Thus, n={Austria, Belgium, France, Germany, Italy, Netherlands, Spain, UK}.

Within a country, natural gas is consumed in three main sectors: g={households, industry, power generation}. The share of each sector in domestic consumption differs substantially among countries. For example, due to the dominance of nuclear power in France, gas is hardly used to fuel power plants. Based on the eight countries and three market segments, 24 separate gas markets within the EU-15, i.e., 24 gas prices, are distinguished in this study.

3.2 Elasticities

The price elasticity of demand for the case of linear demand is defined as:

$$\varepsilon_{ng} = \frac{\partial(x_{ng} - exog_{ng})}{\partial p_{ng}} \cdot \frac{p_{ng}}{(x_{ng} - exog_{ng})} = \beta_{ng}^{-1} \cdot \frac{p_{ng}}{(x_{ng} - exog_{ng})},$$
$$i.e.,\ \beta_{ng} = \frac{p_{ng}}{\varepsilon_{ng} \cdot (x_{ng} - exog_{ng})}\ and\ \alpha_{ng} = p_{ng}\left(1 - \tfrac{1}{\varepsilon_{ng}}\right) \qquad (12)$$

We specify the price elasticity of the demand curve for each country and sector at the 1995 price/quantity pairs (Table 3.1). Elasticities are taken from Pindyck (1979). However, he did not distinguish power generators as a separate sector, therefore, in the base case we take the elasticities for industry as a proxy. (Sensitivity analyses in Appendix A consider other elasticities for the power sector.) Moreover, Austria and Spain were not distinguished as consuming countries by Pindyck. In this study, elasticities in Austria and Spain are set equal to those of Germany and France respectively.

These elasticities are admittedly dated, but the Pindyck study provides the most complete and consistent set of elasticities for our purpose (for several households and industry in several countries). The gas markets in the different European countries have developed considerably since the end of the seventies, and consequently their demand elasticities may also have changed. Another difficulty is the difference in the level of gas market maturity between the countries. In a mature gas market, where the infrastructure for substitutes of natural gas has deteriorated (e.g., fuel oil delivery for household heating), we might expect lower price elasticities. Finally, a review of gas elasticity estimates obtained by a variety of methods in other jurisdictions shows wildly divergent results, with long run values in the range of 0 to -3.44 in the residential sector and 0 to -2.27 for the commercial sector (Dahl, 1993, summarised in Wade, 1999), with most of the elasticities being in the range of -0.2 to -2. Therefore, for want of a more recent complete set of elasticities, we use the Pindyck values as a starting point, and conduct sensitivity analyses to assess the robustness of our conclusions with respect to those values (see Appendix A).

Table 3.1 *Assumed elasticities and 1995 market prices and consumption*

Country	Market Segment	Price[a] [US$/1000 m^3]	Consumption[b] [bcm]	Elasticity[c]
Austria	households	386	2.258	-1.50
	industry	163	2.399	-2.23
	generation	163	2.759	-2.23
Belgium	households	409	5.257	-1.51
	industry	119	4.924	-2.23
	generation	92	2.370	-2.23
France	households	421	18.019	-1.39
	industry	135	14.833	-1.45
	generation	135	0.639	-1.45
Germany	households	401	40.266	-1.50
	industry	174	32.757	-2.23
	generation	147	18.117	-2.23
Italy	households	561	22.676	-1.41
	industry	146	20.064	-1.28
	generation	109	11.645	-1.28
Netherlands	households	303	22.169	-1.17
	industry	123	13.649	-1.39
	generation	121	12.347	-1.39
Spain	households	512	1.357	-1.39
	industry	114	6.240	-1.45
	generation	140	1.400	-1.45
UK	households	276	39.955	-1.33
	industry	107	20.810	-1.35
	generation	99	13.363	-1.35
Total			330.273	

a Source: IEA (1998a), p.355-357 (1000 m^3=1.19x10^7 kcal on a gross calorific basis). Gas prices for power generators in Austria and France were unavailable. Therefore, they are assumed to equal prices for industry in the respective countries.

b Source: IEA (1997) (1 Mtoe=1.322 bcm). Consumption by power generation in Spain was 0.858 bcm; however, we used a higher amount in order to get reasonable parameters for the demand function.

c Source: Pindyck (1979), table 4.7 and 5.2. Elasticities in Austria are assumed equal to Germany. Elasticity for industry in Belgium is assumed equal to industry in Germany. Elasticities in Spain are assumed equal to France. Elasticities for power generation are assumed equal to industry.

3.3 Upstream production and costs

The ownership structure on the supply side of the European gas market is a complex oligopoly. The most important upstream gas companies supplying the EU - in terms of production volumes - have been selected as the Cournot producers in our model (see Table 3.2: i = {Gazprom,..,Lasmo}). Production of subsidiary companies (e.g., BEB in Germany, owned 50:50 by Shell and Exxon) are allotted to the companies owning the subsidiary.

For simplicity, production and sales of natural gas by Gazprom, Sonatrach and GFU (the Norwegian Gas Negotiating Committee) are assumed equivalent to the production and sales by the Former Soviet Union, Algeria and Norway, respectively. Exogenous production is defined as total consumption in each country minus total production from Cournot producers. Note that total production per Cournot producer only consists of the production that is destined for the eight consuming countries considered here. Other production quantities of the companies, such as production of Gazprom for their domestic market or for Poland, are not taken into account.

We assume that upstream gas is simultaneously extracted from several fields that may have different unit costs. The yearly capacity of the fields that are exploited by producer i is given by Q_i.

A profit-maximising producer who extracts from two or more fields extracts gas from a particular field until its marginal cost equals the marginal cost of the other fields (net of transmission costs). Thus, the marginal cost of producer *i* equals the highest marginal cost among active fields. The marginal cost functions have to satisfy our assumptions of being increasing and convex in production. Assume the following form for the marginal cost function (see Golombek et al, 1995):

$$c_i'(q_i) = \gamma_i + \delta_i \cdot q_i + \kappa_i \cdot \ln(1 - q_i / Q_i) \qquad \gamma_i, \delta_i > 0,\ \kappa_i < 0,\ 0 < q_i < Q_i \tag{13}$$

The associated primary cost function is:

$$c_i(q_i) = \gamma_i \cdot q_i + \tfrac{1}{2}\delta_i \cdot q_i^2 - \kappa_i \cdot (Q_i - q_i) \cdot \ln(1 - q_i / Q_i) - \kappa_i \cdot q_i \tag{14}$$

In the equations above, $q_i = \sum_{n,g} q_{ing}$.

The parameters of the marginal cost function, γ_i, δ_i and κ_i, are selected consistent with available information (mainly from Golombek et al, 1995). The intercept, γ_i, is interpreted as the marginal cost of the first unit of production. Table 3.2 shows the assumed parameters for the marginal cost function of each Cournot producer.

Table 3.2 *Production, market share, capacity and cost parameters, 1995 data*

Producer	Production [bcm]	Market share [%]	Capacity [bcm]	γ_i	δ_i	κ_i
Gazprom	68.053	21	100	12	0	-22
Sonatrach	33.072	10	50	11	0	-5
GFU	31.557	10	40	37	0.75	-10
Shell	28.105	9	40	3	0	-12
ExxonMobil	40.480	12	55	3	0	-12
EBN[a]	33.200	10	35	3	0	-12
Agip/ENI	20.221	6	35	11	1.35	-10
BG	12.142	4	20	50	0.75	-10
BP Amoco	10.929	3	15	37	0.75	-10
TotalFinaElf	18.394	6	30	37	1.35	-10
Amerada Hess	2.761	1	5	37	0.75	-10
Wintershall	2.100	1	5	37	0.75	-10
Lasmo	1.344	0	5	37	1.35	-10
Exogenous	27.915	8	-	-	-	-
Total	330.273	100	435			

a Energie Beheer Nederland, the Dutch state enterprise that participates in the Groningen gas field.

