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THE MORE COOPERATION, THE MORE COMPETITION? A COURNOT ANALYSIS OF THE BENEFITS OF ELECTRIC MARKET COUPLING

Abstract: If spot markets for electric power decide to cooperate and eliminate barriers between them, what will happen to competition and prices in those markets? And who will benefit? In the case of the Belgian and Dutch markets, market coupling would permit more efficient use of inter-country transmission by counting only net flows against transmission limits, by improving access to the Belgian market, and by eliminating the mismatch in timing between interface auctions and the energy spot market. A Cournot market model that accounts for the region's transmission pricing rules and limitations is used to simulate market outcomes with and without market coupling, accounting for the first two of these three impacts of coupling. The result would be an improvement in social surplus on the order of 10^8 €/year, unless market coupling encourages the largest producer in the region to switch from a price-taking strategy in Belgium to a Cournot strategy due to a perceived diminishment of the threat of regulatory intervention. Whether market coupling would benefit Dutch consumers also depends on the behavior of this company. The results illustrate how large-scale oligopoly models can be useful for assessing market integration.

Keywords: Electric power, Electric transmission, Liberalization, Oligopoly, Complementarity models, Computational models, Netherlands, Belgium, France, Germany, Market Coupling

1. INTRODUCTION

In response to European Union directives on electricity market liberalization, physical and institutional linkages between markets in different European countries are being expanded. These changes will particularly affect the Dutch market because of its relatively high dependence upon imports (amounting to about 20% of its electric load, excluding self-supply by industry). The price spikes that occasionally occur on the Amsterdam Power Exchange (APX), the Dutch spot market, reflect this dependence. In August of 2002, for instance, a maintenance outage on one of the three

Dutch-German interconnectors (Maasbracht – Rommerskirchen) caused a significant rise in prices on the APX. In June of 2001, high prices on the APX were blamed on the outage of two reactors in Belgium, which decreased Belgian production by almost 2000 MW, along with a reduction of 300-400 MW for the interconnector capacity between Belgium and France. These examples illustrate how changes in import capability and generator availability in other countries can affect the Dutch market. Other factors in neighboring countries, such as market concentration, market regulation, and environmental policy, can also have an impact.

However, stronger market linkages are generally viewed as being economic beneficial for several reasons. These include: granting access to lower cost imports, enhancing export opportunities for producers, and, in the long run, decreasing the amount of spare generation capacity ("reserves") required to maintain a given level of reliability. Further, closer linkages can dilute local market power (Market Surveillance Committee, 2002). Of course, the benefits of linking markets are not uniformly distributed; for instance, consumers in regions that export more power may suffer price increases. Policy makers are keenly interested in distributional questions; we demonstrate a method for quantifying both the total benefits of market coupling and their distribution.

Proposals have been discussed recently for coupling the Dutch power markets with the neighboring German and Belgian markets (EuroPEX, 1993; Giesbertz *et al.*, 2004). The first goal of this paper is to quantify the short-run production and allocation efficiency benefits of such market coupling, along with the distribution of these benefits among market parties. Because the Dutch-Belgian proposal has been seriously considered by governments and market parties involved, while the Dutch-Germany proposal is preliminary (Giesbertz *et al.*, 2004), we focus on the former. "Market coupling" in the Dutch-Belgian case would comprise three basic changes: greater access by foreign suppliers to the Belgian market (as market coupling would require the development of a Belgian spot market); counting only net flows against transmission limits (rather than constraining gross transactions in each direction); and simultaneous rather than sequential clearing of transmission and energy markets. The first two changes are the focus of this paper.

It turns out that the issue of producer market power and how it is exercised is key to the conclusions of this analysis; differing assumptions change the total benefit and its distribution. Consequently, any analysis of the proposal must account for strategic behavior. A second goal of this paper is to illustrate how a large-scale (thousands of variables) model of oligopolistic competition in transmission-constrained markets can help evaluate the structure and design of electricity markets. Such models are increasingly useful in energy policy analysis (Smeers, 1997). The model used is COMPETES (COmpetition and Market Power in Electric Transmission and Energy Simulator; Hobbs and Rijkers, 2004; Hobbs *et al.*, 2004). The model covers the northwestern European electricity markets (the Netherlands, Belgium, France, and Germany). It can simulate strategic behavior by generators while representing how transmission system operators (TSOs) set prices for the transmission services they provide.

The paper is structured as follows. In the next section, the market coupling proposal for the Dutch-Belgian markets is described. Then, in Section 3, an overview of the oligopoly simulation model and its adaptation for this case study is given; a full mathematical development is available elsewhere (Hobbs and Rijkers, 2004). Data assumptions are also summarized in that section. Section 4 presents the results of the analysis. Sensitivity analyses are also undertaken concerning the behavior of the large generator Electrabel in its home market (Cournot or, as a result of perceived regulatory threats, price-taking). Section 5 offers some conclusions.

2. THE BENELUX MARKET AND PROPOSALS FOR MARKET COORDINATION

Electricity trade in the Benelux Market

Compared to its neighbors, power is relatively expensive in Belgium and the Netherlands. This is because more than half of the Dutch generating capacity and about one-quarter of Belgian capacity is natural gas-fired, whose marginal cost exceeds that of nuclear and coal plants, the dominant fuels in France and Germany, respectively (Newbery *et al.*, 2003). Transmission limits restrict imports from these cheaper sources. From Germany, 2200 MW can be exported to the Netherlands, while from France, approximately 1800 MW can be transmitted to Belgium (*ibid.*). These transmission limits are small compared to the 35,500 MW of generation capacity (including about 7,000 MW of distributed or "local" generation) in Belgium and the Netherlands. As a result, the interconnectors from France to Belgium and from Germany to the Netherlands are congested approximately 90% of the time (Harris *et al.*, 2003).

However, there is also the possibility of beneficial power trade between Belgium and the Netherlands. This is because their demand distributions do not perfectly coincide and they have different fuel mixes. Of the 15,500 MW of capacity in Belgium, the following percentages are fueled by gas, oil, coal, nuclear, and other, respectively: 23%, 16%, 7%, 37%, and 17%. For the central generation capacity of 14,000 MW in the Netherlands, the respective percentages are instead 56%, 24%, 1%, 3%, and 16%. Transmission between the two countries is limited to approximately 1150 MW. Presently, it is fully used approximately one-third of the time in each direction (Harris *et al.*, 2003), although the prices paid for capacity are negligible (exceeding 1 €/MWh only 1% of the time for the day-ahead market in 2002; Newbery *et al.*, 2003). It should be noted that it is possible for interconnection to be considered "congested" in both directions at once, as under the present allocation scheme, flows in opposite directions are not considered to cancel each other out. Instead, the gross sales in each direction are constrained separately. The analysis later in this paper indicates that this “no netting” policy is a significant source of inefficiency because it restrains the ability of producers to compete in each others’ markets.[1]

Such limits on competition are of concern because the Dutch and, especially, Belgian electricity markets are concentrated. Table 1 shows the distribution of capacity among the four major generating companies in the Benelux region, along with ownership distributions for France and Germany, the major sources of imports.[2] Notable is Electrabel’s dominance of the Belgian market. If all of northwest Europe is considered (France, Belgium, the Netherlands, Germany), the Hirschman-Herfindahl Index (HHI) is approximately 1800, indicating that the region’s market is only moderately concentrated. However, the HHI is misleading when applied to electricity because transmission constraints isolate markets, greatly increasing effective concentration.

Presently, transmission capacity between the Netherlands and its neighbors (Germany and Belgium) is divided into three interfaces, and is sold in a series of auctions with various restrictions. Meanwhile, French-Belgian interface capacity is administratively allocated because of fears that one player (Electricité de France) would dominate any auction. Two of the Dutch interfaces are between the Dutch transmission system operator (TenneT) and the two major TSOs in northwestern Germany, with an aggregate capacity in the year 2000 of approximately 2200 MW in each direction (varying by season). The other Dutch interface is between TenneT and Elia, the Belgian TSO, and consists of 1150 MW in each direction. Some of this capacity (about 900 MW in 2000) is tied up in long-term contracts from the pre-liberalised era with German and French energy companies. The rest of the interface capacity is sold in a series of yearly, monthly, and daily auctions.

The auctions for interconnectors with the Netherlands are run by TenneT’s subsidiary TSO-

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[1] This policy also applies to the Dutch-German interconnections. Hobbs *et al.* (2004) consider the impact of allowing netting on all the interfaces between the Netherlands and its neighbors.

Auction. From the beginning of the auction system, approximately one-third of the capacity has been allocated through the yearly auction, and another third through the monthly auction. Some of the remaining third is reserved for TenneT's system-balancing obligations to other European TSOs, and the rest is available for the daily auction. Yearly and monthly contracted capacity not nominated day-ahead is then released for sale in the daily auction ("use it or lose it"). Interface capacity prices are set by the lowest accepted bid in each auction after supply and demand curves for each interface are constructed from the submitted bids. The daily auction closes before day-ahead prices are posted on the APX and the German power exchange EEX.

