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Price patterns resulting from different producer behavior in spatial equilibrium

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Abstract

We are concerned with economic analyses of markets from the perspective of supporting a decision maker selling in the market. The competitive pressure and the price formation are central issues. The goal of this paper is to highlight the remarkably different price patterns obtained from different modes of seller behavior in a spatial market. This is exemplified by models of price taking versus the oligopolistic Cournot mode of behavior. Although a particular market, namely the European market for natural gas is used for illustration, the insights from this exercise apply to any industry where suppliers have market power, their locations differ, and their costs of supplying individual segments of the market are non-negligible and differ. When market power is present and one seeks insight into competition and price formation, details in other dimensions cannot compensate for not modeling the exertion of market power.

Key words: Price formation, Spatial market, Market power

JEL Codes: C68, D41, D43, L11, L13

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1. Introduction

The conduct and performance of an industry are determined by several characteristics. Which are most relevant to consider depend on the particular industry and the issue in question. Our concern is economic analyses to support a corporate decision maker selling in the market. One central issue is then to provide insight into the price formation. We consider a case where sellers have market power in a spatial market and where transportation costs are non-negligible.

Spatial equilibrium theory deals with two types of decisions. Originated by Hotelling (1929), one is the location of individual firms in the market place. See *e.g.* Hamilton *et al*. (1989) and Greenhut *et al*. (1991) who consider location with spatial price discrimination of Bertrand vs. Cournot. The other issue takes firms' locations as given and considers their pricing. Greenhut and Greenhut (1975) and Anderson *et al*. (1989) both consider the effect on prices of rival locations and the intensity of their competition, and Anderson and Neven (1991) compare uniform pricing, mill pricing and spatial price discrimination. We will follow this second line and consider pricing where firms' locations are given. We also consider a time horizon of a few years within which capacities are given.

A related area is trade theory, which studies international trade and policies aimed at modifying trade patterns. Of particular relevance are analyses of intra-industry trade in a model of a homogenous product and imperfect competition; see Brander (1981) and Brander and Krugman (1983).

Analyses of actual markets, *e.g.* international commodity markets, use numerical rather than analytical models, allowing for asymmetries and details in the various dimensions of the industries. Despite its popularity, the paradigm of spatial competitive equilibrium suffers from significant deficiencies, most notably poor performance in explaining trade patterns. (Kolstad and Burris, 1986). We will demonstrate another and certainly related deficiency regarding the price pattern. To do this, we compute equilibrium prices under the alternative assumptions of suppliers being price takers or oligopolists following the Cournot hypothesis. One may doubt that competition according to either of these stringent models per se really exists in practice. They are both, however, regarded as convenient workhorses in theoretical and numerical analyses. (Greenhut *et al*. 1991.) In a particular analysis, the question is: Which assumption performs best?

Prices are an integral part of an economic equilibrium. In fact, they guide the agents of the model such that equilibrium obtains. Yet, price patterns are seldom the focus of analyses. More often the analyst is concerned with issues on the economic-political agenda, policies to enhance investments in production capacities or infrastructure, changes in the organizational structure like deregulation\ liberalization or cartelization of an industry, or disruption of supply. Such issues are important to all firms in the industry, not only those that undertake the investment or are directly affected by the organizational change, and of course, the price pattern is part of the model solution. For good reasons the analyst may disregard the price information; his focus in the mentioned issues is on aggregate measures as regional or total production, consumption, and welfare.

Our focus, however, is on the price patterns that result from different modes of seller behavior. Which insights can be gained to support a firm's sales decisions from modeling the combination of space and behavior? We illustrate our points using the European market for natural gas. Although there is wide-spread agreement that the European market for natural gas is non-competitive, models based on the assumption of price taking behavior are also used. For some classes of analyses such simplification may be acceptable as it allows more details in other dimensions. For understanding the competitive pressure and price formation, however, it seems detrimental, and adding details in other dimensions can hardly compensate for a simplistic representation of behavior.

The importance of modeling the critical features is of course well known and it is demonstrated over and over again. E.g. when developing a model to explain and predict the pattern of comparative advantage across many regions, it was suggested to use the Armington assumption for net imports. This assumption, however, implies that if a region is a net importer in the bench-mark it stays a net importer in all subsequent periods and runs, *i.e.*, the trade pattern is assumed exogenously and not derived endogenously. Hence such a model would only explain trade in a simplistic way. (Haaland *et al.*, 1987). Similarly, Norman (1990) found that modeling imperfect competition makes a significant quantitative difference to the effects of trade liberalization on inter industry trade patterns and that the Armington approach was no substitute for explicit incorporation of oligopolistic interaction. Balistreri *et al.* (2010) reached the same conclusion that industrial organization matters to trade and welfare.

The remainder of the paper is structured as follows. Chapters 2 review characteristics of the natural gas industry in Europe and some of the models that are developed. The focus is on behavior and price formation within a time horizon where capacities are given. Chapter 3 discusses the modeling of behavior embedded in a spatial model. In Chapter 4 the striking differences of solutions from two different modes of behavior are illustrated. Chapter 5 concludes.

2. The European natural gas industry and models

At the aggregate level a market is defined by supply and demand. The performance of the market is determined by several features behind supply and demand, *e.g.* the nature of products, the numbers of sellers and buyers, transaction costs, degree of economies of scale in production and distribution, temporal and spatial dimensions, uncertainties about long run developments, etc.