In addition to the production cost, delivering one unit of gas to market *ng* involves the expense of transport, distribution, load balancing and storage. There are costs involved in the transport of gas over long distances from the wellhead to the border of the consuming country (t_{in}). These costs depend on distance, and offshore transportation is usually more expensive than onshore transportation, if available. We assume that these costs are borne by the upstream producer. There is a difficulty in defining the international transport cost from each producer to each country, since a particular production company usually exploits several gas fields that are located in different regions. We assume that gas is sold from the nearest or main production field of the producer. Table B.1 in Appendix B documents the long distance transport costs we assume.

3.4 Downstream trade and TPA tariffs

Downstream European trade of gas traditionally had a monopolistic structure. Roughly speaking, each country used to have a major (state-owned) company responsible for the import, export, transit, and within-country transmission of gas and for operating the high-pressure pipeline network. Germany is the exception, where the share of the largest trading company, Ruhrgas, is limited to about 70% of the market. Therefore, the initial group of trading companies in our model contains two companies in Germany and one company in each of the other countries, r={OMV, Distrigas, GdF, Ruhrgas, Wingas, Snam, Gasunie, Gas Natural, Centrica}. However, in subsequent runs of the model, the number of traders are varied and a trader may be allowed to operate in different countries. Note, however, that the number of traders in a country is specified exogenously in every run; we do not model endogenous entry.

In our model, the trading companies are pure traders; they purchase gas from the producers and supply it to the consumers. This activity requires the use of the within-country pipeline system for transport of gas. We assume that the trading companies face given TPA tariffs for the use of these pipelines. These tariffs are country specific and we assume that they cannot be influenced by the trading company. We have based our calculation of the TPA tariffs on a study of PHB Hagler Bailly (1999). The TPA tariff distinguishes a more-or-less national or HTL tariff, and a regional or RTL tariff.[3] The within-country transmission costs strongly depend on distance ($distRTL_{ng}$) and load factor ($loadRTL_{ng}$). Equation (15) describes the final format of the within-country transmission costs in our model for larger (industrial and power) customers.

$$dc_{ng} = 2 \cdot HTLtariff_n + RTLtariff_n \cdot (8000 / loadRTL_{ng}) \cdot (distRTL_{ng} / 100) \tag{15}$$

The distance and load for HTL are assumed to be 200 km and 8000 hours respectively in all countries and market segments.[4] For RTL, the distance and load differ between countries and market segments. However, RTL tariffs in Spain and the UK are neither distance-related nor load-related, i.e., the last two terms in equation (15) are assumed to equal one. The Dutch RTL tariffs are not distance-related (last term is one) and Italy's tariffs not load-related (next to last term is one). For industry and power generators we assume a RTL distance of 30 and 5 kilometres, respectively. As a load factor, we assume 5000 hours for industry and power generators. Corresponding transmission costs per country are given in Table 3.3.

The cost of gas transportation, distribution, and account service for residential customers is much larger than for industrial and power customers. Indeed, these costs can exceed the commodity cost of gas (IEA, 1998b). In the absence of country-specific cost data, we assume that the difference between 1995 industrial and residential rates primarily reflects differences in transport, distribution, and account costs. As a first approximation, dc_{ng} for each nation's residential customer class is set equal to the assumed value for industrial customers plus the 1995 difference in prices between the two classes (Table 3.3). Better estimates would be based on actual costs of service in each country, how those costs are split between fixed and commodity charges, and existence of cross-subsidies, including taxes.

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[3] HTL = High-pressure Trunk Lines, RTL = Regional Trunk Lines.

[4] This results in the factor 2 = (8000/8000) · (200/100) for the HTL tariff in the equation.

Table 3.3. *HTL and RTL tariffs [1998 US$/1000 m^3/8000 hours/100 km] and transmission and distribution costs [US$/1000 m^3]*

	Tariffs		Pipeline transmission and distribution cost		
Country	HTL	RTL	Industry	Power generation	Households
Austria	2.75	5.5	8.14	5.95	230.98
Belgium	2.81	5.05	8.05	6.03	298.46
France	1.92	5.5	6.48	4.28	291.77
Germany	2.75	5.5	8.14	5.94	234.79
Italy	9.21	21.99	25.01	19.51	439.75
Netherlands	2.56	3.84	11.26	11.26	191.24
Spain	12.79	1.69	27.27	27.27	425.86
UK	2.56	9.67	14.79	14.79	184.25

Source: PHB Hagler Bailly (1999).

3.5 Non-eligible and non-mature markets

In two sub markets, there is little reason to expect that the way in which prices on the natural gas market are formed will change, namely emerging (immature) markets and non-eligible (captive) customers. Immature gas countries are omitted from the analysis. For captive customers, developments are the result of autonomous factors (such as expansion of gas distribution networks) and not of market opening. Demand of the captive customers in the model is exogenous; that is, $x_{ng} = const\_x_{ng}$ (see also Chapter 7).[5] The projected demand determines retail gas prices in the non-eligible markets, based on the assumed demand functions and price elasticities (see Table 3.1). Non-eligible markets are assumed to be served by a monopoly trader whose sales are fixed at the assumed level. The amount that each producer sells to a non-eligible market *ng* is defined as $q_{ing} = const\_q_{ing} = s_{ng} \cdot const\_q_{in}$, where s_{ng} is the share of segment *g* in country *n*, and $const\_q_{in}$ the given production of producer *i* for country *n*. As an approximation, border prices in non-eligible markets are determined using either the competitive or oligopolistic relationships of equations (3) or (4), respectively.

[5] We use 1995 demand data (IEA, 1997).

4. EQUILIBRIUM MODEL

The combined first-order conditions (10) for producers in Chapter 2 (which account for equilibrium reactions of downstream traders), together with the empirical assumptions presented in Chapter 3, define a set of conditions that can be solved for an equilibrium. This equilibrium represents a Cournot equilibrium among producers, each of which is also a Stackelberg leader with respect to either monopolistic, Cournot, or purely competitive traders. By varying the (number of) elements of several sets and activating additional constraints, different cases are simulated with this system. Before we discuss some of these cases in the next Chapter, we will describe the overall equilibrium model and the additional constraints.

4.1 Basic Cournot producer model

Based on the development above, the market equilibrium when producers are Cournot players is a solution to the following mixed nonlinear complementarity problem.[6]

Find $\{q_{ing}, y_{rng}, x_{ng}, bp_{ng}, p_{ng}\}$ *such that:*

$$\tfrac{\partial \pi_i}{\partial q_{irng}} = \alpha'_{ng} + \beta'_{ng}\left(\sum_j q_{jng}\right) + \beta'_{ng} \cdot q_{ing} - (t_{in} + c'_i) \le 0 \qquad \forall i, \forall ng \in E \qquad \text{(16a)}$$

$$q_{ing} \ge 0; \quad \tfrac{\partial \pi_i}{\partial q_{irng}} q_{ing} = 0$$

$$q_{ing} = const\_q_{ing} \qquad \forall i, \forall ng \in NE \qquad \text{(16b)}$$

$$c'_i = \gamma_i + \delta_i \cdot \sum_{n,g} q_{ing} + \kappa_i \cdot \ln(1 - \sum_{n,g} q_{ing} / Q_i) \qquad \forall i \qquad \text{(17)}$$

$$x_{ng} = exog_{ng} + \sum_i q_{ing} \qquad \forall ng \qquad \text{(18)}$$

$$y_{rng} = (x_{ng} - exog_{ng}) / R_{ng} \qquad \forall r, \forall ng \qquad \text{(19)}$$

$$bp_{ng} = \alpha'_{ng} + \beta'_{ng} \sum_i q_{ing} \qquad \forall ng \qquad \text{(20)}$$

$$p_{ng} = \alpha_{ng} + \beta_{ng}(x_{ng} - exog_{ng}) \qquad \forall ng \qquad \text{(21)}$$