Several other restrictions are applied to the transmission market. In attempt to prevent market dominance, no single party (generator or trader) can control more than 400 MW of import capacity to the Netherlands, summed across all interfaces. Also, TenneT limits total imports to the Netherlands by all parties to 3350 MW or slightly more, depending on system conditions. The individual interface limits, along with the aggregate 3350 MW limit, are set to ensure that real and reactive power flows through the region's transmission lines, transformers, and other components would not violate thermal limits (overheating), voltage constraints, and system stability requirements (the ability to recover from disturbances) under a variety of spatial patterns of supply and demand, even if any of a number of significant "contingencies" (equipment outages) occur (Haubrich *et al.*, 2001). These limits are chosen conservatively, in part because the auctions are designed as if power flows can be routed along a single path, rather than following all parallel paths consistent with Kirchhoff's laws. For instance, a trader exporting from France to the Netherlands can either purchase interconnector capacity through Belgium, or through Germany; Kirchhoff's laws, however, imply that actual power flows will be split between these and other parallel paths. As a result of this conservatism, flows through the components are rarely close to their limits, and

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[2] Only for the Netherlands is distributed generation taken into account, as it is a large share of total production.

interregional energy transfers are usually less than what is physically possible.[3]

This system of simplified transmission auctions separated from energy markets has been criticized as presenting a barrier to efficient trade (Barale, 2003; Boucher and Smeers, 2002; Knops *et al.*, 2001; Perez-Arriaga, 2002). Thus, various reform proposals have been made. Critics cite the following inefficiencies: the path-based accounting system for selling interfaces does not match the physical reality; the resulting conservatism restricts trade, as does the no-netting policy; and separate and temporally mismatched energy and transmission auctions hamper arbitrage between the markets. Not helping matters is that transparent and liquid spot markets do not exist in all countries; of special interest to us is the lack of such a market in Belgium.[4]

Proposed market coupling for the Benelux region

There have been two major proposals for improving the efficiency of electricity trade between Belgium and the Netherlands (Harris *et al.*, 2003). The first, which was offered by Elia and TenneT in June 2001,[5] would create a single spot market covering the two countries, with a single day-ahead price. There would be no charge for use of the cross-border interconnector capacity. If day-ahead schedules of power sales would violate transmission constraints between or within the two countries, TenneT and Elia would issue instructions to generators to adjust their dispatch to clear the congestion. This procedure would be similar to the constrained-on/constrained-off payment system of the old England-Wales pool system.

The second proposal (Harris *et al.*, 2003) would couple the markets by coordinating spot markets. The APX is proposed to evolve into two spot markets, one per country. The APX would

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[3] Haubrich *et al.* (2001) detail the conservative nature of the interface constraints. Boucher and Smeers (2002) critique the inefficiencies that result from simplifying transmission constraints into a few between-country interface constraints. The order of magnitude of the conservatism can be appreciated by noting that the sum of the individual power line capacities into the Netherlands is 11,600 megavolt-amperes. However, even if efficiently managed, not all of this can be used for power transfer because of Kirchhoff's laws and the need to accommodate reactive power.

[4] A small real-time market is run in Belgium so that market parties can correct imbalances in their scheduled power sales, and Electrabel does buy small amounts of power on a spot basis.

then arbitrage between the two markets, selling power from one to another if prices differed. Should transmission limits prevent complete arbitraging of the two markets, the difference between their prices would reflect the shadow price of the binding constraint. There would be no day-ahead sale of interconnector capacity, and the TSOs would retain the resulting economic rents from any day-ahead transfers between the countries. Some interconnector capacity might still be reserved for longer term contracts, but we do not consider this in our analysis below, where we instead assume that all interconnector capacity will be available for coupling the day-ahead markets.

The second proposal is similar in spirit to that of the Nordpool market splitting system in Scandinavia (Glachant and Finon, 2003; Knops *et al.*, 2001) and locational marginal pricing as widely used in the U.S. (Hogan, 1992); in both, TSOs perform an arbitraging function, and spatial price differences equal the marginal cost of transmission between locations. Harris *et al.* (2003) considered this proposed reform, along with the single market proposal, and recommended the former, at least as an initial step, because of the potential for transmission congestion. Their concern was with the potential for gaming in the single market proposal when congestion between Belgium and the Netherlands necessitates redispatch in real-time.[6] For this reason, policy makers have focused on the second proposal, and so do we in this paper. Harris *et al.* (2003) also recommended that Electrabel divest some of its Belgian generating capacity to prevent possible market power problems that could arise because the Belgian spot market might otherwise be illiquid.

There are three important differences between the current market situation in the Benelux countries and this market coupling proposal. One is that market coupling will eliminate the diffi-

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[5] www.tennet.nl/nieuws/archief/samenwerking_met_belgische_tso.asp

[6] The best known of these games is the “dec” game in which a generator on the exporting side of a transmission constraint overschedules day-ahead, receiving the (relatively high) single market price, and then is redispatched in real time by buying its power back at (a usually lower) real-time price. On net, it is paid to do nothing. Elsewhere, for example, the dec game has been costing California millions of dollars per month in 2003 and 2004 because its zonal market design does not recognize certain transmission constraints within its southern zone (Sheffrin, 2004).

culties that Dutch market participants (claim to) face when attempting to sell electricity into the Belgian market. Although the Belgian power market is nominally open to outside purveyors, in fact it has been very difficult for non-Belgian providers to secure customers. Personal communications with market participants indicate that it is difficult for large Belgian customers to even receive bids from generators other than Electrabel. Reasons cited include uncertainties about Belgian-Dutch transmission availability (changes in which could cut sales with little warning), and the absence of a liquid balancing market in Belgium (meaning that out of country suppliers cannot be confident that they can purchase balancing power at competitive prices). These difficulties can be interpreted as high transaction costs. We model them as constraints on the ability of generating firms and traders other than Electrabel to export from the Netherlands to Belgium.

A second important difference concerns "netting" of transmission capacity between Belgium and the Netherlands. From an electrical point of view, energy flows in a transmission system can be constrained by thermal limits, stability considerations, voltage bounds, and other technical constraints (Schweppe *et al.*, 1988). In most situations these are translated into limits on the net energy flow through particular transmission system components or collections of components. Thus, if the limit between regions A and B is 1000 MW, then a sale of 500 MW from A to B means that up to 1500 MW can be sold by B to A. Because the sale from A to B relieves congestion, a TSO who "nets" flows would pay it a per MWh amount equal to the transmission price paid by the B to A sale. However, such netting of flows is not considered in the transmission capacity auctions between the Netherlands and its neighbors. Instead, capacity in each direction is sold separately without regard to the additional capacity made possible by counterflows; in the case of our simple example, sales from B to A could not exceed 1000 MW no matter how much is sold from A to B. In general, such "no netting" provisions restrict the ability of competitors from other countries to enter a market, increasing effective concentration and prices (Hobbs *et al.*, 2004). In order to enhance transmission access, EU Electricity Regulation 1228/2003 requires that

> "*(t)ransmission system operators shall, as far as technically possible, net the capacity requirements of any power flows in opposite direction over the congested interconnection line in order to use this line to its maximum capacity.*"[7]

The third important difference is the mismatch of timing between transmission capacity auctions and the APX. In particular, bids for the auction are submitted before energy prices are posted on the APX, and there are no organized resale markets for transmission capacity. Consequently, the price of a given interface may deviate significantly from price differences between the two countries. Because there is no organized Belgian spot market, this potential discrepancy is not easy to verify for the Belgian-Dutch interface. However, it is readily observed between the EEX and APX, whose price differences are poorly correlated with daily German-Dutch interface prices (Haubrich *et al.*, 2001).[8] The potential for inefficient arbitrage stemming from the divergence of daily interface prices from price differences between countries is proposed to be eliminated by market coupling, since the APX would efficiently arbitrage the Belgian and Dutch spot markets, based on supply and demand bids submitted to each. Generators and traders would not have to submit separate transmission bids, and would not have to guess at spot prices when submitting such bids.

We consider the first two of the above three changes that would result from implementation of coupling of the Belgian and Dutch power markets. The potential effects of giving German and Dutch market players access to the Belgian market and the elimination of the "no netting" restric-

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[7] http://europa.eu.int/eur-lex/pri/en/oj/dat/2003/l_176/l_17620030715en00010010.pdf , Article 6, Sub 5.

[8] However, longer term averages are broadly consistent (Newbery and McDaniel, 2003). Price inconsistencies do not necessarily signal inefficiencies. If flows on an interface only affect that interface and no other transmission facility, then if the spot energy price is higher at the receiving end, full use of the interface in that direction is all that is required for efficiency. The price of the interface does not have to be equal to the spot market price differences. Inefficiencies are obvious if instead there are spot market price differences, but the interface is not fully used in the correct direction. Inefficiencies can also occur if there are interactions with other transmission facilities.

tion is assessed using the oligopolistic power market model COMPETES, summarized in the next section. COMPETES can represent a variety of systems of transmission pricing, including fixed transmission tariffs, congestion-based pricing of physical transmission, and auctioning of interface capacity between countries. In this paper, we take advantage of that flexibility to represent how Belgian market access and flow netting between the Netherlands and Belgium would alter the ability of power generators to compete in different markets. Changes in surpluses earned by various market parties are described, as are changes in economic efficiency (as gauged by total surplus).[9]

3. MARKET SIMULATION METHOD

Many models for simulating oligopolistic power markets have been proposed (see reviews by Daxhelet and Smeers, 2001; Day *et al.*, 2002; and Ventosa *et al.*, 2004). For our problem, it is desirable that such a model have the following characteristics. One is computational convenience. A second is the ability to represent either "bilateral" competition among producers who compete to sell power to ultimate consumers while purchasing transmission services from a TSO (Figure 1), or "pool"-type competition in which producers sell to their local spot market, and either the TSO or a trader/arbitrager transfers power between markets.