First and foremost is the *nature of the product*. Except for the low-calorific gas from Groeningen gas from other fields are mixed in the pipelines. Of course, consumers may prefer deliveries from a particular seller based upon other conditions of sale, *e.g.* for security reasons, but largely natural gas is considered a homogeneous good. With price competition, theory predicts there will be one price.[1]

The next characteristic is the *number of players*. In the European gas market there are a few large suppliers, some very influential transmission and distribution companies, as well as some large consumers, although most consumers are small. Fewness and size imply potential *market power*, that is, ability to influence price. In production, fewness is related to the availability of resources; only a few countries are endowed with large reserves of natural gas. Furthermore, extraction rights are allocated to only a few companies. In transportation, fewness results from large economies of scale with respect to pipeline dimension both in terms of putting the pipeline in the ground and its carrying capacity. Transmission and distribution networks are examples of natural monopolies. Despite an incentive to install large capacities, old pipelines or monopolistic behavior may constrain flows and hinder some sellers' access to a market and thus impede competition.[2]

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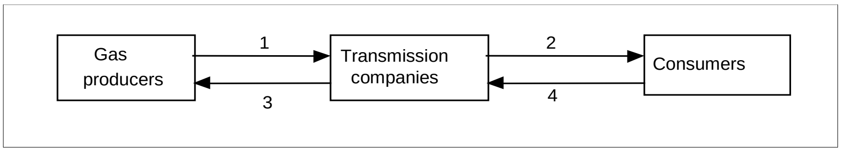
[1] 'Cointegration tests show that different border prices for gas to Germany move proportionally over time indicating an integrated market (the Law of One Price)'. (Asche *et al.*, 2002.) Subsequent work by these authors supports the same conclusion for France.

[2] Hubert and Ikonnikova (2011) analyzed the strategic value of a adding the Russian pipeline *North Stream*.

One question is who has power another is how to model market power. Consider the stylized structure in Figure 1, where one or more gas producers sell to a transmission company, which resells to final consumers. The numbered arrows represent exertion of market power. *1*, for example, means that producers exploit market power versus price taking transmitters, while *3* represents the opposite when a transmission company exploits its power versus a price taking producer. While several or even all of these relationships may co-exist in a particular industry, some combinations are difficult to model. The problem is whether the theory provides a (locally) unique solution or not.

Figure 1. Combinations of market power.



Within *non-cooperative* game theory, it is well known how to model *1* as an oligopoly of producers selling to price taking transmitters. This is the Cournot model which we return to below. *3* is that model turned upside down, *i.e*., an oligopsony of buyers. Combination *1&2* describes a situation of successive market power, where producers sell to price taking transmitters, who in turn exploit their power over price taking customers. Finally, combination *2&3* is about a (transmission) company that has market power in both factor and product markets. It can be generalized to an oligopolistic setting.

Combination *1&3*, however, signals a situation where both sides of a market have power. Conceptually this case is similar to the so-called bilateral monopoly. Rather than having a unique solution, it involves a continuum of solutions. The impasse may be resolved by using the Nash bargaining solution concept of *cooperative* game theory. This theory, however, is not as easily available as the non-cooperative theory for detailed numerical modeling.[3]

Space is an important dimension for at least two reasons. The distances from a major field in Russia, Algeria or Norway to the market are large. Also, distances between various consuming regions in Europe are considerable, whereby net-back prices for a given supplier differ considerably between the regions he may supply, which obviously influence his decisions to supply these markets.

Several features of the gas industry signal that *time* is important. In economic theory resource extractive industries are studied from the perspective of optimal inter-temporal depletion paths.[4] The lead times between a decision to develop a field or build a major pipeline and the resulting deliveries to the market are very long and investment costs are enormous. Uncertainties about future market conditions and the economic feasibility of projects have made producers insist on long term contracts in order to make irreversible investments in fields and transmission lines. Even though contracts specify fairly detailed volume and price conditions, there is flexibility to allow the contracting parties to adapt to changing conditions. In addition, the expectation of establishing new contracts in the future makes parties willing to renegotiate terms in existing contracts. Thus, the European gas market may be analyzed as if prices are flexible enough to do their job of equating supply and demand.[5]

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[3] Hoel *et al*. (1987) modeled a cooperative game between producers and transmission companies.

[4] Brekke *et al*. (1987) modeled a dynamic game where producers responded to previous actions. The time-dimension and the complexity of the strategy-space necessitated a condensation of other dimensions, *e.g*. space. Smeers (1997) concluded that the incentive to invest strategically did not turn out to be that important.

[5] Cf. Asche *et al*. (2002).

Another aspect of time is the *seasonal* pattern within a year. Some consumers have much higher demand in winter than in summer. With costly production capacity, it may be profitable to apply an average production rate and use storage to balance seasonal demand in addition to allowing the winter spot price to increase (peak load pricing).

The above mentioned features, in addition to a number of details in each dimension, are relevant for some analyses. But typically, all details are not equally relevant for a given class of issues. Even though present day PCs have an enormous computing capacity one has in practice to abstain from considering every dimension in minute detail. If not for other reasons, one should acknowledge that a model is meant to support and not make decisions. Hence understanding the mechanisms of the model and the basis for its solutions is essential for the model to be useful.

As our focus is price formation in the medium term let us review models that may support such analysis. The Gas Trade Model (GTM) developed in the Systems Optimization Laboratory at Stanford University in the early 80ies (Beltramo *et al*. 1986) was an early effort to model a natural gas market. It assumes price taking behavior in supply and demand and is a multi-regional transportation type model. [6] Boucher and Smeers (1984) applied this model structure to an analysis in Europe.

Observing that the European market was dominated by few and not many players, Mathiesen *et al*. (1987) analyzed various kinds of seller behavior, viz. price taking, Cournot, and collusion.[7] They focused on the exertion of market power by three large exporters to continental Europe: Algeria, Norway, and the Soviet Union and found that the Cournot behavior gave the best replication of the observed sales pattern, price level and profits of the industry. Smeers (1997) rationalized this finding stating that '[n]atural gas is (still) mainly traded in Europe through long term contracts and competition can thus be expected to take place through quantities'. Mathiesen (1987) extended the model to include a network of pipelines with finite capacities. It was constructed for the marketing division in Statoil.[8] We return to an analysis with this model in Chapter 4.