The set *E* is defined as the set of eligible markets *ng*, while *NE* is the set of non-eligible markets. Condition (16) defines the equilibrium producer sales; (16a) is the first-order profit maximizing condition for each producer in each eligible market (equation (10), Chapter 2), while (16b) sets q_{ing} to a prespecified production allocation in non-eligible markets, as previously explained. Note that α'_{ng} and β'_{ng} need to be defined according to whether traders are assumed to be Cournot or perfectly competitive, as discussed in Chapter 2. The marginal cost term in (16a) is defined by (13) (Chapter 3). Equations (18) and (19) define consumer demand and trader quantities supplied, respectively, for both eligible and non-eligible markets; the quantities are

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6 In general, a pure complementarity problem is to find vector *x* such that $x \ge 0$; $f(x) \le 0$; and $x^T f(x) = 0$. The dimension of the two vectors *x* and *f(x)* must be the same. A mixed complementarity problem augments the problem to include an additional vector of variables *y* and a set of equality conditions with the same dimension as *y*: $x \ge 0$; $f(x,y) \le 0$; $x^T f(x,y) = 0$; and $g(x,y) = 0$. The complementarity problems are linear if *f(x,y)* and *g(x,y)* are affine; otherwise the problems are nonlinear (Cottle et al, 1992). Energy sector models are often phrased as complementarity problems and solved using widely available complementarity solvers (e.g., Labys and Yang, 1992; Capros et al, 2000; Hobbs, 2001).

free variables for eligible markets and are exogenously specified in non-eligible markets. Finally, equations (20) and (21) define the border and retail prices, respectively. The equilibrium solution can be obtained by first solving the nonlinear complementarity problem (16)-(17) for producer sales q_{ing}. Then we can use q_{ing} to solve (18) for consumption x_{ng}, and finally insert q_{ing} and x_{ng} in (19)-(21) to obtain trader sales y_{rng} and the border and retail prices.

As in any mixed complementarity problem, the problem (16)-(21) must be 'square', with the number of conditions (16)-(21) equalling the number of variables $\{q_{ing}, y_{rng}, x_{ng}, bp_{ng}, p_{ng}\}$. This is the case here. Nonlinear mixed complementarity problems can be solved by complementarity solvers such as PATH and MILES, which are available in standard optimization packages (e.g., GAMS and AIMMS). Cottle et al (1992) describe necessary and sufficient conditions for assuring that a solution exists for a linear mixed complementarity problem. Because the above nonlinear complementarity problem can be converted into a linear one by appropriate piecewise linearisation of the increasing marginal cost function (13), these results can be applied here.

An alternative solution approach is to instead define a nonlinear programming problem whose first-order (Karush-Kuhn-Tucker) conditions are (16)-(21). If such a NLP exists, and is convex (i.e., any local optimum is also a global optimum), then any solution to it is also an equilibrium. Any convex NLP problem has an equivalent mixed complementarity problem, but the reverse is not true (Cottle et al, 1992); therefore, it might not be possible to define such a NLP. However, Hashimoto (1985) defines an equivalent NLP for a spatial Cournot equilibrium with affine demand that is applicable to our problem. Consider the following NLP:

$$\begin{aligned}\max_{q_{ing}\geq 0} & \sum_{ng\in E}\left[\alpha'_{ng}\sum_i q_{ing} + \frac{\beta'_{ng}}{2}\left(\sum_i q_{ing}\right)^2\right] + \sum_{ng\in E}\frac{\beta'_{ng}}{2}\sum_i q_{ing}^2 \\ & -\sum_i\left[\sum_{n,g} t_{in} q_{ing} + c_i\left(\sum_{n,g} q_{ing}\right)\right] \\ s.t. \quad & q_{ing} = const\_q_{ing} \quad \forall i, \forall ng \in NE\end{aligned} \tag{22}$$

The first square bracketed term in the objective is the integral of the effective demand curves facing producers, and the last square bracketed term represents costs to producers. Thus, with the crucial exception of the middle term $\sum_{ng\in E}\frac{\beta'_{ng}}{2}\sum_i q_{ing}^2$, the objective of this NLP is identical to the standard 'social welfare (producer + consumer surplus) maximising' NLP widely used to calculate perfectly competitive equilibria in commodity markets (Takayama and Judge, 1971; Labys and Yang, 1991). The middle term, which is Hashimoto's (1985) contribution, converts the standard perfect competition condition 'P=MC' to 'MR=MC', where MR is the marginal revenue for the Cournot producer. After some algebraic simplification, it can be shown that the Karush-Kuhn-Tucker conditions for this NLP are equivalent to the original equilibrium conditions (16)-(17) for producers. After solving the optimisation problem for the q_{ing}, equations (18)-(21) can then be used to infer the values of the other quantities and prices, as before. As the objective function of (22) is to be maximized and is strictly concave, while the feasible region of (22) is a convex set, there is a unique optimum set of q_{ing} that is also a unique solution to (16)-(17). As a result, any solution to (22) is therefore also an equilibrium among Cournot producers.

4.2 Additional constraints

Two modifications can made to the model the results of arbitrage and legal restrictions on market share. The first modification arises from the possibility of within-country arbitrage. Up until now we used a general definition for the border price, i.e., specific border prices for each combination of *ng*. However, in the presence of arbitrage within a country, it is unlikely that a given trading company *r* operating in country *n* will face different border prices for different market segments. Therefore, a reasonable alternative assumption is that there is no border price discrimination among *g*, i.e., $bp_{ng} = bp_n$ for all *g*. There are at least two ways this can be modelled. One is to introduce costless arbitrage variables between market segments in a country within the NLP. Another is to sum the three demand functions (one per segment) for each country into one aggregate demand curve. This results in a piecewise linear convex demand curve. However, if we assume that the border price is below the price intercept for each and every market segment, then we can derive the following expression from (7) to represent the portion of the total national demand curve in which all segments of the market have positive quantities demanded:

$$bp_n = \alpha''_n + \beta''_n \cdot \sum_{ig} q_{ing} \tag{23}$$

where $\beta''_n = 1/\sum_g (1/\beta'_{ng})$, and $\alpha''_n = \beta''_n \sum_g (\alpha'_{ng}/\beta'_{ng})$.[7] When there are three segments (as in our application) and one of the segments (say, Segment 1) is non-eligible, then the expressions for the coefficients are instead $\beta''_n = 1/\sum_{g=2,3}(1/\beta'_{ng})$ and

$$\alpha''_n = \beta''_n[-(const\_x_{n1} - exog_{n1}) + \sum_{g=2,3}(\alpha'_{ng}/\beta'_{ng})].$$

Aggregation of a nation's demand curves in this manner allows us to simplify the NLP (22) for calculating equilibrium producer outputs in the following manner:

$$\max_{q_{in}\ge 0} \sum_n \left[\alpha''_n \sum_i q_{in} + \frac{\beta''_n}{2}\left(\sum_i q_{in}\right)^2\right] + \sum_n \frac{\beta''_n}{2}\sum_i q_{in}^2 - \sum_i \left[\sum_n t_{in} q_{in} + c_i\left(\sum_n q_{in}\right)\right] \tag{24}$$
$$s.t. \quad q_{in} \ge const\_q_{ing} \qquad \forall i, \forall ng \in NE$$

where $q_{in} = \sum_g q_{ing}$, the total sales by producer *i* to nation *n*. The constraint in (24) is a modified version of the one in (22) so that producer *i*'s sales to nation *n* are at least equal to its assumed sales to the non-eligible market. (The specific formulation of the constraint in (24) assumes that there is no more than one non-eligible market segment *g* per nation *n*.) The following simplified version of (18)-(21) can then be used to calculate the prices and other quantities of interest:

[7] Considering the possibility that price might be above the 'choke' price for some market segments would require that a convex piecewise linear function be defined, with as many pieces as there are demand segments. In general, consideration of such functions poses significant analytical problems, as each producer's optimization problem can no longer be guaranteed to be convex. In fact, the problem becomes a so-called MPEC (mathematical program with equilibrium constraints) (Luo et al, 1996), in which each producer optimizes its profit subject to a demand curve described by a set of equilibrium conditions (Karush-Kuhn-Tucker conditions) that make the constraint set non-convex. There exist algorithms to solve such problems, but MPECs can possess multiple local optima, implying the possibility of multiple and quite distinct market equilibria. Future research should address the calculation and interpretation of equilibria in that case.