A third desirable characteristic is that strategic interaction between energy producers is based on accepted game-theoretic frameworks. Here, we adopt a Cournot-Nash approach. Other approaches are Petrov *et al.*, 2003). However, the Cournot approach has two advantages. One is descriptive in nature: Bushnell *et al.* (2004) argue that it is the most relevant and empirically descriptive game-theoretic concept for markets in which bilateral contracts are the dominant form of exchange. (This is the situation in the Benelux countries, as only about 15% of Dutch power is

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[9] Because COMPETES is an equilibrium model that simultaneously solves for transmission and energy prices, disequilibria between transmission and energy prices resulting from mismatches in market timing cannot be considered by this approach. The possible benefit of efficient arbitrage between generation and transmission markets was considered by Audouin *et al.* (2002) for all of Europe, but under an assumption of price-taking behavior by generators.

exchanged in the APX, and there is no formal spot market in Belgium.) Another advantage is a practical one: pure strategy equilibria for transmission-constrained markets often do not exist for supply function games (e.g., Berry et al., 1999), and even if they exist, they are difficult to calculate.

The fourth desired characteristic is that the model should represent the characteristics of interest of the transmission pricing systems, and how they impact competition in submarkets. Among Cournot models, there are two basic approaches to modeling transmission (Hobbs and Helman, 2004). One is to imbed the first-order conditions that the TSO uses to determine transmission prices as constraints in each producer's optimization problem (*e.g.*, Oren, 1997; Cardell *et al.*, 1997; Hobbs *et al.*, 2000; Cunningham *et al.*, 2002; Neuhoff, 2003b). Thus, each producer is a Stackelberg leader with respect to the transmission pricing system, each anticipating how its production and sales decisions affect transmission prices.[10] Inserting the TSO's first-order conditions in each producer's model makes them difficult to solve, and it is not possible to prove, for the general case, existence or uniqueness of pure strategy equilibria among producers.[11]

The other approach for including transmission in Cournot models is to instead assume that producers are price-takers (Bertrand) with respect to the price of transmission charged by the TSO. This is the approach taken by COMPETES, among other models (*e.g.*,Wei and Smeers, 1999). Its advantage is that the resulting equilibrium problem among Cournot producers takes the form of a

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[10] In the most general case, these first-order conditions take the form of Karush-Kuhn-Tucker (KKT) conditions that are described by the following complementarity problem: $x \geq 0, f(x) \leq 0, x^T f(x) = 0$, where x is a vector of decision variables and $f(x)$ is a vector of the same length of functions (*e.g.*, marginal benefit minus marginal cost).

[11] This is because the constraints in each producer's problem define a nonconvex feasible region, implying that local optima may not be globally optimal. This type of optimization model is termed a mathematical program with equilibrium constraints (MPEC); an equilibrium problem involving several MPECs is called an equilibrium problem with equilibrium constraints (EPEC) (Daxhelet and Smeers, 2001). A simple example of the non-existence of a pure strategy equilibrium for the type of Cournot EPEC described here is given in Hobbs and Helman (2004). The mathematics of these problems is an active area of research.

complementarity problem, defined by concatenating the first-order conditions for each market participant together with market clearing conditions (Hobbs, 2000; Hobbs and Rijkers, 2004). For such problems, existence and uniqueness results are readily obtained (Metzler *et al.*, 2003), and efficient software exists to compute solutions (*e.g.*, PATH: Dirkse and Ferris, 1995).

COMPETES has these desired characteristics. The model is readily solved by complementarity software. Producers compete à la Cournot with each other to sell power bilaterally to consumers. Transmission constraints are explicitly included, with producers behaving as price takers relative to the price of transmission.[12] COMPETES can represent auctions for path-based transmission interfaces (as between Netherlands and its neighboring countries), as well as efficient pricing of transmission constraints in linearized networks satisfying Kirchhoff's laws. It is also possible to include traders who efficiently arbitrage different markets, so that the price difference between markets equals the cost of transmission. Metzler *et al.* (2003) prove that for models with COMPETES' general formulation that a bilateral Cournot market with such arbitrage yields the same profits and prices as a Cournot "pool"-type model.[13] We take advantage of that equivalence to simulate the market coupling proposal. The major compromise made in adopting COMPETES is that the assumption of price-taking by producers with respect to transmission prices may not be viewed as being as realistic as the Stackelberg assumption described previously.[14]

Model Structure

The structure of the COMPETES model is as follows (for details, see Hobbs and Rijkers,

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[12] COMPETES also has the option of a more general type of game in which each producer holds a prior set of conjectures concerning how its rivals will alter their outputs in response to marginal price deviations from the equilibrium; this "conjectured supply function" approach is similar to a conjectural variations model (Day *et al.*, 2002). Each producers can also hold similar conjectures regarding how transmission prices will change if it shifts its output or sales marginally from the equilibrium (Hobbs and Rijkers, 2004). These generalizations are not considered here.

[13] This generalized a similar result for competitive transmission-constrained models (Boucher and Smeers, 2001).

[14] Neuhoff (2003a), in contrast, has assumed a Stackelberg strategy in studying the effects of market coupling; we contrast his approach and results with ours in Section 4, *infra.*.

2004). The mathematical problem defining the market equilibrium in each period of time is defined as the simultaneous satisfaction of the three following sets of conditions:

1. *KKT optimality conditions for each producer.* Each producer maximizes revenue from sales in each market minus (a) the costs of generation from each power plant it owns and (b) the cost of transmitting power, including the expense of any required interface capacity in the path-based system and transmission capacity in the linearized network flow. In this maximization, sales by other producers and any arbitrage are treated as exogenous (Cournot), as are transmission prices from the TSO (Bertrand). Price at each node is assumed to follow an affine demand curve. Constraints include capacity for each generation plant, and an energy balance (total sales = total generation). In the case of path-based transmission pricing, the generator buys the least costly combination of interfaces in order to transmit its power to consumers; however, Kirchhoff's laws imply that there is no such choice available for the full network model, as flows will be distributed among the lines in conformance with those laws.[15] If access to some markets is difficult or not possible (as for foreign producers in Belgium), the corresponding sales variables can simply be omitted from the model. If there are limits upon the amount of transmission interface a producer can buy (for instance, the present 400 MW limit per producer between the Netherlands and Belgium), then this is imposed as an explicit constraint in the producer model.

2. *KKT optimality conditions for the arbitrager.* The arbitrager maximizes its profit from buying power at one location, paying TSO fees to transmit the power to another location, and then selling it there. The arbitrager views all prices as exogenous. The only constraint is that its total purchases must equal total sales. The arbitrager can also choose the optimal transmission paths for its flows if path-based pricing is used. If access is not possible for some markets, the relevant sales

and purchase variables are omitted.

3. *Market clearing conditions for transmission.* The precise formulation depends on how transmission is priced. In this application, flows between countries are priced based on the path-based interface system; in addition, a linearized full network model is also imposed to ensure that no flows on individual transmission lines exceed their limits. For the path-based system, a complementarity condition states that the price for an interface can only be positive if the quantity demanded of that interface equals its capacity. By appropriate definition of coefficients, one can represent either the situation of "no netting" or "netting" of flows. For the "no netting" case, non-negative flow variables are defined for each direction in the interface, and quantity demanded for interface capacity is separately tallied for each direction, based upon the path choices of producers and the arbitrager. For the "netting" case, quantity demanded for an interface in a given direction equals the flow in one direction minus the flow in the other. Flows that relieve congestion will be paid (by the TSO) the transmission price that flows in the other direction must pay (to the TSO). For the full network model, equations define the price for transmitting from one location to another as equaling the sum of the prices of each transmission capacity constraint, weighted by the relevant power transmission distribution factors (PTDFs).[16]

The resulting equilibrium problem should have the same number of variables as conditions.[17] In this application of COMPETES, the model has approximately 1800 variables and an

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[15] As a consequence, with efficient pricing of transmission in the full network model, no profitable arbitrage will be possible among transmission rights. For instance, the price of transmission from A to B will be the same as the sum of the transmission price from A to C and then C to B.

[16] PTDFs in linearized electrical networks describe the incremental flow on each transmission element resulting from a unit injection at one location and a unit withdrawal from another. The linearized network model does not represent resistance losses or reactive power, but does capture the parallel flow nature of power flows. Schweppe *et al.* (1988) derive the linearized model (termed, misleadingly, a "DC" load flow model); they also derive the mentioned relationship between transmission prices and individual constraint prices.