The non-competitive nature of the European gas market and the complementarity formulation are widely accepted by analysts.[9] Golombek *et al.* (1995, 1998) modeled various aspects of deregulation of the European energy market. Boots *et al*. (2004) considered the successive oligopoly (combination *1&3*) in a multiregional network model. Egging *et al*. (2007) provided an even finer disaggregation of the value chain, while Gabriel *et al*. (2010) studied the potential effects of a gas 'OPEC'.

Still there are models based on the idea of a central decision maker who optimizes overall social welfare. Boothe and Seeliger (2005) forecasted European supplies for the next 30 years. Øygard and Tryggestad (2001) considered the deregulation of the market using the McKinsey model.[10]

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[6] A *transportation* type model observes the unit cost of transporting a good between origins and destinations. A *network* model also may contain intermediate nodes that are neither origins nor destinations and it considers capacities along the various links that are available for transportation between origins and destinations.

[7] Another novelty of this paper was the formulation as a complementarity problem. (Mathiesen 1985).

[8] See Fuglseth and Grønhaug (2001) for a decision oriented experiment.

[9] Gabriel *et al*. (2010) provide a summary of eight gas-trade models. The two models of the European market and one of three with a world-wide perspective consider market power and are of complementarity type, while models of North-America do not consider market power and are mostly optimization models.

[10] Judging from a non-technical description this is a fairly detailed model with large numbers of fields, pipelines, consuming regions and consumer types, but where producers (and other players) are price takers.

3. Behavior

A firm's mode of behavior is about how it views competition. Several suggestions or models exist. As evidenced by the literature, it is a difficult concept both theoretically, analytically, and empirically. In order to demonstrate that the choice of behavioral mode may matter for the price pattern we use the two most common models, the price taker and the Cournot oligopoly. A price taker assumes that price setting is beyond his control and his competitors are of no concern. By definition a player who has market power realizes that price depends on what he does and thereby that his rivals are affected by his actions. A comparison of results from these two modes of behavior is telling.

Consider the market for a homogeneous product, where producers may exert market power, and assume that they make quantity decisions. For the ease of exposition of various behavioral modes, consider first a non-segmented market. Let *i* denote producer, *i* = 1,...,*n*. Further let

x_i and $C_i(x_i)$ denote his quantity and total cost of producing it, and $c_i' \equiv \partial C_i/\partial x_i$. Let
$p(X)$ denote the market price as a function of total supply, *i.e.*, $X = \Sigma_i x_i$, and
$\pi_i(\mathbf{x}) = p(X)x_i - C_i(x_i)$ denote his profits, where $\mathbf{x} = (x_1,\ldots,x_n)$ is the vector of decision variables.

The profit maximization problem of producer *i* is then

$$(1) \quad \text{maximize} \quad \pi_i(\mathbf{x}) = p(X)x_i - C_i(x_i), \qquad i=1,\ldots,n.$$

Through the vector **x**, his maximization problem is a function of rivals' decision variables as well. Provided $x_i > 0$, his first order (necessary) condition for a profit maximum is

$$\begin{aligned} \partial\pi_i/\partial x_i &= p + [(\partial p/\partial x_1)(\partial x_1/\partial x_i) + (\partial p/\partial x_2)(\partial x_2/\partial x_i) + \\ &\qquad \ldots + (\partial p/\partial x_n)(\partial x_n/\partial x_i)]x_i - \partial C_i/\partial x_i \\ &=^{11} p + p'[1 + \Sigma_{k\neq i}(\partial x_k/\partial x_i)]\, x_i - c_i' \\ (2) \qquad &= \{p + p'[1 + \theta]\, x_i\} - c_i' = 0. \end{aligned}$$

The term $\theta \equiv \Sigma_{k\neq i}(\partial x_k/\partial x_i)$ represents the sum of rivals' responses to a change in producer *i*'s quantity. It is called *conjectural variations* (cv) signaling that producer *i* holds conjectures about his rivals' responses. The entire bracketed term is marginal revenue, and the condition says that optimal production is at a level where marginal revenue equals marginal cost.

(2) subsumes several behavioral types. The *Cournot* hypothesis is that producer *i* conjectures that his rivals do not react to his change of volume, *i.e.*, $(\partial x_k/\partial x_i) = 0$, $k\neq i$, whereby $\theta = 0$. Thus

$$(2.1) \qquad \partial\pi_i/\partial x_i = \{p + p'x_i\} - c_i' = 0.$$

Bertrand's model can be thought of as having $\theta = -1$; the firm believes that its increased output will be exactly offset by the other firms, and we are left with $p - c_i' = 0$. This model should be distinguished from the case of the *price taker* who ignores his influence on price, *i.e.*, who thinks $p' = 0$, in which case we also are left with the condition that price equals marginal cost,

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[11] For a homogeneous product $\partial p/\partial x_1 = \partial p/\partial x_2 = \ldots = \partial p/\partial x_n = p'$.

(2.2) $\partial\pi_i/\partial x_i = p - c_i' = 0$.

The general case is when $(\partial x_k/\partial x_i)$ is of any sign and value, whereby $\theta \neq 0$.[12] The *Stackelberg* model is one example and the model of a *dominant firm* with a fringe of price-takers is another.[13]

A final example is a *cartel* of producers, $i \in \Lambda \subseteq N = \{1, 2,\ldots, n\}$, *i.e.*, a subset of the *n* producers. Each cartel member *i* considers aggregate production of the cartel when he adjusts his own production

(2.3) $\partial\pi_i/\partial x_i = \{p + p'(\Sigma_{k\in\Lambda} x_k)\} - c_i' = 0$.