$$x_{ng} = exog_{ng} + \frac{bp_n - \alpha'_{ng}}{\beta'_{ng}} \qquad \forall ng \in E \qquad (25a)$$

$$x_{ng} = const\_x_{ng} \qquad \forall ng \in NE \qquad (25b)$$

$$y_{rng} = (x_{ng} - exog_{ng}) / R_{ng} \qquad \forall r, \forall ng \qquad (26)$$

$$bp_n = \alpha''_n + \beta''_n \sum_i q_{in} \qquad \forall n \qquad (27)$$

$$p_{ng} = \alpha_{ng} + \beta_{ng}(x_{ng} - exog_{ng}) \qquad \forall ng \qquad (28)$$

The second modification we consider follows from derogation possibilities in the Gas Directive. Member States having only one main external supplier (a supplier having a market share of more than 75%) may derogate from the Directive. Producers' market share per country is therefore not allowed to exceed 75% in the model. That is, the following constraint is added to the NLP (22), in the case of price discrimination among sectors:

$$\sum_g q_{ing} \leq 0.75 \cdot (\sum_{g,j} q_{jng} + \sum_g exog_{ng}) \qquad (29)$$

In the absence of price discrimination, (29) simplifies to:

$$q_{in} \leq 0.75 \cdot (\sum_j q_{jn} + \sum_g exog_{ng}) \qquad (30)$$

The following Chapters show results of the model under several alternative assumptions and conditions.

5. PERFECTLY COMPETITIVE VERSUS OLIGOPOLISTIC TRADERS

In order to examine the effects of strategic behaviour of downstream trading companies, four alternative model runs are analysed. First, we either assume perfectly competitive behaviour or oligopolistic behaviour for the traders. Secondly, the border prices are either constrained to be equal across market segments and traders within a country or they are not constrained. The latter situation represents the possibility of price discrimination by the producers. If price discrimination on the border prices is allowed in the model, it means that producers can increase prices for less elastic consumers (generally households) while competing more intensely for more elastic market segments (industry and power generators). Moreover, if producers apply price discrimination, the margin that can be set by traders for inelastic consumers will be reduced. The four alternatives are denoted as case PC-ND, PC-D, O-ND and O-D, see below, where PC-ND represents the most competitive downstream case and O-D the least competitive.

Table 5.1 *Modelled cases*

	No price discrimination	Price discrimination
Perfectly competitive traders	PC-ND	PC-D
Oligopolistic traders	O-ND	O-D

All other assumptions are held equal across these four cases. Upstream producers are assumed to behave oligopolistically. The group of downstream traders is fixed by set *r* defined in Chapter 3. We assume that all consumers, i.e., gas-fired power generators, industrial gas consumers, and households, are free to contract for their gas supply. Thus, all consumer markets are assumed eligible (complete market opening).

The four cases are compared with the 1995 data in Table 3.1 and with a benchmark case, representing perfectly competitive market structures (both upstream and downstream) and no price discrimination. Effects are described in terms of resulting end-use prices, border prices, production, profits, consumer surplus, and social welfare (total profit plus consumer surplus).

5.1 Results

Comparing end-use prices under market opening (Table 5.2) with the 1995 data (Table 3.1) reveals some striking results. Competitive benchmark prices in the UK are similar to 1995 prices (see Figure 5.1), indicating the UK is a frontrunner in effective gas market liberalisation. UK gas prices already were unregulated and reasonably competitive in 1995 (see e.g., IEA, 1998c). German 1995 prices are similar to, and for industry and power generation even higher than, simulated oligopolistic prices (see Figure 5.2), suggesting that gas producers and traders had quite some market power in Germany. Indeed the German market was characterised by a complex structure in which cross-ownership and vertical integration were widespread. Exclusive demarcation and concession agreements limited competition in Germany (EJC Energy, 1997). In general, for most countries, actual 1995 prices are closest to simulated prices under oligopolistic producers and competitive traders.