[17] If all profit functions are quadratic or linear in the firm's decision variables, and all constraints are linear, then the *f(x)* in the complementarity conditions are linear, and the equilibrium problem is termed a linear complementarity problem (Cottle et al., 1992).

equal number of conditions for each time period simulated.

Data Assumptions

Demand, transmission, and generation data are meant to represent year 2000 conditions in the study region. Data sources are documented in Hobbs *et al.* (2004).

Demand curves represent net wholesale electricity demands ("loads") on the high voltage grid for six network nodes in the Netherlands, two in Belgium, and one aggregate node each in France and Germany. The French and German loads include net exports to other countries outside this region, and Luxembourg is included in Germany. Further, the Dutch loads include loads served by decentralized sources, such as combined heat and power systems, whose capacities are included in the model. Four demand periods for each of three seasons (summer, winter, and spring/fall) are defined for each node in the network (*e.g.*, Figure 2). The highest load period in each season includes the 200 hours with the highest sum of the hourly loads for the four countries. The three other periods in each season have equal numbers of hours and represent the rest of the seasonal load distribution. Demand curves are affine. The intercept and slope of each are defined such there is a demand elasticity of –0.2 at the price-quantity pair for the competitive solution.

Turning to generation, we model the few largest generation firms in the Netherlands and Germany as strategic players (Table 1). EdF, the dominant player in France (Table 1), is assumed to price at marginal cost within France, but can behave strategically in the other markets, including Germany where it owns some generation plant. This assumption is made because EdF's present prices in France are well below the near-monopolistic levels that the Cournot solution would yield because of the tight transmission constraints into that country. It is clear that EdF exercises restraint in its home market, perhaps because an obvious exercise of market power would invite regulatory interference. Electrabel is modelled either as a Cournot firm or price-taking (similar to EdF) in Belgium, depending on the case considered. In other countries Electrabel is always assumed to be playing a Cournot game.

We define each generating "firm" as owning capacity belonging to its subsidiaries in proportion to the firm's ownership share, assuming that the firm participates in operating decisions. (Other assumptions can be made; Amundsen *et al.*, 2000.) Capacity not owned by the strategic companies is incorporated in the model as a price-taking competitive fringe. Altogether, 5272 generating units are considered; for simplicity, units at the same location that have similar costs and the same ownership have been combined. Fuel costs are based upon ECN scenarios, and capacity is season-dependent (*e.g.*, depending on streamflow for hydroplants). Figures 3-6 summarize the generating firm data in the form of marginal cost curves for the winter for each large generating firm in each country, summed across all locations within a country.

Our simulations assume that the presence of forward contracts or vertical integration does not restrain the incentive to exercise market power. This is not an unreasonable approximation, since forward contracts in the Netherlands tend to be relatively short-term, a year or less in duration. We therefore assume that market power would be equally exercised in the forward and spot markets.[18]

Regarding transmission, as mentioned, we consider the limits on flows and transactions resulting from both the high voltage system (using a linearized network model) and path-based constraints. The network representation is based on an aggregation of the Benelux network and neighboring French and German lines into 19 nodes (Hobbs *et al.*, 2004). To better represent constraints upon exports from France and Germany, portions of their networks near the Benelux bor-

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[18] In reality, however, there is some vertical integration in the Benelux countries, which would dampen the incentive to restrict capacity and raise prices if the utility is obliged to provide power at fixed retail rates (Green, 1999). Also, some models of endogenous forward contract prices indicate that forward market will reduce market power (Allaz

ders are also represented, although generation and demand in each of those countries are aggregated to a single node. Disregarding the internal network of those two countries means that their price results are more approximate than the Benelux countries, the focus of this analysis.

If network capacity constraints are binding, our full network representation is analogous to an assumption that the TSOs run efficient balancing (real-time) markets to clear intracountry congestion. Boucher and Smeers (2002) point out that, in reality, within-country congestion in the EU is run inefficiently. However, we believe that ours is an acceptable approximation, as network constraints rarely bind in our solutions, and the path constraints are more important economically.

Data from Haubrich *et al.* (2001) are used to define the path-based flow limitations; these are differentiated by season. The small arcs that cross the arrows in Figure 7 indicate what constraints are considered. Besides the Dutch interfaces discussed in Section 2, the most important constraint limits total exports from France to Belgium and Germany to 3750 MW.

Finally, we assume that the presence of a dominant firm and a *de facto* lack of market access in France and Belgium mean that arbitragers only have effective access to the power markets in the Netherlands and Germany under the present transmission management system.

4. RESULTS

The sets of results summarized here include (1) a competitive baseline; (2) present transmission pricing system vs market coupling, assuming Electrabel behaves as a Cournot player; and (3) present transmission system vs market coupling, assuming Electrabel exercises pricing restraint in Belgium because of perceived regulatory threats. Table 2 summarizes the assumptions regarding management of the Dutch interfaces with Belgium and Germany for the competitive baseline, present transmission system, and market coupling proposals. As we stated earlier, the present Belgian-

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and Vila, 1993). However, this is disputed by others (Harvey and Hogan, 2000) and experimental evidence is con-

Dutch situation imposes a cap of 400 MW on any single firm importing to the Netherlands and, because of the Belgian market's opacity, an effective limit of zero into Belgium. Historical import data on the Dutch-Belgian interconnector shows that some imports occur from Netherlands to Belgium[19]. Therefore it is assumed that 200 MW on the interconnector is available for traders (arbitrageurs). The remaining import capacity (950 MW) is solely available to Electrabel, since Electrabel does have access to its home market in Belgium. However, we do not restrict any company's access to the French-Belgian interface, because that capacity is allocated by nonmarket mechanisms, and is fully used. Flows on the Dutch interfaces are not presently netted, as discussed. In contrast, the market coupling proposal imposes no limits on individual firm or arbitrager flows (as noted earlier, this yields profits and prices equivalent to a system where a TSO or other market operator undertakes all intermarket transmission). Net flows, rather than gross flows in each direction, are counted against transmission constraints between Belgium and the Netherlands; however, no-netting is still imposed in the German-Netherlands interfaces.

Table 3 summarizes energy price, quantity, and welfare outcomes for the solutions. The welfare results should be interpreted as follows. "Profit" is the gross margin earned by producers, as fixed costs are excluded. TSO revenues are equal to the price of transmission constraints times the flows; these exclude fixed payments made by consumers and producers for use of the grid, which we assume do not distort trade. Consumer surplus is, of course, very sensitive to the elasticity and linearity assumptions; the total consumer surplus matters less than the change in consumer surplus between the solutions. Likewise, because consumer surplus is a component of social surplus (which also includes profit and transmission surplus), differences in social surplus are more meaningful than totals. Therefore, we indicate the change in social surplus relative to the competi-

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tradictory (Brandts *et al.*, 2003; Le Coq and Orzen, 2002).

[19] Historical import data can be found on the website of Elia, the Belgian TSO; www.elia.be.

tive baseline in the last line of the table.

Competitive vs Cournot Results

The competitive equilibrium is the leftmost column, and is also shown in Figure 8.[20] There, all firms are price takers, and prices equal marginal cost in all markets. Price differences between markets equal the sum of the prices of congested path interfaces between them. For instance, the Belgian price of 28.4 €/MWh equals the French price of 14.4 plus the prices for the F-B constraint (9.5) and the F-B/D constraint (4.5). Thus, in our model, essentially all congestion costs are due to the tight path-based constraints, and not the full network constraints. These prices are roughly 10% above estimated marginal costs in the Netherlands and Germany for 2001 as reported in Brattle (2002), although the price differences are similar. Their estimates may differ from ours because different years and fuel prices are used, and the Brattle estimates are not based upon a full regional transmission-constrained market model.

In contrast, average actual market prices in 2001 (24.1 €/MWh in the German EEX and 34.2 €/MWh in the Dutch APX) are well above our competitive levels, and more closely resemble the Cournot results in Table 3 (especially the Cournot solutions under the present transmission pricing system). Thus, market power does appear to be exercised in these markets. Our four Cournot solutions result in ranges of prices from 29 to 45 €/MWh in Belgium and 29 to 37 €/MWh in the Netherlands, the extremes of which are slightly higher to almost double the competitive levels. Meanwhile, Cournot prices are 20% higher than competitive prices in Germany, and nearly unchanged in France. As would be expected, the ranges of Cournot results are much smaller in France and Germany than in the Benelux countries, because the Cournot solutions differ in their assumptions about the Benelux market. Generally, when prices are higher in Belgium and the

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[20] The Belgian, Dutch, and French competitive prices are slightly higher than in Hobbs *et al.* (2004) because of minor updates to the generation database.

Netherlands, they are also slightly higher in Germany because German producers export more power. (French exports are nearly always transmission constrained, so higher Benelux prices generally do not elicit more exports from that country.)