The spatial dimension

Assume now that the market consists of *m* submarkets and let *j* index submarkets, $j = 1,\ldots, m$. Let x_{ij} and t_{ij} denote the sale from producer *i* to submarket *j* and the unit transportation cost of such sales. In applications and in particular when the market is segmented it will often be the case that seller *i* does not sell in all segments. Profit maximization of producer *i*, $i = 1,\ldots,n$, is then constrained

maximize $\pi_i = \{\Sigma_j p_j(X_j)x_{ij} - C_i(\Sigma_j x_{ij}) - \Sigma_j t_{ij} x_{ij}\}$ subject to $x_{ij} \geq 0$, $j = 1,\ldots, m$.

The first order (Kuhn-Tucker) conditions of Cournot player *i*, $i = 1,\ldots,n$, are:

(3.1) $-\partial\pi_i/\partial x_{ij} = -\{p_j + p_j'x_{ij}\}+ (c_i'+ t_{ij}) \geq 0$, $x_{ij} \geq 0$, and $x_{ij}\,[-\{p_j + p_j'x_{ij}\}+ (c_i'+ t_{ij})] = 0$, $j = 1,\ldots, m$.

The first part of (3.1) states that his marginal profit on sales has to be non-positive. Assume the opposite, namely that $\partial\pi_i/\partial x_i$ was positive in equilibrium. Then, profits are increased by expanding sales, invalidating this position as equilibrium. The second condition is that flows have to be non-negative. Thirdly, if a flow is positive, the marginal profit is zero, while on the other hand, if marginal profit is negative, the flow is zero. It is not profitable to sell even the first unit.

Assume that the *i'th* player represents an aggregate of many individual price taking firms. Considering this aggregate of individual firms as *the* supplier, *i* is also a price taker, and the first order conditions for this player's profitable sales to region *j* are

(3.2) $-\partial\pi_i/\partial x_{ij} = -p_j + (c_i'+ t_{ij}) \geq 0$, $x_{ij} \geq 0$, and $x_{ij}\,[-p_j + (c_i'+ t_{ij})] = 0$, $j = 1,\ldots, m$.

Let us now compare implications of different behaviors and assume that $x_{ij} > 0$. Price taker *i* (in 3.2) sells to region *j* considering his *net-back price* $[p_j - t_{ij}]$, and his decision rule is:

(4.1) Sell to region *j* when: $(p_j - t_{ij}) \geq (p_k - t_{ik})$, for all $k\neq j$.

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[12] θ-values different from 0 and -1 are seldom used. Egging *et al.* (2007) computes solutions for intermediate values, but offer no arguments for preferred values. Bresnahan (1981a) and Boyer and Moreaux (1983) discussed the notion of consistent conjectures. Bresnahan (1981b) presented a scheme to estimate the cv-parameter, while Corts (1999) questioned the inferences to be made from such estimates.

[13] A Stackeberg leader assumes that his rival plays Cournot whereby $\theta = \partial x_F/\partial x_L$, which is the slope of the rival's best response function. A dominant firm assumes his rivals are price takers producing to satisfy $p = c'$. Then $\theta = p'/(c'' - p')$, where c" is the slope of the rivals' (industry) cost curve.

Thus, he will only sell to those submarkets that offer him the highest net-back price. The Cournot player, however, realizing that his supply affects the price he obtains, considers the net-back of marginal revenue $[(p_j + p_j' x_{ij}) - t_{ij}]$, and his decision rule is:

(4.2) Sell to region *j* when: $[(p_j - t_{ij}) + p_j' x_{ij}] \geq [(p_k - t_{ik}) + p_k' x_{ik}]$, for all $k \neq j$.

The net-back in (4.2) is an explicit function of his volume x_{ij} which he adjusts to make sales in submarket *j* profitable. Hence, he will only sell a little to a region far away from which the net-back price often may be only slightly above his marginal cost, while he will sell more in nearby submarkets.

Computation of equilibria

The first order conditions in (3.1) stem from *n* interrelated optimization problems. Mathiesen (1985) showed that a set of first order conditions and commodity balances is an instance of a complementarity problem (see also Okuguchi 1983) and suggested that this problem could be solved by the SLCP-algorithm.[14] Kolstad and Mathiesen (1991) showed under which conditions the spatial Cournot model as defined by (3.1) has a unique solution and SLCP will compute the solution. Variational inequalities provide an equivalent formulation of the Cournot model. (See *e.g.* Harker, 1986).

A popular approach is to convert conditions like (3.1) or (3.2) into a single optimization problem.[15] The question is under what conditions there exists a (fictitious) function $\Pi(\mathbf{x})$ with the property that:

(5) $\partial\Pi/\partial x_{ij} = \partial\pi_i/\partial x_{ij}$, $j = 1,\ldots,m$, $i = 1,\ldots, n$.

If such a function $\Pi(\mathbf{x})$ exists, the game of *n* agents maximizing individual profit functions would be equivalent to a problem where a central planner maximizes this fictitious objective.[16] In general, the function $\Pi(\mathbf{x})$ exists if and only if first-order conditions, like (3.1), are integrable.[17]

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[14] The acronym stands for A Sequence of Linear Complementarity Problems, describing a Newton-like iterative process where the linearized conditions in each step are solved by Lemke's almost complementary pivoting method. Today one may use the PATH solver in GAMS. See www.gams.com for details.

[15] Samuelson (1952) showed that in order to compute the competitive equilibrium one could maximize the sum of consumers' and producers' surpluses subject to commodity balances. (See Takayama and Judge, 1971).

[16] $\Pi(\mathbf{x})$ exists for the homogeneous product Cournot model with linear demand, $p = a - bX$. (Slade, 1994.)

[17] Cf. integrability of demand in economic theory. See *e.g.* Varian (1992).