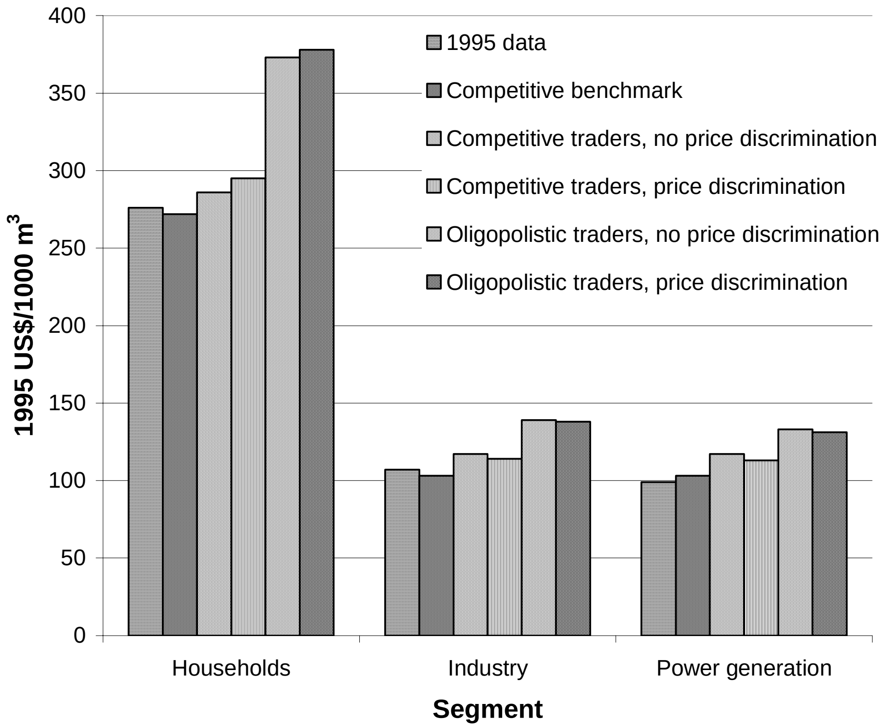

Figure 5.1 *End-use prices in British markets*

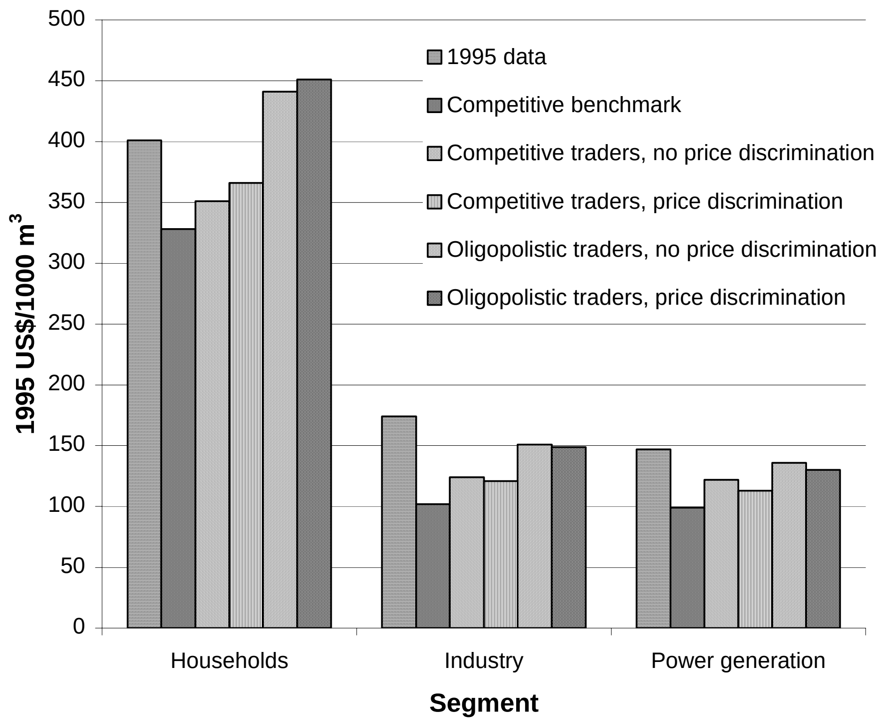

Figure 5.2 *End-use prices in German markets*

Given oligopolistic production, results in Table 5.2 show that assumptions regarding the behaviour of traders have a large effect on prices. If the downstream structure is also oligopolistic (successive oligopoly), the result is substantially higher end-use prices, lower throughput, and lower border prices than when traders are perfectly competitive. With oligopolistic traders, end-use prices are 7 to 89% higher than the benchmark, while with competitive traders they are only 3 to 36% higher. Traders make no economic profit when they are competitive; all profits accrue to the upstream producers. Consequently, total producers' profits are higher when traders behave competitively. In that case, the division in market shares between two (or more) traders in the same country (in this case Ruhrgas and Wingas in Germany) is irrelevant as they make no profit (and no losses). In an oligopolistic downstream trading structure, however, trader market share is relevant regarding the optimal solution. Given the symmetric and linear transmission costs we assume, total throughput is equally divided among the traders.

As expected, price discrimination widens the gap between prices for small consumers (households) and large consumers (industry and power generation), because the latter have more elastic demand. Thus, large gas users gain at the expense of households. Comparing profits in cases O-ND and O-D reveals that when price discrimination occurs at the country border, upstream producers gain at the expense of traders; trader profits fall because the margin they can charge on the end-use prices is reduced (Table 5.2). Indeed, trader profits fall so much that total producer and trader profit is less under price discrimination.

Figure 5.3 highlights the changes and redistribution of social welfare between the cases considered in Table 5.2[8] Total surplus falls as the market moves from the competitive benchmark to oligopolistic producers/competitive traders and then to oligopolistic producers and traders. This decrease in surplus occurs even as producer and trader profits rise, because consumer surplus falls even more. The figure also shows that if border price discrimination occurs, then producer profit increases at the expense of both trader profits and consumer surplus. However, this effect is not large; it would be greater if the producer market was more concentrated, or if elasticities are more divergent than assumed in Table 3.1 (as considered in Appendix A).

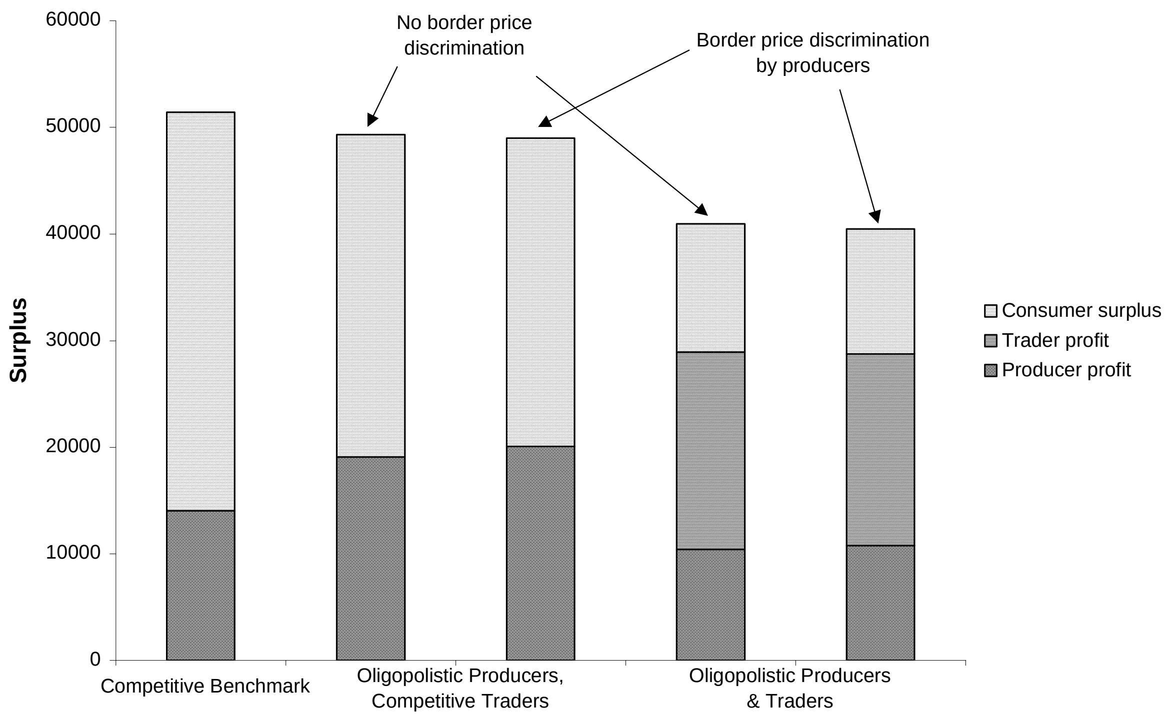

Figure 5.3 *Total social welfare and its allocation among consumers, traders, and producers*

8 Note that the indicated surplus for producers excludes fixed costs, and so should be interpreted as representing just the producers' operating margin. Producer profits are positive even under the competitive benchmark; this occurs not only because fixed costs are not netted out, but also because marginal production costs are strictly increasing.

As we noted earlier, price elasticities of demand are uncertain. Therefore, in Appendix A, we re-examine some of these conclusions under alternative elasticity assumptions. When elasticities are decreased (or increased) by 50%, the demand curves become steeper (less steep). In case of the competitive benchmark, prices are 1 to 12% lower with 50% lower elasticities. With oligopolistic producers and competitive traders, prices increase with 1 to 8%. However, the price impacts under a successive oligopoly are significantly higher under the lower elasticity assumptions. In another sensitivity analysis, increasing the elasticities for power generators, while at the same time decreasing household elasticities, increase the effects of price discrimination. This is even more so in the oligopolistic trader case. However, the general conclusion that a successive oligopoly (both strategic producers and traders) is much more distorting than only a single layer of oligopoly (strategic producers alone) holds in all cases.

Table 5.2 *End-use prices - border prices [1995 US$/1000 m^3], profits [mln US$] and production [bcm] for the benchmark and cases PC-ND, PC-D, O-ND and O-D*

			Perfectly competitive traders		Oligopolistic traders	
		No discr.	No discr.	Discr.	No discr.	Discr.
Country	Segment	Benchmark	PC-ND	PC-D	O-ND	O-D
Austria	households	314-83	346-115	364-133	484-93	493-111
	industry	91-83	123-115	120-112	169-93	167-90
	generation	89-83	121-115	118-112	168-93	166-90
Belgium	households	391-92	402-104	419-121	529-80	539-98
	industry	100-92	112-104	109-101	130-80	129-77
	generation	98-92	110-104	101-95	110-80	105-71
France	households	386-94	409-117	422-131	555-96	562-108
	industry	101-94	124-117	118-111	165-96	162-90
	generation	98-94	122-117	116-111	164-96	161-90
Germany	households	328-93	351-116	366-131	441-93	451-107
	industry	102-93	124-116	121-113	151-93	149-89
	generation	99-93	122-116	113-107	136-93	130-83
Italy	households	533-93	556-116	580-140	746-94	758-118
	industry	118-93	141-116	139-114	189-94	188-91
	generation	113-93	135-116	126-106	154-94	149-84
Netherlands	households	283-92	301-109	312-121	420-86	425-97
	industry	103-92	121-109	118-106	155-86	153-82
	generation	103-92	121-109	117-106	153-86	151-82
Spain	households	516-90	538-112	564-138	699-90	712-116
	industry	118-90	139-112	136-109	155-90	153-87
	generation	118-90	139-112	143-115	177-90	179-94
UK	households	272-88	286-102	295-111	373-78	378-88
	industry	103-88	117-102	114-99	139-78	138-75
	generation	103-88	117-102	113-98	133-78	131-74
Producer profit		14051	19088	20068	10414	10785
Trader profit		0	0	0	18505	17954
Consumer surplus		37366	30257	28944	12053	11742
Social welfare		51417	49345	49012	40973	40482
Production		376.8	327.3	328.8	212.8	214.4

6. VARYING THE NUMBER OF TRADING COMPANIES

As Chapter 3 indicates, the linear assumption for within-country TPA tariffs implies that changing the number of traders that operate within a country (each facing the same transmission and distribution costs) has no effect if a competitive within-country trading structure is assumed. Therefore, here we consider just an oligopolistic trading structure, along with no price discrimination (O-ND).