Figures 8-10 display the prices for the competitive case and the two "Electrabel Cournot" cases. Figure 9 highlights (in parentheses) how much prices rise compared to the competitive case. However, as demand is relatively inelastic, the high price increases resulting from Cournot behavior do not necessarily imply large impacts on aggregate welfare. The welfare loss in the worst case (Electrabel Cournot, Present Transmission) amounts to 0.7 €/MWh, averaged over the load in the four country region (or about double that if only averaged over the three countries where market power raises prices significantly). In contrast, the average price increase is 2.5 €/MWh, averaged over the four countries (again doubling if averaged only over German, Dutch, and Belgian consumption). Most of the price increase is simply an income transfer from consumers to producers. Cournot gross margins are from one fourth to one third higher than competitive levels.

The transmission operators also earn more congestion revenue in the Cournot equilibria. At first glance, this is surprising, since lower loads together with the no-netting provisions for some interfaces might be expected to translate into lower net quantities transmitted through the interfaces. Furthermore, the lack of access to the Belgian market under the present transmission system would imply that producers would not be willing to pay for that country's interface with the Netherlands (as Figure 9 indicates is indeed the case). However, there are two explanations for the higher TSO revenue in the Cournot solutions. One is that the no-netting provisions mean that congestion revenue can be earned in both directions on an interface. For instance, during some periods, the Dutch-German interface in the Cournot solution in Figure 10 is constrained both for imports to and exports from the Netherlands. This is indicated by the positive prices for both constraints. This is possible even though German prices are lower than Dutch prices, as a large producer in the Netherlands with only a small market share in Germany can have a higher marginal revenue in the latter country, and thus be willing to pay to export to that market. The other explanation for the higher congestion revenue is that when Electrabel behaves à la Cournot, the high prices it charges in Belgium induce large congestion revenues on the French-Belgian interconnector. (Note the higher prices for the French interface in Figure 9 compared to Figure 8.)

Electrabel Behavior: Cournot vs Price Taking

Here we compare the four Cournot solutions of Table 3, focusing on the strategic behavior of Electrabel. The second and third columns of results in Table 3 are Cournot equilibria under the assumption that Electrabel behaves in a Cournot manner in all markets. On the other hand, the equilibria in the last two columns instead assume that Electrabel perceives a threat of regulation from the Belgian authorities and therefore acts as a price-taker in Belgium (but still Cournot elsewhere). The latter assumption results in lower prices in the Benelux countries; the most dramatic effect is in Belgium under the present transmission system, where prices are a full one-third lower (mainly because under the present situation of no-netting and essentially no market access for Dutch and German producers, Electrabel is nearly a monopolist). Market coupling mutes this effect somewhat. In contrast, a price-taking Electrabel results in Belgian prices in the Cournot solutions that are only one or two € per MWh above competitive levels. Prices do not fall completely to competitive levels there because Cournot prices are higher elsewhere, increasing Electrabel's opportunity cost of selling in its own market instead of in other countries.

A price-taking Electrabel in Belgium benefits the Netherlands also, most dramatically under market coupling. In the latter case, lower prices in Belgium mean that the opportunity cost for Dutch and German producers of selling in the Netherlands is much less, so Dutch prices fall by over 8 €/MWh, on average. Overall, if Electrabel is a price-taker in Belgium, the deadweight loss due to market power is one-half or less than if Electrabel is Cournot everywhere (see the last row of Table 3). Of course, Electrabel's present pricing behavior in Belgium may presently lie somewhere between the price-taking and Cournot extremes, rather than being pure-price taking. Hence, the welfare consequences of lessening the perceived regulatory threat in Electrabel's home market may be less extreme than considered here.

The Impact of Market-Coupling

First, we consider the effect of the changes that market coupling would bring to transmission allocation and pricing procedures (Table 2), assuming that Electrabel is a Cournot player everywhere. These effects can be assessed by comparing Figures 9 and 10, and the second and third columns of Table 3. The prices in parentheses in Figure 10 indicate the impact of market coupling (the difference between prices in Figures 9 and 10). These figures indicate that coupling would greatly enhance competition within Belgium; the resulting average price there (37 €/MWh) is closer to the competitive Belgian price (28 €/MWh) than it is to the present transmission system level (45 €/MWh). The greater market opportunities for Dutch producers result in more exports to Belgium. Congestion turns out to be infrequent for the Belgian-Dutch interconnection and prices are nearly equal for those two countries. Thus, market coupling would eliminate the ability of a Cournot Electrabel to price discriminate between Belgium (where in the absence of coupling there is little competition and no arbitrager access, thus allowing it to raise prices) and the Netherlands (which would be the more competitive market if there is no coupling, so that the residual demand curve facing Electrabel would be more elastic and prices would wind up being lower).

On the other hand, nearly equal prices in the two countries in the presence of Electrabel market power would not be a pleasing prospect for Dutch consumers, as their prices under market coupling actually rise by over 4 €/MWh, due to higher exports by Dutch producers. The higher profits by Dutch producers (excluding Electrabel plants in the Netherlands) do not make up for the consumer surplus lost by Dutch consumers.

Market coupling, assuming a Cournot Electrabel everywhere, increases social surplus over the present transmission situation by about 200 M€/yr. This benefit arises from both production efficiencies (as cheaper imports substitute for costly Electrabel production), and allocative efficiencies (as the incremental Belgian consumption exceeds the cost of providing it). As just noted, though, not everyone benefits. Although consumer surplus in Belgium increases by approximately 600 M€/yr, Dutch consumer surplus instead falls—by about half that amount—due to the price rise that the solutions indicate they would suffer. Concern over this possibility has been expressed by the Netherlands Market Surveillance Committee (Newbery *et al.*, 2003).

The conclusions change significantly if instead Electrabel behaves as a price-taker in Belgium. It is true that market coupling would improve the total consumer surplus in just Belgium and the Netherlands by about 300 M€/yr in both the Cournot and price-taking Electrabel cases. But comparing the two price-taking Electrabel solutions (the last two columns of Table 3), we see that the benefits of market coupling are now equally shared by Belgian and Dutch consumers, as prices fall by nearly the same amount in each country.[21] Yet the aggregate increase in social surplus due to market coupling (53 M€/yr = 282-229) is only a quarter of that projected if instead Electrabel behaves strategically (Cournot) in Belgium.

Thus, the behavior of Electrabel in its main market is key to both the total benefits of market coupling and their distribution. As a worst case for market coupling, we could compare the fourth column with the third in Table 3: the present transmission situation with a price-taking Elec-

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[21] Although average prices are about the same in the two countries, they do differ from period to period, resulting in their shared interconnector being constrained in different directions at different times.

trabel, with market coupling assuming that Electrabel is Cournot throughout. This would be the appropriate comparison if it was believed that Electrabel now prices in a very restrained manner, but would feel free of any potential regulatory restraint if the markets were coupled. Electrabel might feel that way because it would not appear to be a monopolist in the coupled market. However, Electrabel would control fully half of the capacity in the combined Belgian-Dutch market (Table 1), and its resulting market power would only be partially mitigated by imports from France and Germany. The consequence, as a comparison of those two columns shows, would be that market coupling, together with Electrabel flexing its market power, cause prices to increase by about 6 €/MWh in both the Netherlands and Belgium, compared to the present transmission system under a price-taking Electrabel. Another consequence is that deadweight loss would double, from 282 M€/yr to 550 M€/yr.

These conclusions about the impacts of market coupling can be compared to other studies. Petrov *et al.* (2003) used a supply function equilibrium approach to simulate a coupled Benelux market, and concluded that prices would decrease. However, that analysis did not explicitly represent transmission constraints or separate Dutch and Belgian spot markets, nor were the German and French markets considered. In another study, Neuhoff (2003a) considered the present transmission situation in the Benelux region using a Cournot model (Neuhoff, 2003b) that simulates a game with the following structure: traders buy physical transmission rights between countries, which commits them to buy energy in the spot markets, while generators sell energy in their home spot markets, recognizing only the local elasticity. In contrast, he assumes a Stackelberg structure under market coupling, in which generators bid into a pool, anticipating how the pool will price transmission (*i.e.*, by including the TSO’s first-order conditions in the generators’ constraint sets, similar to, *e.g.*, Cardell *et al.*, 1997). He finds that if all producers are Cournot (including Electrabel, which he represents as a local monopolist in Belgium), consumers in all countries are better off under market coupling, in contrast to our conclusion that Dutch consumers could be worse off. However, Neuhoff's analysis differs from ours in two important respects. First, the two-stage structure of his present system model assumes that generators only consider the elasticity in their home markets; in our model (and in reality), generators can sell elsewhere (*e.g.*, Dutch generators to Germany), and the effective demand they face can be more elastic, yielding lower prices. Second, the Neuhoff analysis does not consider all the effects of market coupling considered here, especially the effect of eliminating the "no-netting" policy. He assumes that flows are netted both in the present system and under coupling. In general, differences in the treatment of transmission allocation and pricing models can make a significant difference in the conclusions of different models, even if they all are Cournot in energy sales (Neuhoff *et al.*, 2004).