4. Simulations

Using three examples we show the divergent insights from solutions of a competitive versus a non-competitive (Cournot) model. The first two examples are stylized in order to make the points, while the third is based upon simulations with a model that was designed for Statoil. (Mathiesen, 1987).

Numerical example 1.

Consider a market consisting of *4* producers and *6* consuming regions. For the illustration of consequences of different behavioral assumptions we use identical linear demand and identical non-linear marginal cost functions[18]

$$Z_j = 60 - 2p_j,\ j = 1,\dots,6, \quad \text{and} \quad c_i = 4.1667 + (Q_i/40.166)^3,\ i = A, B, C, D.$$

Unit transportation costs represent the spatial dimension and are assumed to differ. The numbers of Table 1 are largely consistent with a spatial view of Western Europe. They are costs along least cost routes assuming that network capacities are sufficient and do not constrain flows.

Table 1. Unit transportation cost

From/ to	1	2	3	4	5	6
A	1,4	2	1,9	2,7	3,7	3,5
B	0,5	1,2	0,9	1,7	2,6	2,5
C	2,6	3,3	1,8	2,3	2,2	3,3
D	3,5	3,3	2,5	2,5	1	2

Equilibrium volumes

As is well known, the competitive (CE) and the non-competitive (Cournot) equilibria (NCE) differ in several ways. First, at the aggregate level the NCE has a smaller quantity (-17%) and a higher price (36%).[19] Table 2 and 3 show trade flows, total supplies and marginal cost per producer, and aggregate deliveries and price per region. Second, even though demand and marginal cost functions are identical across regions, the unequal transportation costs make regional production and consumption volumes differ. Observe that percentage differences in volumes and prices between regions in one solution as well as between solutions for a given region are consistent with our assumed price elasticities of 0.75 for supply and -0.5 for demand.

Third, the spectacular difference between these equilibria is their trade patterns, with 9 positive flows in CE and 24 in NCE. Unless unit transportation costs (t_{ij}) of producer *i* differ too much between regions, a Cournot producer will supply all regions and the solution will have all *nm* flows positive. A price taker, however, supplies only a few of his neighboring regions. The rationale of a CE is to provide commodities at the lowest cost. Average unit transportation cost is 1.58 in CE, while it is 2.16 in NCE. Minimal transportation cost implies at most (*n*+*m*-1) positive flows in CE. This is known within operations research as the number of variables in a basic solution to the transportation model of LP and within trade theory through the notion of 'no cross-hauling'.

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[18] Parameters of these functions are chosen such that at a reference point (p, Z) = (10, 40) the price elasticity of demand is -0.5 and similarly, at (c, Q) = (7.5, 60) inverse marginal cost (supply function) has a price elasticity of 0.75. These elasticities relate to a time horizon of 3-5 years and their values are chosen to be within the ball-park of empirical wisdom. See *e.g.* Asche *et al.* (2008) on household demand in Europe and Huntington (1992) on demand and supply elasticities in models of North America.

[19] Egging and Gabriel (2006) report -20% and 86%, indicating an average demand price elasticity of -0.25.

Table 2. Volumes and prices of the competitive equilibrium (CE)

From/ to	1	2	3	4	5	6	sum	mc
A	17,287	41,421	0	0	0	0	58,71	7,29
B	25,334	0	38,546	0	0	0	63,88	8,19
C	0	0	3,28	40,821	14,612	0	58,71	7,29
D	0	0	0	0	26,409	39,021	65,43	8,49
sum	42,621	41,421	41,821	40,821	41,021	39,021	246,7	
P	8,69	9,29	9,09	9,59	9,49	10,49	9,42	

Table 3. Volumes and prices of the Cournot equilibrium (NCE)

From/ to	1	2	3	4	5	6	sum	mc
A	10,19	9,71	8,83	8,07	6,19	7,31	50,28	6,13
B	10,82	10,14	9,66	8,90	7,22	8,14	54,85	6,71
C	7,85	7,17	9,09	8,93	9,25	7,77	50,03	6,10
D	5,91	7,03	7,55	8,39	11,51	10,23	50,61	6,17
sum	34,756	34,036	35,116	34,276	34,156	33,436	205,8	
P	12,62	12,98	12,44	12,86	12,92	13,28	12,85	

In the European natural gas market, a CE would never have Norway supplying Italy and Spain *and* at the same time Algeria supplying Belgium and Germany, or Norway supplying regions in Eastern Europe, while Russia supplied regions in the west. Such solutions would imply cross-hauling and inefficient transportation.[20] Such a trade pattern, however, is characteristic of an NCE and also the European gas market.[21] In line with the disaggregation of this example, *i.e.*, 4 supplying and 6 consuming regions, the European natural gas market has at present about 20 positive flows.

The unit transportation cost is an important parameter in this model. It drives a wedge between the supplier's marginal cost of production (his supply price in the CE) and the demand price in the market. Increasing all unit costs equally leads to higher prices and smaller aggregate volumes and reduces overall profitability, but disturbs relative profitability of flows only indirectly and fairly little. Trade patterns are slowly modified with increasing unit costs. *E.g.* it takes an addition of almost 12 to all unit costs of Table 1 - or seven times the average transportation cost of the above solution - for any of the positive flows of Table 2 to become zero. NCE-flows are positive even when all unit costs are increased by 15, whereby aggregate volumes are 40 % of those in Tables 2 and 3, and the average transportation cost amounts to 75 % of average market price and totally dominates the industry.