Recall the strict separation between the pipeline company, i.e., the transmission system operator (which charges a given TPA tariff), and the trading company (which incurs the TPA tariff as a cost to transmit the gas from the wholesale market to the end user). For each trader, the TPA tariffs of the country in which it operates apply. This means that if we allow e.g., Ruhrgas to operate also in Austria and the Netherlands, its transmission tariff is the same as its competitors in the respective countries. Therefore, under our simplifying assumptions, it does not matter which company is transmitting in which country; only the number of traders within the country matters.

Two alternatives are analysed. First, the number of traders within Germany is increased. Besides Ruhrgas and Wingas, sixteen new trading companies enter the German market (case ‘Germany-18’: eighteen traders in Germany). Second, we verify that allowing a large group of (in fact all nine) traders to operate in all countries will push prices towards competitive levels (case ‘All-9’: nine traders in all markets).

6.1 Results

As expected, end-use prices in Germany are much lower when many traders operate there (households -21%, industry -25% and power generators -19%), see case ‘Germany-18’ in Table 6.1. Total production, consumption, consumer surplus, and social welfare are higher than in case O-ND in Table 5.2. However total throughput is divided over more traders and profit of the trade companies in Germany is much lower. Prices in other countries are slightly higher (0 to 2%) than in the initial case O-ND, primarily because increased production has pushed the marginal cost of producing gas upwards.

When all nine traders are active in all eight countries (case ‘All-9’), the results tend to the competitive trader outcomes (case PC-ND in Table 5.2). That is, prices are lower and demand and throughput are higher than in the original case O-ND of Table 5.2.

Table 6.1 *End-use prices - border prices [1995 US$/1000 m³], profits [mln US$] and production [bcm] for cases Germany-18 and All-9*

		Oligopolistic traders, no price discrimination	
		Eighteen German traders	Nine traders in all markets
Country	Segment	Germany-18	All-9
Austria	households	487-99	372-110
	industry	172-99	130-110
	generation	171-99	128-110
Belgium	households	532-85	426-99
	industry	133-85	113-99
	generation	112-85	108-99
France	households	558-101	437-113
	industry	168-101	130-113
	generation	167-101	128-113
Germany	households	350-98	378-111
	industry	114-98	133-111
	generation	110-98	127-111
Italy	households	749-99	592-111
	industry	192-99	149-111
	generation	157-99	137-111
Netherlands	households	423-91	323-105
	industry	157-91	126-105
	generation	156-91	125-105
Spain	households	702-96	568-108
	industry	158-96	141-108
	generation	180-96	145-108
UK	households	376-83	302-97
	industry	142-83	119-97
	generation	135-83	118-97
Producer profit		12263	17051
Trader profit		13428	5724
Consumer surplus		16843	25757
Social welfare		42534	48532
Production		238.2	305.2

7. INCOMPLETE MARKET OPENING

This Chapter focuses on the effects of asymmetric market opening in Europe. It is assumed that selected countries (Austria, Belgium, France and Italy) will not open their gas market completely, i.e., households in those countries will stay captive. For these captive markets, consumption is defined by (18) or (25b), where the 1995 consumption is taken as the constant in the latter equation (IEA, 1997). Or, to put it in another way, prices are regulated in those markets. All other circumstances are the same as in Chapter 5, so the analysis is done for the benchmark and four alternative cases of market structure. Thus, the results can directly be compared with those in Table 5.2, representing complete market opening (all consumers eligible to choose their natural gas supplier).

7.1 Results

Table 7.1 shows that trader profits become positive with incomplete market opening, perfectly competitive traders and no price discrimination. This is the result of straightforward application of equation (1) to calculate profits, as the difference between border and end use prices for captive sectors is more than the assumed cost of within-country distribution dc_{ng}. However, it is not credible to assume that competitive traders would continue operating at a profit; a more reasonable scenario is that government regulators would alter regulated prices, taxes, or subsidies to avoid this outcome. For simplicity, we assume here that this adjustment takes the form of some lump sum transfer (e.g., fixed customer charge or refund) that does not affect consumption.

Table 7.1 also shows the prices of natural gas in the different countries and market segments. Incomplete market opening, compared to the cases with complete opening in Table 4, is advantageous for the consumers that stay captive when traders are oligopolistic. Prices for households in Austria, Belgium, France and Italy are substantially lower in that case (-20 to -26%). Other countries and industry and power generators in the four countries mentioned face somewhat higher end-use prices (0 to 1%). The lower prices result in lower trader profits (-10 to -25%), while producer profits increase by 5-13%. In case of competitive traders when no price discrimination is allowed (benchmark and PC-ND), captive customers face higher prices. Producer profit, consumer surplus, social welfare and production are somewhat lower. Results in case of price discrimination combined with competitive traders (PC-D) are ambivalent.

Table 7.1 *End-use prices - border prices [1995 US$/1000 m^3], profits [mln US$] and production [bcm] in case of incomplete market opening*

		Incomplete opening				
Country	Segment	No discr. Benchmark	No discr. PC-ND	Discr. PC-D	No discr. O-ND	Discr. O-D
Austria	*households*	*386-82*	*386-116*	*386-155*	*386-98*	*386-155*
	industry	90-82	124-116	119-111	171-98	168-90
	generation	88-82	122-116	117-111	170-98	167-91
Belgium	*households*	*409-91*	*409-101*	*409-111*	*409-80*	*409-111*
	industry	99-91	109-101	108-100	130-80	129-77
	generation	97-91	107-101	100-94	110-80	105-70
France	*households*	*421-91*	*421-120*	*421-129*	*421-98*	*421-129*
	industry	98-91	126-120	117-110	166-98	163-90
	generation	95-91	124-120	115-111	165-98	162-90
Germany	households	327-92	350-116	364-129	442-94	451-107
	industry	101-92	124-116	120-112	152-94	149-90
	generation	98-92	122-116	112-106	137-94	131-84
Italy	*households*	*561-92*	*561-117*	*561-121*	*561-97*	*561-121*
	industry	117-92	142-117	137-112	191-97	188-91
	generation	111-92	137-117	125-105	156-97	150-85
Netherlands	households	282-91	301-109	310-119	420-87	426-97
	industry	102-91	121-109	116-105	155-87	153-82
	generation	102-91	121-109	116-104	153-87	151-82
Spain	households	515-89	537-111	562-137	699-91	712-116
	industry	116-89	139-111	136-108	155-91	154-87
	generation	116-89	139-111	142-115	178-91	180-95
UK	households	273-89	286-102	294-110	373-79	378-88
	industry	103-89	117-102	112-97	140-79	138-75
	generation	103-89	117-102	111-96	133-79	131-74
Producer profit		13276	18947	19428	10888	12149
Trader profit		1608	391	0	14818	13517
Consumer surplus		36070	29749	29801	17676	17698
Social welfare		50954	49087	49229	43382	43364
Production		374.3	325.5	333.4	232.9	237.1

Note: Figures in italic denote prices faced by non-eligible sectors.