5. CONCLUSIONS

Coupling the Belgian-Dutch electricity markets would increase electricity trade by enhancing access to the Belgian market, eliminating "no-netting" provisions for electricity flow, and facilitating arbitrage by eliminating the mismatch in timing between daily transmission interface markets and spot energy markets. *A priori*, one would expect that increases in economic efficiency would follow from implementation those reforms. As measured by aggregate social surplus, the transmission-constrained oligopoly analysis of this paper supports this expectation, as long as Electrabel's behavior (price-taking or Cournot) does not change when market coupling is implemented. However, the magnitude of increases in efficiency and their distribution depend strongly on the amount of market power. In particular, there is uncertainty over how much market power the largest player in the Benelux countries (Electrabel) now exercises in Belgium and how that might change if the markets are coupled. If Electrabel plays a Cournot game in Belgium, our simulation under year 2000 conditions indicates that the market coupling would enhance social surplus for Northwest Europe by a large amount (about 200 M€/yr), but would hurt Dutch consumers by raising their prices. But if Electrabel is and continues to be a price-taker in Belgium, gains in social surplus would be more modest (about 50 M€/yr) but would be shared more evenly, with Belgian and Dutch consumers benefiting equally.

But market coupling could actually decrease social surplus in the extreme case in which Electrabel acts as a price-taker in Belgium under the present transmission system (perhaps due to an unstated but perceived threat of regulatory intervention) but feels free to switch to a Cournot strategy under market coupling. The deadweight loss due to oligopoly in Belgium, the Netherlands, Germany, and France almost doubles if market coupling enables Electrabel, which controls half of the Benelux generation capacity, to start to fully exercise its market power in generation.

Therefore, we agree with Newbery *et al.* (2003) that it is important for the Dutch and Belgian regulators to monitor market developments closely, and to be prepared to implement market power mitigation measures. There are several possible types of measures. One consists of structural changes to the generation market, including requiring that the largest generation firm(s) divest assets or auction off the rights to the gross margin from their outputs ("virtual power plants", VPPs). VPPs have been imposed previously in the Netherlands as a condition upon a proposed vertical merger, and divestment was an important tool of the UK regulator. As we noted *supra*, Harris *et al.* (2003) has proposed that Electrabel be required to divest assets as a precondition for coupling the markets.[22] Another mitigation approach is to place regulatory constraints on price offers, such as requiring marginal cost bidding into spot markets by the largest producer. This is the approach to be implemented in the Irish market. A variant is the "automated bid mitigation"

(AMP) that is used in several US markets.[23]

Investigations of these and other possible mitigation measures are underway.[24] The simulations presented here show that much could be at stake. In particular, if the largest generating firm in the Benelux region feels free to price strategically as a result of market coupling, then the potential production and allocative efficiency benefits of market coupling could be lost.

We note several limitations of this analysis. One is that there are many alternative formulations of transmission-constrained electricity oligopoly games. Other formulations, such as the two-stage model of Neuhoff (2003b) or supply function equilibria could (and do) yield different conclusions. For instance, it might be argued that because of its size, Electrabel should be viewed as a Stackelberg leader in the Benelux market, correctly anticipating how transmission prices and competitors' outputs would change in response to its actions (Harris *et al.*, 2003). Analyses could also be done assuming implementation of market power mitigation, such as divestment or bid caps. Also, the effects of different degrees of long-term forward contracting or financial transmission rights could be assessed (Green, 1999; Joskow and Tirole, 2000). We believe that there is no single "correct" model, and no model should be used for precise prediction of prices; rather, such models should be used to suggest possible outcomes of market changes.

Another limitation is that we disregard the inefficiencies of the present transmission system

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[22] Bower (2004) argues that such divestment is a much more cost-effective means of enhancing competition in European markets than building transmission lines. However, coupling of the Belgian-Dutch markets does not involve transmission construction.

[23] There, whether or not bids are mitigated is determined day-by-day, the argument being that a market that is competitive today might not be so tomorrow because of changes in load or availability of transmission or generation. AMP consists of a pair of tests. The conduct test flags a bid as a candidate for mitigation if it is more than a given multiple either of estimated marginal costs or previous bids made under more competitive conditions. Then if the bid also fails an impact test, it is mitigated to a "reference level", consisting either of a multiple of marginal cost or previous bids. The impact test then consists of assessing whether mitigating bids that fail the conduct test would result in price decreases anywhere that exceed a specified threshold.

[24] The Dutch Minister of Economic Affairs recently requested that the Dutch regulator investigate the auctioning of VPPs as a way to mitigate market power. See the letter by the Minister to the Parliament on 23 April 2004 (ME/EM/4028011) as a response to the market liquidity study performed by DTe (www.dte.nl/en/Images/13_20107.pdf).

that are caused by mismatches between the timing of day-ahead transmission and electricity markets. Consideration of sequentially settled markets with imperfect arbitrage is much more difficult, but could indicate that market coupling has significantly more benefits than indicated here. A third limitation is the short-run nature of our analysis. Only short-run operating decisions in the year 2000 have been simulated. A more complete analysis would encompass a decade or longer, and would consider the effect of market coupling on the location, timing, and type of generation entering the market. In the long run, market coupling could bring additional efficiencies by lowering the amount of installed generation capacity that is needed to ensure system reliability.[25]

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Table 1. Ownership Distribution for Generation Capacity in Study Region

Country	Firms	Total generation capacity [MWe]	National market capacity share	Market share in the four countries
Belgium	Electrabel SA	12587	83%	6%
France	Comp Nationale Du Rhone	3068	3%	1%
	Electricite de France	102089	90%	38%
Germany	Berliner Kraft und Licht AG	1096	1%	0%
	E.ON Energie AG	28743	24%	11%
	ENBW Energie-Versorgung Schwaben	9360	8%	4%
	Hamburgische Elec-werke AG	4150	3%	2%
	Neckarwerke Suttgart AG (NWS)	2181	2%	1%
	RWE Energie AG	25625	21%	10%
	STEAG AG	4302	4%	2%
	Vattenfal Europe AG	11688	10%	4%
Netherlands	E.ON Energie AG	1813	10%	--
	Electrabel SA	4563	26%	--
	Essent Energy Production BV	3305	18%	1%
	Nuon (Reliant)	3578	20%	1%
		218147		82%

Table 2. Comparison of Transmission and Market Access Assumptions

Cases		Import cap on firms			Import cap on arbitrageurs			Flow Netting
		B → NL	B←NL	B ←NL Electrabel	B → NL	B ←NL	G ↔NL	
Competitive (Efficient) Case		No limit	No limit	No limit	No limit	No limit	No limit	Yes
COURNOT	Current B-NL situation	400[a]	0	950	0	200	No limit	No
	Market Coupling Proposal	None*	None*	None*	No limit	No limit	No limit	B ↔ NL

a. No restrictions are assumed on the French-Belgian interface, which is usually fully used.

Table 3. Price, Quantity, and Welfare Results under Alternative Cases

		Electrabel Cournot		Electrabel Price-Taking in Belgium	
	Competitive Baseline	Present Transmission	Market Coupling	Present Transmission	Market Coupling
Mean Market Prices by Country [Euro/MWh][a]					
Belgium	28.36	45.01	36.69	30.72	29.27
France	14.40	14.15	14.25	14.32	14.32
Germany	18.86	22.41	22.06	22.39	22.40
Netherlands	27.34	32.87	37.08	31.54	28.94
Mean Sales by Country[MW][b]					
Belgium	9539	7263	8396	9211	9401
France	54119	54408	54282	54215	54216
Germany	53061	48875	49276	48887	48878
Netherlands	8510	7807	7288	7972	8303
Annual Welfare Measures [M€/yr]					
Generation cost	12993	12072	12206	12072	12206
Consumer surplus	26139	22974	23371	23965	24315
Generator profit	6820	8914	8721	8609	8363
TSO congestion revenue	470	796	787	574	523
Social surplus	33430	32684	32879	33147	33201
Loss of social surplus compared to baseline	0	-746	-550	-282	-229

a. Calculated by weighting each period and node's price by the total MWh demanded at that price

b. Calculated by weighting each period's quantity by the number of hours in the period.