Changing unit costs proportionally modifies their absolute differences and hence affect relative net-back prices faster. See (4.1) - (4.2). Thus, an increase of 200% of all unit costs changes both trade-patterns. Increasing unit costs by 400%, *i.e.*, to five times the numbers of Table 1 results in equilibria where the average unit transportation cost amounts to 49% and 41% of average price, and total volumes are 76% respectively 66% of volumes in Tables 2 and 3. In the CE seven flows are positive, while the NCE has 16 positive flows. Trade patterns are still very different. Hence, the trade pattern is robust to the level of transportation costs.

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[20] Of course, even though actual contracts involve sales from north to south and vice versa, transmission companies may avoid cross-hauling by swapping volumes of this homogenous good.

[21] Responding to a journalist's question why Norway should sell in faraway countries like Spain, a sales man said that the alternative, namely to sell larger volumes in nearby Germany would depress prices there. This is definitely not price-taking behavior, but that of a supplier exerting market power, like *e.g.* a Cournot oligopolist.

Consider now increasing one of the unit transportation costs holding all others constant. The corresponding traded volume in a CE changes in a step-like manner, much like it does in the transportation model of linear programming. The difference in net-back prices between a market that is served and one that is not served may be arbitrarily small. In the example behind Table 2, producer A will not serve market 3 until this unit transportation cost is below 1.8. But at a unit cost of 1.79, A shifts his entire volume (17.3) from market 1 to market 3 and B shifts a similar volume oppositely. Thus, who sells where in CE may be extremely sensitive to relative transportation costs. This feature obscures learning about regional competition from the CE. Individual flows in the NCE, however, are robust to such parameter changes; A increases supply to region 3 by 1.8%, rival flows are reduced by about 0.4%, and total supplies to region 3 increase by 0.12%.

Production and consumption volumes are robust to parameter perturbations in both models, which is why it makes sense to consider aggregate volumes while neglecting trade flows. It is surprising, however, that the percentage volume change in region 2 that is only indirectly affected by reduced transportation cost from A to region 3, is three times larger than the corresponding change in region 3 in the CE. This follows because A is the sole supplier to region 2 (Table 2) and his slightly increased production affects supply to region 2. Region 3 has more suppliers (in the CE) and thus more flexibility to adapt to shocks, *i.e.*, when A increases sales his rivals reduce theirs. The competitive pressure, here the number of suppliers, matters. This factor is only simplistically represented in CE.

Equilibrium prices

It is interesting to note that prices may vary more both in absolute and relative terms across regions in a CE than in a NCE. Here, in NCE the absolute difference is 0.84 (12.44 vs. 13.28) and the highest regional price is only 7% above the lowest price. In CE the difference is 1.8 (8.7 vs. 10.5) or 21%. Price variations between regions in a CE are bounded by differences in transportation costs. *E.g.* the prices of 8.7 and 9.3 in regions 1 and 2, that both are supplied by producer A, differ by 0.6 equal to the difference in transportation unit cost for A of supplying these two regions. The smaller price differences in NCE are caused by cost absorption and hence price discrimination by sellers.

Price discrimination occurs when the seller exploits his market power to charge different prices from different customers. Exertion of market power is to charge a higher price than marginal cost. One might therefore think that price variation would be largest in a NCE. What we see here is that producer A, by absorbing part of the additional cost of selling in region 2, charges a relatively higher price in region 1 than in region 2.

The price elasticity of demand determines how much higher than marginal cost the seller will set price. The small price variation in NCE follows from employing equal elasticities in the calibration of demand. This may not be a totally tenuous assumption. Even though price elasticities differ between different uses, e.g. between households, services, light industry, etc., the elasticities of aggregate demand may be fairly similar if the different regions have roughly the same mix of uses.

Rather than discussing which are reasonable elasticities, consider the effect on the equilibria of different price elasticities between regions. Assume that the price elasticity in regions 4-6 is -0.5 as above, while the elasticity of regions 1-3 is -0.35 at (p, Z) = (10, 40). Because the price elasticity is irrelevant to a price taker the CE is hardly affected. A firm that knowingly affects the price, however, adjusts to the elasticities. Thus in the NCE, prices in regions 1-3 increase by about 13%, while prices in regions 4-6 are marginally reduced; volumes are shifted from regions 1-3 to regions 4-6, and production is reduced by 11%. In this case the largest difference between regional prices is the same in the two equilibria. With a price elasticity of regions 1-3 of -0.25 NCE has the largest price differences.

A producer's incentive for selling differs between the two models. From (4.1) it follows that the price taker sells only in markets yielding the highest net-back price. Producer A, for example, has net-back prices 7.29, 7.29, 7.19, 6.89, 5.79 and 6.99 from markets 1 to 6. He sells in markets 1 and 2, and does not sell in market 3 (Table 2), even though his net-back price from this market is only slightly lower, namely 7.19 versus 7.29. In the NCE, net-back *marginal revenues* are equalized, while net-back *prices* may differ between the markets he supplies. See (4.2). Producer A sells to all six markets (Table 3) and his net-back prices are 11.22, 10.98, 10.54, 10.16, 9.22, and 9.78. It is noteworthy that he sells in markets (1 and 5) with a difference in net-back price as large as 2, while a price taker does not sell in markets where the difference may be as low as 0.01.

Numerical example 2

The regional price-patterns of the two models follow different logics. An immediate result of the CE (see (4.1)) is that when a supplier sells in several markets, the price from one market to the next increases with transportation cost (distance to the market) and covers his combined costs of production and transportation. The Cournot equilibrium, however, may have decreasing price with transportation cost (distance) to markets depending on the level of competition in these markets. This feature is present in the above example but let us highlight it.

Consider three regions 1-3 along a line. There are pipelines with a unit transportation cost of 1 between neighboring regions. Suppliers are located in regions 1 and 3, but not in region 2. Demand in region *j* is $Z_j = 15 - p_j$, $j = 1, \ldots, 3$, and the industry cost curves of regions 1 and 3 are respectively

$$c_1 = 3 + 0.25Q_1 \quad \text{and} \quad c_3 = 8 + 0.2Q_3.$$

In a CE, producers of region 1 sell volumes 8, 7, and 1 to regions 1, 2, and 3, while producers of region 3 sell 5 units in region 3 only. Equilibrium prices are 7, 8, and 9, *i.e.* the price increases with the transportation cost going from region 1 to region 3.