8. DISCUSSION AND CONCLUSIONS

This paper describes the empirical model GASTALE and shows several illustrative analyses of the European gas market using this model. GASTALE extents and applies the successive oligopolist model of Greenhut and Ohta (1979) to a situation in which there are multiple consumer markets separated in space and upstream producers have nonlinear production costs. GASTALE makes an explicit distinction between upstream producers and downstream traders in the gas market. It is possible to simulate alternative strategies for producers and traders (oligopolistic or perfectly competitive). GASTALE is a flexible model as the number of producers, traders, countries, etc. can be easily altered, so it can be used for different applications. Liberalisation of the gas market can be examined with GASTALE in several ways: allowing consumer groups to be either eligible or captive; varying the assumed behaviour of traders between perfect competition and oligopoly; constraining price discrimination; and varying the number of traders.

A number of simplifications have been made in GASTALE that should be addressed in future work, as we discuss at the close of these conclusions. Nevertheless, the model is the first to explicitly address the sequential oligopoly nature of the European gas market. We present several sets of results that illustrate how the interactions of oligopoly in production and trade can affect market outcomes, although the model's simplifications imply that specific numerical results for particular sectors should interpreted cautiously. The analyses in this paper focus mainly on the role of the downstream trading companies. Our model results show that as a result of our assumed linearity of within-country transmission tariffs (no scale economies), traders make no profits above a normal return to capital in a perfect competitive market. But under oligopolistic competition, traders do make a profit and the level of this profit depends on the ability of producers to price discriminate at the border. Assuming an oligopolistic downstream structure, we saw that end-use prices converge to prices corresponding with perfectly competitive trading when the number of traders increases.

Although it is often thought that vertical integration stimulates market power and puts the end-consumer at a disadvantage, the opposite might be true. The results in this paper show that, given the oligopolistic structure of the upstream industry, it is important to prevent (or abolish) monopolistic/oligopolistic structures in the downstream gas market. As Tirole (1988) states: "What is worse than a monopoly? A chain of monopolies."

In general, the economic literature (Tirole, 1988) concludes that in the case where there is both upstream and downstream oligopoly, vertical integration between upstream and downstream is favourable for consumers. Vertical integration prevents double marginalisation, i.e., two successive mark-ups, and end-use prices would be lower. This suggests that in the case where monopolistic or oligopolistic competition between downstream gas companies cannot be prevented, vertical integration should be supported (or at least not be discouraged!). The conclusion is confirmed by the results of Chapter 5 in which a comparison was made between the behaviour of the competitive and oligopolistic traders. A vertically integrated gas company can be compared with the results of case PC-D. Producers set their border prices with the knowledge that the traders will not charge a second margin on the prices, consistent with our Stackelberg assumption. Therefore the most optimal end-use prices, from the point of view of producers, are set and maximum profit is attained. (Alternatively, PC-D can be viewed as a simulation of a situation in which every producer integrates vertically by creating a trading operation in each country, and those operations displace the assumed independent traders.) In contrast, if independent traders form an oligopoly and there is no vertical integration (case O-D), the traders also set a margin on the end-use price. Consequently all end-use prices are higher, whereas consumer surplus and social welfare are lower compared to vertically integrated companies.[9] Considering these results, vertical integration indeed should not be discouraged in case the trading market is dominated by oligopolies. The best form of vertical integration would be to allow producers to enter national markets alongside existing traders by forming their own trading operations. This possibility should be simulated in future work.

Our model has several limitations that should be addressed in future research. First, demand, and thus price effects, depend on the assumed price elasticities. Because of the structure of the model, i.e., the assumption of oligopolistic producers and traders, the assumed elasticities can significantly affect price and welfare results. For now, our sensitivity analyses show that the main conclusions concerning the undesirability of successive oligopoly are unaffected by variations in elasticities. However, the magnitude of the effects and their distribution among different consuming sectors are impacted. Therefore, priority should be placed upon obtaining better elasticity estimates for a more disaggregated set of consuming sectors. For instance, market models for the electric sector (e.g., the power module in PRIMES (Capros et al, 2000) could be used to obtain that sector's demand elasticity for gas, explicitly considering how gas competes with other boiler fuels.

Second, we have incomplete information about new TPA tariffs. Most countries are still developing TPA tariff structures and they are not (yet) public. GASTALE should be updated as new information becomes available. To the extent that those tariffs depend on load and distance, it may be desirable to further divide consuming sectors by customer size and location. Third, price discrimination is incorporated at the level of producers, i.e., on the border prices. The traders are still allowed to discriminate between end-consumers, which they do. However, partial arbitrage (for instance among industrial and generation customers) could reduce that discrimination, and could be simulated in GASTALE.

Fourth, costs of long distance transport from producers to the borders of the consuming countries could be more realistic, i.e., by explicitly representing pipeline capacities and tariffs associated with alternative transport routes, and competition among oligopolistic producers for those transport services. It may be possible to adapt representations of such competition that have been used in models of oligopolistic power generators located on power networks (e.g., Day et al, 2002). A final area in which improvements are desirable is the possible representation of offsetting market power on the part of large consumers of gas. This represents an interesting theoretical challenge because there are no generally accepted paradigms for modelling games involving bilateral oligopoly in which both producers and consumers (and perhaps also traders) have market power.

[9] Total profit is also higher under successive oligopoly, which at first glance contradicts theoretical results that show a shrinkage in profits (e.g., Greenhut and Ohta, 1976). However, in our case, trader markets are more concentrated than production markets. Therefore, when traders integrate vertically, they lessen market concentration in trading. Thus the profit increasing effect of vertical integration identified by theory is more than compensated for by the profit decreasing effect of decreased market concentration.

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APPENDIX A: SENSITIVITY ANALYSIS OF ELASTICITIES

In order to assess the effects of the elasticities on the modelling results, some sensitivity analyses have been conducted. When elasticities are assumed lower (higher), corresponding α's and β's will be higher (lower) in absolute terms. Several cases are considered in this appendix; although levels of prices, profits, and consumer surplus vary among them, the basic conclusion that successive oligopoly is undesirable is robust to elasticity assumptions.

Since our initial elasticities seem to be somewhat high relative to many estimates in the literature (e.g., Dahl, 1993; Söderholm, 2001), Table A.1 shows results for the benchmark and the four cases with 50% lower elasticities. The results can be compared with the respective cases in Table 5.2.

Table A.1 *End-use prices - border prices [1995 US$/1000 m^3], profits [mln US$] and production [bcm] for the benchmark and cases PC-ND, PC-D, O-ND and O-D with 50% lower elasticities*

			Perfectly competitive traders		Oligopolistic traders	
		No discr.	No discr.	Discr.	No discr.	Discr.
Country	Segment	Benchmark	PC-ND	PC-D	O-ND	O-D
Austria	households	303-72	352-121	381-151	615-97	629-126
	industry	80-72	129-121	124-116	208-97	205-92
	generation	78-72	127-121	122-116	207-97	204-92
Belgium	households	379-81	405-107	437-139	666-81	682-114
	industry	89-81	115-107	111-103	157-81	115-76
	generation	87-81	113-107	102-96	131-81	125-68
France	households	375-83	418-127	442-151	710-103	722-126
	industry	89-83	133-127	124-117	216-103	211-93
	generation	87-83	131-127	122-117	214-103	210-94
Germany	households	317-82	357-122	384-150	535-97	550-123
	industry	90-82	130-122	125-117	180-97	176-92
	generation	88-82	128-122	117-111	161-97	153-84
Italy	households	529-89	566-127	607-167	949-103	969-142
	industry	114-89	152-127	146-121	251-103	248-97
	generation	109-89	146-127	131-111	201-103	194-87
Netherlands	households	272-80	308-117	331-139	552-92	563-113
	industry	92-80	128-117	122-111	202-92	198-85
	generation	92-80	128-117	122-110	199-92	196-84
Spain	households	512-86	544-119	589-163	885-95	907-138
	industry	114-86	146-119	141-114	197-95	194-90
	generation	114-86	146-119	149-122	228-95	230-99
UK	households	270-86	294-109	311-126	480-85	489-103
	industry	101-86	124-109	120-105	182-85	179-78
	generation	101-86	124-109	118-103	173-85	169-76
Producer profit		11065	20015	22087	10194	11071
Trader profit		0	0	0	29780	28734
Consumer surplus		65281	53557	51152	18746	18122
Social welfare		76346	73572	73239	58720	57927
Production		349.6	305.2	305.9	184.3	185.4

When all elasticities are assumed to be 50% lower than in Table 3.1, production, throughput and consumption quantities will be lower (7 to 14%) while end-use prices are generally higher (except for the benchmark, which yields lower prices with lower elasticities). Consumer surplus and social welfare increase substantially, as would be expected (as a lower elasticity implies a higher price intercept for the demand curve, so the area under the demand curve will likely be higher). The welfare impact of oligopoly relative to the baseline is also greater in Table A.1 than in Table 5.2 because the lower elasticities result in greater impact for market power. Results are in the opposite direction when all elasticities are 50% higher, although the percentage changes are less pronounced.