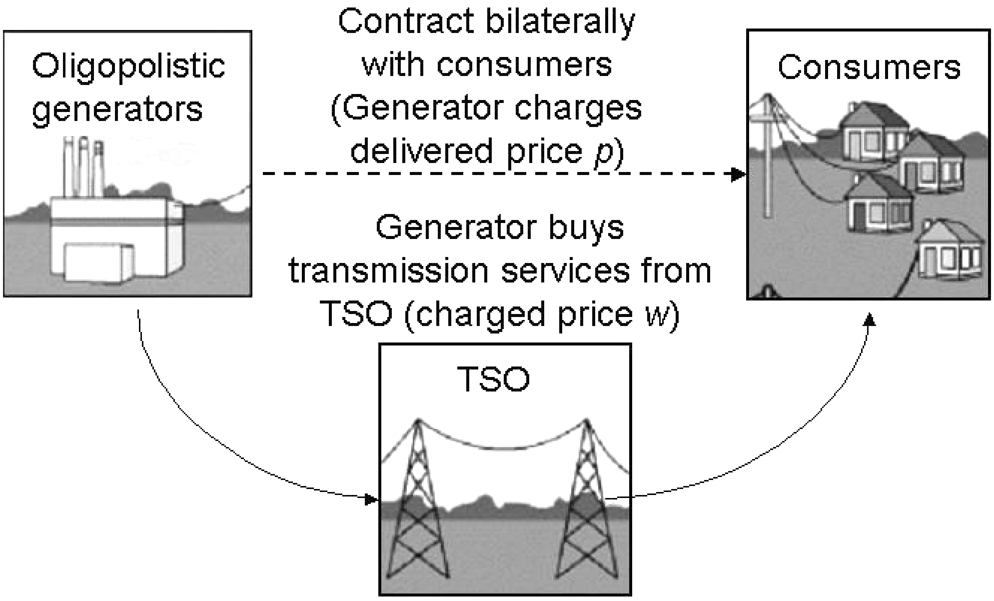

Figure 1. Schematic of Generator-Consumer-TSO Relationships in COMPETES

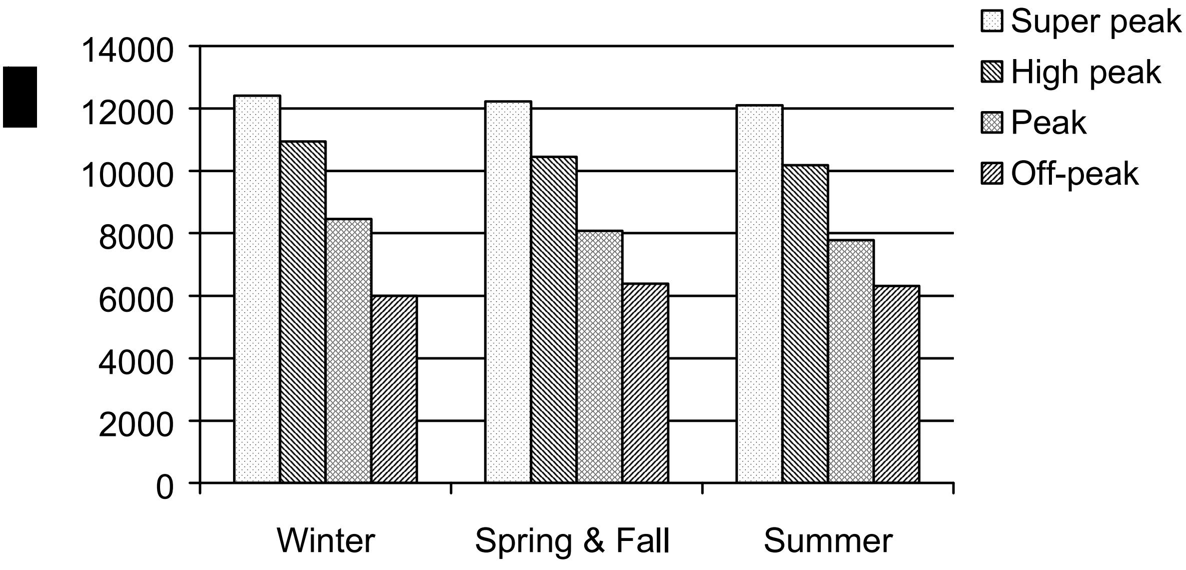

Figure 2. Electricity Demanded (Under Perfect Competition) in the Netherlands (Sum over Six Nodes)