Assume there is one producer in region 1 with the above marginal cost c_1 and two producers in region 3, each with a marginal cost $c_{3i} = 8 + 0.4q_i$, $i = 1, 2$. This may be interpreted as if each producer has half the aggregate supply. The NCE has prices 10.33, 10.28, and 10.03, *i.e.*, decreasing and not increasing going from region 1 to 3, even though producer 1 still sells in all three regions. Clearly this is price discrimination by producer 1; his net-back prices are 10.33, 9.28, and 8.03. '[t]he more competitive the distant location, the greater will be the freight absorption of firms located at site (1).' (Greenhut and Greenhut 1975.)

Greenhut (1981) found that negative changes in delivered price are frequently observed in West Germany and Japan over increasing distances along a given line. He also stated that his data indicated that location of the competitors and the degree of competition, were in general the most important factors influencing spatial pricing policies. It is precisely the degree of competitive pressure that differs between regions 1 and 3; monopoly in region 1 and duopoly in region 3.

When establishing a gas model for the European market in the mid 80ies it seemed that actual gas-prices were reduced going east to west in Europe.[22] One reason could be that USSR met no competition in eastern markets (Poland and Eastern Germany), while there were alternative suppliers and hence competition in the west resulting in lower prices there (Western Germany). This feature could not be captured in MIT's gas market model of Europe as it assumed price-taking behavior.

The simulation of non-competitive behavior with a competitive model

Based on the observation that price exceeds supply cost in the NCE, it has been suggested that by allowing mark-ups on cost, the competitive model can be employed to simulate the NCE. That is, the solution x^* to the Cournot model: $(p+p'x) = c'$, could be obtained from a modified CE-model: $p = c'(1+m)$, with $m = - p'x^*/c'$, provided one knew the Cournot solution x^*. Even in a non-spatial context this may be asking too much. In a spatial model this approach becomes even more questionable. Inspection of condition (3.1) and (3.2) reveals that a markup-factor (m_{ij}) has to be

$$m_{ij} = - (p_j' x_{ij}^*)/(c_i' + t_{ij}), \qquad i = 1,...,n, \text{ and } j = 1,...,m.$$

There are two problems here. One is that the information content is demanding as these markups differ both by producer and submarket. In fact, the entire Cournot flow-matrix (x_{ij}^*) is involved. So, if that solution matrix is known, why bother use another model to replicate it?

The next problem is related to the model, its solver and the structure of the solution. Assume the NCE is known and compute values of parameters m_{ij} as distinguished from functions of variables. Modified by markups ($1+m_{ij}$) on marginal cost the resulting CE-model has multiple solutions. One is the NCE. Another has the trade pattern of Table 2, only flows are smaller. But there are more solutions.[23] With multiple solutions, it is unclear which solution will be reported by the solver. It is likely to be a competitive-looking one. As illustrated above, such a solution may be inappropriate for some managerial purposes, *e.g.* analyzing marketing strategy, because its trade pattern is so sensitive to changes in transportation costs.

Numerical example 3.

This example is based upon an analysis of strategic interaction in the Western European market as of 1987 where prices of crude oil and oil products were low, and where the pricing rules of contracts implied low prices for natural gas as well. The issue was the following.

> 'Assume that prices of crude oil and oil products are expected to increase only slightly from the present low levels during the 90ies. Assume further that one or several of the suppliers Algeria, Norway, and USSR shifts strategy to focus on larger volumes rather than obtained prices. What will be the effects on prices, quantities, and producers' profits of such intensified competition?'

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[22] This was observed during the work of Mathiesen *et al*. (1987).

[23] The PATH-solver of GAMS replicated the NCE-pattern when the mark-up equilibrium was computed immediately following the computation of the (true) Cournot, but generated a trade pattern with 9 flows when the mark-up equilibrium was computed immediately following the competitive one or when the matrix of m_{ij}'s was input to a new run. Although both these solutions had 9 positive flows only two flows appeared in both. The reason for these seemingly arbitrary solutions in a mark-up equilibrium stems from the definition of m_{ij}. When $x_{ij}^* > 0$ in NCE, the reduced cost $r_{ij} = \{p_j - (c_i + t_{ij})(1+ m_{ij})\} = 0$ in CE. This feature allows any trade pattern that adds up to equilibrium production and consumption volumes.

The model observes five large producers Algeria, Norway, USSR, the Netherland, and UK[24] by cost functions, and indigenous production in FRG, France, Italy, and Austria by stipulation of quantities. For each of the five producers there are two marginal cost-functions; one for fields that are already developed and one for not yet developed fields.

Final consumption is aggregated into 12 regions of four different types of consumers: Industry, services, households, and electric utilities. Each group is characterized by an estimated demand function where gas demand depends on several parameters, *e.g.* own- and cross-price and income. These parameters simplify making alternative assumptions about the driving forces of demand. Of course, parameters other than the gas price (own-price) have to be stipulated by the analyst.

The transportation of natural gas from a producer to a consumer is separated into two stages: The transmission between regions through large pipelines or by LNG-ships, and the distribution to consumers within a region. The transmission network is considered explicitly, although at an aggregate level of about 50 links. Each pipeline is represented by its carrying capacity and its unit tariff. It is assumed that a transmission company charges the same tariff to all producers on a given pipeline. Optimal decision making by transmission companies is outside the model. The distribution network is represented only by tariffs, where tariffs vary by consumer group, but not by producer.