Since Germany is the biggest consumer market in our model, we have also analysed what happens if only the elasticities in Germany are 50% lower. Elasticities in other countries remain unchanged. As a result, producer profit and production are lower, while consumer surplus and social welfare are higher than in the cases with initial elasticities. In the competitive benchmark, end-use prices are lower (0 to 7%), also in Germany. However, in case of imperfect competition, German prices are higher (2-6% when traders are competitive; 20-22% when traders are oligopolistic), while prices in the other countries are lower (0-4%) because producer marginal costs have fallen as output has decreased. Consumption is lower in Germany and somewhat higher in other countries. In contrast, changing elasticities just in Spain, the smallest consumer market, hardly has any effect on the model results.

A drawback of our model is the assumed similarity of elasticities between industry and power generators due to a lack of consistent data. When power generators have the capacity to switch between fuels, e.g., from gas to coal, their responsiveness on changes in relative fuel prices is bigger than single-gas-fired sectors. Dual- or multi-fuel capacity is quite common in electricity production. Hence gas price elasticities may be higher for power generators than for industry. Therefore, additional analyses of the benchmark and the four cases of market structure, assuming 50% higher elasticities for power generators have been conducted. At the same time, in order to increase the potential for price discrimination, we also decrease elasticities for households by 50%. Results are shown in a Table A.2.

Table A.2 *End-use prices - border prices (1995 US$/1000 m3), profits (mln US$) and production (bcm) for the benchmark and cases PC-ND, PC-D, O-ND and O-D with 50% higher elasticities for power generators and 50% lower elasticities for households*

			Perfectly competitive traders		Oligopolistic traders	
		No discr.	No discr.	Discr.	No discr.	Discr.
Country	Segment	Benchmark	PC-ND	PC-D	O-ND	O-D
Austria	households	314-83	344-113	386-155	612-92	632-131
	industry	91-83	121-113	120-111	168-92	167-90
	generation	84-83	119-113	114-108	155-92	153-87
Belgium	households	391-92	400-102	441-143	664-79	684-119
	industry	100-92	110-102	109-101	129-79	129-77
	generation	98-92	108-102	98-92	102-79	96-67
France	households	386-94	411-119	447-155	708-98	724-131
	industry	101-94	125-119	117-111	166-98	162-90
	generation	98-94	123-119	111-107	150-98	144-85
Germany	households	328-94	349-114	389-154	529-92	554-129
	industry	102-94	122-114	121-113	151-92	149-89
	generation	99-94	120-114	109-103	129-92	120-79
Italy	households	535-93	553-114	611-171	944-92	971-147
	industry	118-93	139-114	138-113	189-92	188-91
	generation	113-93	133-114	121-101	139-92	133-81
Netherlands	households	283-92	300-108	335-144	549-86	565-118
	industry	103-92	120-108	118-106	154-86	153-82
	generation	103-92	120-108	113-101	138-86	134-78
Spain	households	516-90	537-111	593-167	883-90	909-143
	industry	118-90	139-111	136-109	155-90	153-87
	generation	118-90	139-111	138-110	161-90	160-89
UK	households	272-88	286-102	315-130	477-78	492-108
	industry	102-88	116-102	115-100	140-78	139-77
	generation	102-88	116-102	110-95	121-78	118-72
Producer profit		14043	18821	22500	10353	11991
Trader profit		0	0	0	27654	25707
Consumer surplus		55976	49203	44721	17591	16443
Social welfare		70020	68024	67221	55598	54141
Production		376.5	327.1	330.6	213.8	217.0

Note: Bold faced sectors have different elasticities than in Table 5.2

The effects for the benchmark are very small, although consumer surplus and thus social welfare are much higher (50 and 36%). However, when traders are assumed to form an oligopoly, prices for the power generators are 5 to 11% lower than in the respective cases (O-ND and O-D) with original elasticities (Table 5.2). Meanwhile, household prices are 20 to 33% higher, while prices for industrial gas consumers remain essentially unchanged (changes vary from -1 to 1%). As expected, border price discrimination is more advantageous for power generators, because their demand is relatively more elastic. Obviously, effects of oligopolistic market structures and price discrimination are less severe for power generators when their fuel substitution possibilities are better (price elasticity higher). Since producers are better able to price discriminate at the border with the more divergent elasticities assumed here, their profits are higher (11-12%) when price discrimination is allowed.

APPENDIX B: COST OF TRANSPORT

Table B.1 *Cost of transport from producer to country in [1995 US$/1000 m^3]*

To: / From:	Austria	Belgium	France	Germany	Italy	Netherlands	Spain	UK
Gazprom[a]	39.54	55.71	49.87	51.22	58.41	56.16	75	72.33
Sonatrach[b]	71.43	93	75.03	134.73	67.84	139.73	65	93
GFU[c]	54.36	44.48	54.36	46.28	54.36	43.58	54.36	16.17
Shell[d]	26.06	8.54	16.62	9.88	24.26	8.09	24.26	16.17
Exxon Mobil[d]	26.06	8.54	16.62	9.88	24.26	8.09	24.26	16.17
EBN[d]	26.06	8.54	16.62	9.88	24.26	8.09	24.26	16.17
Agip/ENI[e]	3.59	23.8	20	10	17.52	24.26	23.8	57.51
BG[f]	59.31	33.25	41.33	43.13	57.51	33.25	50	14.38
BP Amoco[g]	59.31	33.25	41.33	46.28	57.51	33.25	50	14.38
TotalFinaElf[f]	49.87	16.52	54.36	35.95	17.52	16.52	50	14.38
Amerada Hess[f]	59.31	33.25	41.33	43.13	57.51	33.25	50	14.38
Wintershall[h]	16.18	9.88	19.76	21.57	14.38	9.88	30	43.13
Lasmo[f]	59.31	33.25	41.33	46.28	57.51	33.25	50	14.38

Source: Dahl and Gjelsvik (1993), Table 2. Values have been converted from 1988 US$/Mcf into 1995 US$/1000 m3 by multiplying with the US$ inflation factor 1.2715 and dividing by 0.0283.

a From Urengoi fields to Waidhaus at the Czech-German border (38.64) and from Waidhaus to the respective countries (to Austria 0.9, to Belgium 17.07, to France 11.23, to Germany 12.58, to Italy 19.77, to the Netherlands 17.52, to the UK 72.33 (=56.16+16.17)).

b Pipeline gas to Italy and Austria, LNG shipments to other countries.

c From the Heimdal fields to Emden, Germany (24.71) and from Emden to the respective countries (to Belgium 19.77, to France 29.65, to Germany 21.57, to the Netherlands 18.87). For Austria and Italy, costs are assumed the same as to France). The UK is directly delivered from the North Sea.

d From the Netherlands to the respective countries.

e To Austria: from Taravisio, Italy to Northern Italy. To Italy: from Taravision to Southern Italy. To the Netherlands: see Note d.

f Transport cost from the Ekofisk fields to Emden is taken as a proxy for transport to the UK. Additional costs from Emden to the Netherlands. To Belgium is assumed the same as to Netherlands. From the Netherlands to the other countries are taken as additional costs (to France +16.62-8.54).

g See Notes c and f. From Elf to Germany: Ekofisk-Emden plus Emden-Germany.

h From Emden to Germany.