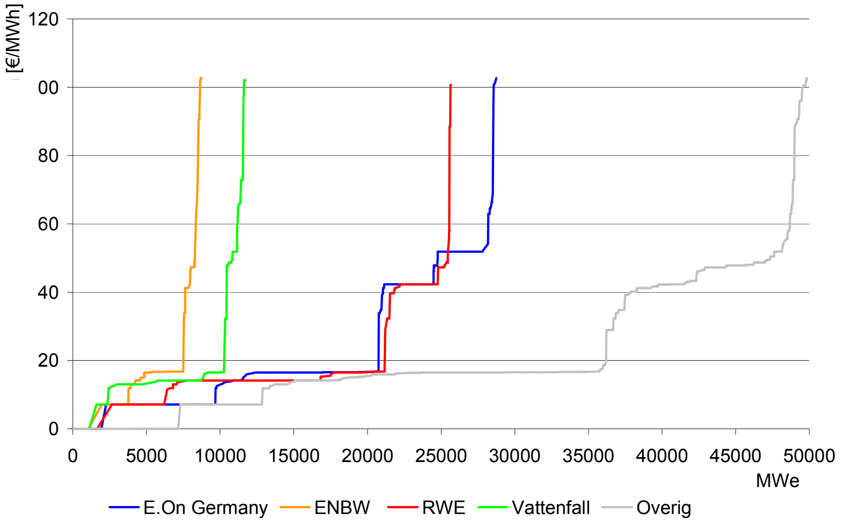

Figure 3. Marginal Cost Curves for German Producers, 2000

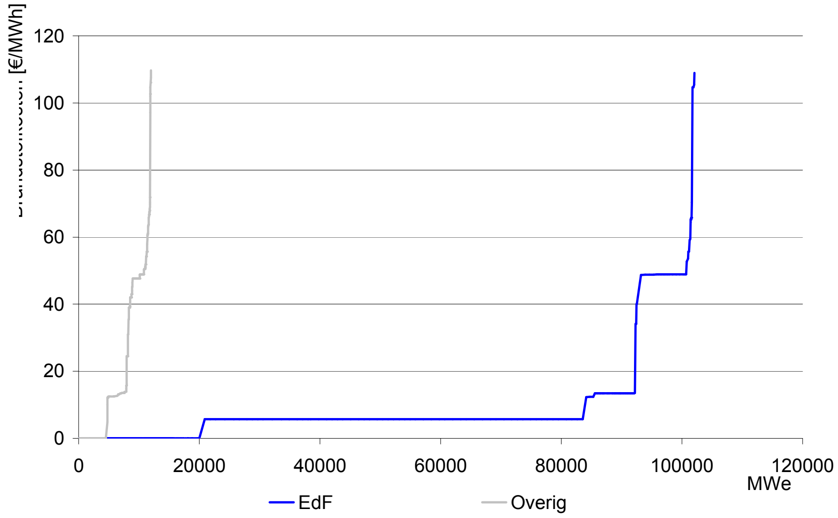

Figure 4. Marginal Cost Curves for French Producers, 2000

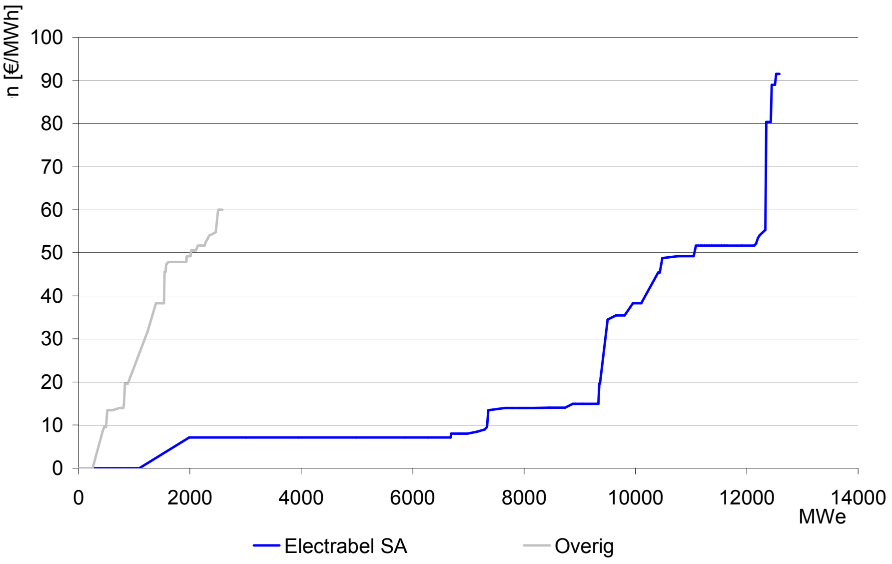

Figure 5. Marginal Cost Curves for Belgian Producers, 2000

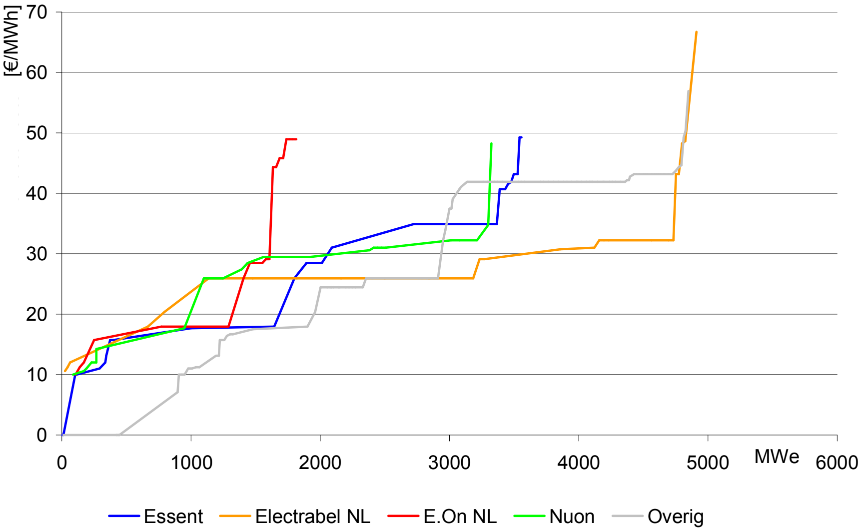

Figure 6. Marginal Cost Curves for Dutch Producers, 2000

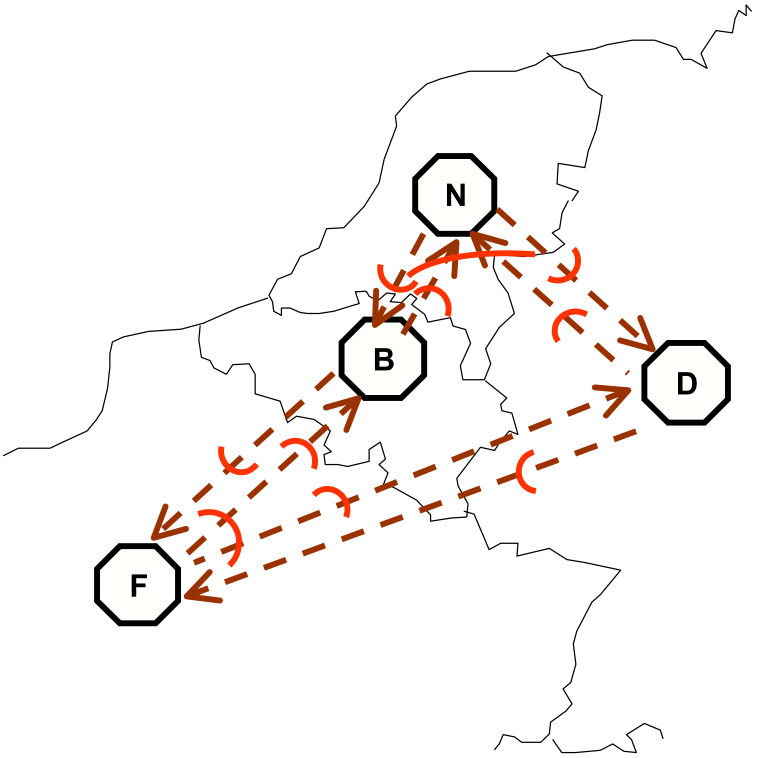

Figure 7. Path-Based Transmission System and Constrained Interfaces (Includes Constraints on Total Imports to Netherlands and Total Exports from France)

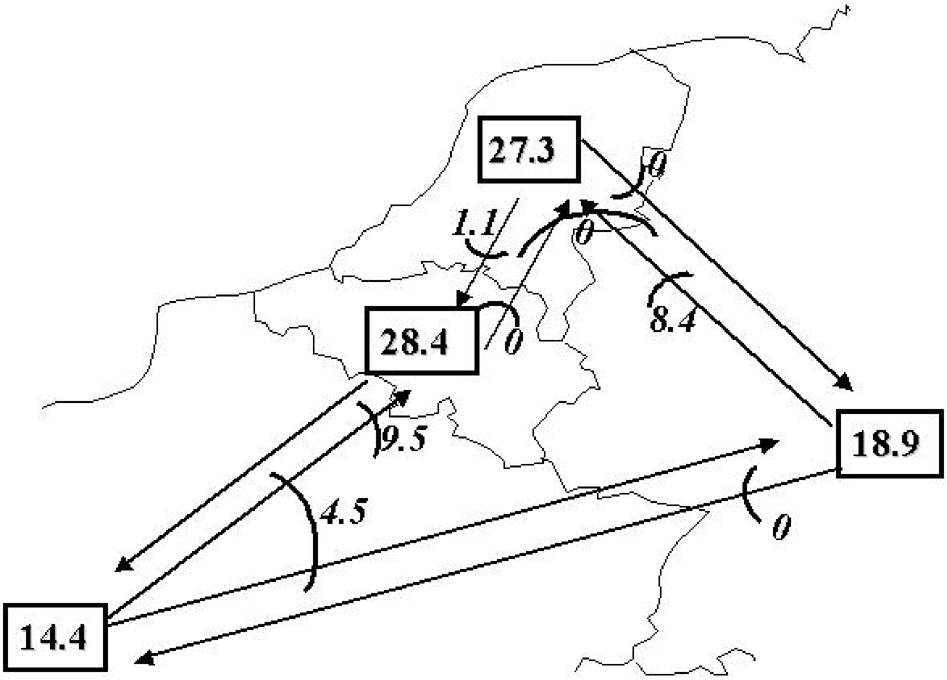

Figure 8. Perfect Competition Solution (Prices in Boxes are Quantity-Weighted Averages of Energy prices; Italicized Prices are Quantity-Weighted Averages of Interface Prices)

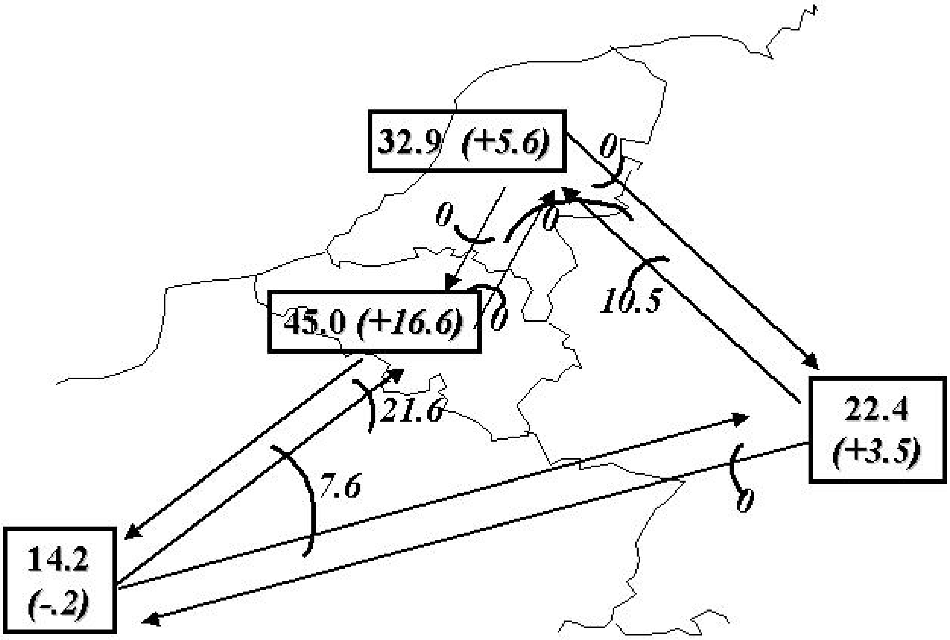

Figure 9. Cournot Solution, Present Transmission Institutions (Prices in Boxes are Quantity-Weighted Averages of Energy prices, with Changes Compared to Perfect Competition in Parentheses; Italicized Prices are Quantity-Weighted Averages of Interface Prices)

Note: EdF assumed to be price-taking within France, Electrabel assumed to behave à la Cournot

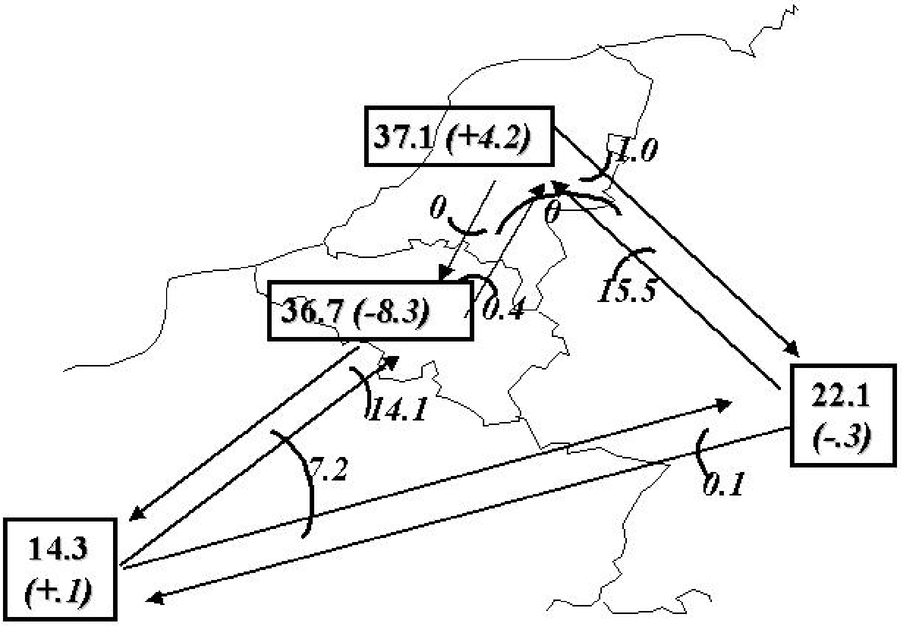

Figure 10. Cournot Solution, Market Coupling Case (Prices in Boxes are Quantity-Weighted Averages of Energy prices, with Changes Compared to Cournot/Present Transmission Institutions inParentheses; Italicized Prices are Quantity-Weighted Averages of Interface Prices)

Note: EdF assumed to be price-taking within France, Electrabel assumed to behave à la Cournot