In line with Mathiesen *et al*. (1987) the bench-mark behavior of the model was that Algeria, Norway, and USSR acted as Cournot-players. What would happen if one (or several) of these players changed its strategy producing larger volumes than those of the Cournot equilibrium? Producing more means larger supplies and thus reduced prices. In a non-spatial context the solution is then given. Also in a spatial market the solution is given if we assume that decisions about production and sales are taken simultaneously. If we allow for these decisions to be separated, however, producing more does not necessarily pinpoint the sales pattern of increased sales.[25] Let us consider two distinct modeling strategies for a generating a given producer's sales. Assume the producer plays:

S: Cournot in all submarkets and stimulate his sales by a *subsidy* (or rebate) to consumers.
P: like a *price-taker* in all submarkets, but restrict the increase in his total production.

The S-strategy generates a spatial NCE, where all producers follow the Cournot behavior, and one producer provides an exogenously stipulated rebate on his sales. The P-strategy generates a mixed equilibrium where one producer acts as price-taker, but where his total production is restricted to the volume of the bench-mark NCE, while the other producers play Cournot. Thus in both types of models production volumes are based upon the Cournot bahavior. In S-models also sales are based upon Cournot, while in P-models the sales of the distinguished producer follow from price-taking behavior.

Comparing Tables 2 and 3 gives an immediate insight into the differences in sales patterns from following either of these two strategies. For a given producer the S-strategy implies increasing sales (a little) in all regions, while the P-strategy results in a radically new sales pattern where he withdraws from faraway regions and sells much more in nearby regions.

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[24] In these simulations the capacity of an interconnector between Britain and the Continent was set to zero.

[25] This approach is in line with Anderson and Fisher (1989) who analyzed consequences of separating decisions of production and sales.

Consider first the cases where one player pursued the P-strategy, while the other two followed their benchmark Cournot strategy for production and sales. Changes in profits varied significantly. If Norway deviated, all three suppliers lost. If Algeria or USSR deviated, Algeria increased its profits considerably while the two others lost in both cases. And if all three followed a P-strategy Algeria gained even more, while Norway and USSR lost more.

These results follow from differences in competitive pressure over the spatial dimension. A look at the map of continental Europe shows that Algeria is clearly the closest supplier in the south-west, while Norway competes closely with Dutch gas and supplies from the USSR in the north. Thus, if Norway increased its sales in the north, Dutch and USSR sales were not much reduced and prices in the north became too low for increased sales from Norway to be profitable. When Algeria increased its sales in the south-west, however, Norway and USSR pulled out to a larger extent. This is because of the long distances and high transportation costs and hence low net-back prices from these regions. Thus market prices in the south did not fall as much as in the north whereby Algeria gained. When the USSR followed the P-strategy and shifted its sales closer to home, it reduced sales in the south-west, thus easing the competitive pressure on Algeria, which again gained.

The gain from pursuing an S-strategy for one of these players, while the other two followed their benchmark Cournot strategy was small: USSR gained a little, Norway ran break-even, while Algeria lost a little. Observe that theory of a non-spatial market says that one cannot gain from unilaterally deviating from the Cournot equilibrium. This result may not hold in a spatial setting where the competitive pressure may differ between sub-markets and be endogenous to the model.

In addition to demonstrate the importance of space and behavior, the exercise exemplifies how a model can be used to answer what-if questions to provide insight into a meta-game where behavior is endogenous. Of course, some of the computed solutions did not represent equilibria as they implied loss of profit to the player who was assumed to change his strategy, whereby he would not play it.

In these exercises one producer was allowed (by the analyst) to enjoy a first-mover advantage. One might question why rivals in the industry would allow him to reap this benefit. Rather than object to the idea, the analyst could compute what-if solutions with modified follower behavior to see if some of them could profitably react and possibly block what the first mover tried to obtain.

Such analysis of changes in behavior and strategy would be difficult if not impossible to perform in a model relying on the concept of price-takers and social welfare maximization.

5. Conclusion

This paper has shown that qualitatively different solutions may result from different producer behavior in a spatial setting where transportation costs are non-negligible. Producer locations relative to each other and to the various submarkets imply that the competitive pressure differs throughout the market, giving some producers a competitive advantage over rivals in some regions. Such advantages may be significant. *E.g.* the last example showed that because of its location to the south of the market Algeria could benefit from a more aggressive selling strategy than its competitors.[26] This observation was made possible because the model allowed simulating various behavioral modes. The issue was what could happen if a producer changed his selling strategy because of a (dramatic) change in his economic environment. The result which seems obvious with hindsight exemplifies the types of insights that simulations with a competitive model would not produce.

The competitive model asserts that when one producer supplies several regions his delivered prices increase with transportation cost (distance) to the market. A non-competitive model, like the one we have used, however, could have declining prices with increasing distance. This is because the competitive pressure is endogenous and may vary between submarkets, whereby suppliers' willingness to absorb costs differ. In the competitive model, however, competitive pressure is not an issue. Producers do not consider each other as competitors.

Common insight from a non-spatial market may not apply in a spatial setting. While no producer can gain by unilaterally deviating from the Cournot equilibrium in a non-spatial setting, that possibility may exist in a spatial context as illustrated above. Again it is the differences in competition that causes this effect. 'Our data indicate that the location of competitors and the degree of competition [..] were *in general* the most important factors influencing spatial pricing policies.' [Greenhut 1981].

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[26] Some might question the model benchmark of a Cournot behavior for all players. The results suggest that Algeria should be modeled with more aggressive behavior. Smeers (1997), however, asserted the opposite, namely that the observed Algerian strategy to an extreme extent supported high prices, that is, a less aggressive strategy. Symmetric treatment of producer behavior might therefore be a reasonable compromise. Conceptually and computationally it is a winner.

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