• *András Kiss* •

THE EFFECT OF THE REGIONAL INTEGRATION OF ELECTRICITY MARKETS ON THE MARKET POWER OF POWER PLANTS*

The purpose of this paper is to construct a short-term economic model for the wholesale electricity market in the Central and Eastern European region – assuming conditions after a complete opening-up of the market. Among the inputs we provide an estimate for the generating capacities available and the cost of generation, demand as well as the transmission network data. The advantage of our modelling approach is that we simultaneously take into consideration the spatial structure of the electricity market and the capability of dominant companies to control prices. Our main conclusions: 1. at the current stage of market integration, major electricity generators are very powerful market players; 2. tighter market integration reduces the chances of abuse of market dominance and prices; however 3. even complete market integration cannot sufficiently limit the power of electricity generators. However, the practical importance of our modelling results cannot be assessed appropriately without determining how realistic they are.

INTRODUCTION

One of the key issues of the liberalisation of the electricity market in our region is *Can real competitive markets develop with the current ownership structure?* and *What threat does the market dominance of certain players pose?* The supply side of the electricity sectors in Central and Eastern European countries is quite concentrated: the overwhelming majority of generating capacities is concentrated in the hands of one or just a few players. This is one of the reasons why it is often argued that effective competitive markets are less likely to develop within a country. So in order to take advantage of the competition between electricity generators we need some kind of regional integration.

* The first, more detailed version of this paper was produced in the Central and Eastern European Energy Market (C3EM) Research Project conducted by the Regional Centre for Energy Policy Research (REKK) in 2005–2006 (*Kiss et al.* [2006]). The numerical model applied in the original version was constructed by the co-authors Julián Barquín and Miguel Vázquez (Universidad Pontificia Comillas, Madrid), and the author would like to express his deep gratitude to them. The author would also like to thank the following individuals: Zoltán Sulyok (MAVIR Hungarian Independent Transmission Operator Company Ltd) and REKK staff for their contribution and valuable suggestions in the course of the study.

In our paper we look at this issue using a numerical model. We have studied seven neighbouring countries in the region: Austria (AT), the Czech Republic (CZ), Croatia (HR), Hungary (HU), Romania (RO), Slovakia (SK) and Slovenia (SI).[1] After the description of: the structure and the workings of the model, generating capacities and costs, demand, and cross-border capacities, we try to find the equilibrium of the model in a competitive market environment and an environment characterized by strategic behaviour. After this we look at what changes can be expected from tighter integration regarding key variables, primarily: prices. At the end of the study we draw some conclusions from the numerical modelling exercise.

REGIONAL MARKET MODEL

We can look at the applied market model from four aspects: market demand, generating technology, spatial structure and corporate behaviour. We look at all four of these issues in detail below. We present not only the theoretical background but the data and estimates used for the numerical simulation.

Market demand

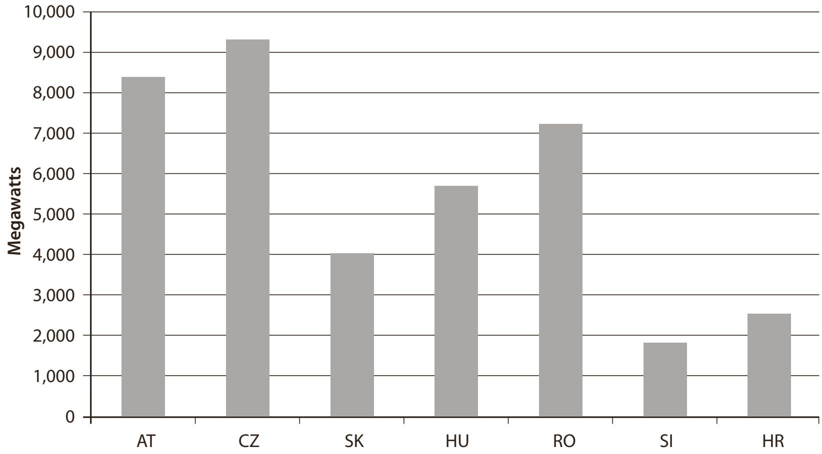
The demand for electricity is represented by an aggregate demand curve for each of the seven countries. It is a well-known fact that the electricity consumption of a country changes by the minute. However, we are not concerned with such temporal fluctuations, as our model is static by nature. Instead we have to record how demand changes at a specific point in time – which is typically the winter peak period – in relation to the market price of electricity. *Figure 1* shows the winter peak load of the various countries in the region.

As we do not have appropriate data to estimate the demand curve, we have to make various assumptions regarding the shape and position of the curve. To make things simple we chose a linear function, which can be described perfectly using three (easy-to-understand) data items.

The first is the demanded quantity, which has been described above, the second is the corresponding market price, which for the sake of simplicity we assume to be 30 EUR/MWh on every market.

By this we have defined a point on the demand curve. The steepness of the curve (the third data item) can be described by the elasticity of demand. Generally, the elasticity of demand for electricity is quite low: it is hard for consumers to find a substitute for the product.

[1] In brackets we use the abbreviations of the UCTE (Union for the Co-ordination of Transmission of Electricity). These abbreviations are used in the figures for the different countries.



Source: UCTE, own calculations.

FIGURE 1 • **Estimated winter peak demand (maximum system load) in the countries studied**

As no hard data are available we are forced to fall back on assumptions: we assume the elasticity of the demand to be –0.1 in every country (at specified demand points). Based on this, for example, a ten percent increase in price (short term) decreases consumption by one percent.[2]

Generating technology

There are numerous primary energy sources available for generating electricity, the most important ones being coal, natural gas, hydropower and nuclear power. As we are modelling short-term competition, we will concentrate on only production marginal costs.

As a good approximation, it can be assumed that, with regard to any given technology, the marginal cost of electricity generation at different production levels fluctuates within a very small range; therefore we assume the marginal cost to be constant.[3]

[2] Due to the nature of the linear function form, demand elasticity continuously changes along the demand function (higher prices mean higher demand elasticity). In the 20–50 EUR/MWh price range, which is interesting for modelling purposes, actual price elasticity is somewhere between –0.06 and –0.18. (However, we must consider that we have no reason to prefer constant price elasticity to the linear function form.)

[3] The average cost of generation is of course not constant because of fixed costs. However, since we are concerned with short-term supply decisions, we treat fix costs (e.g. labour costs and capital costs) as sunk costs, which do not influence the optimal supply decisions of power plants.

In order to estimate the marginal costs, first we need to determine the cost of fuel required to generate 1 MWh of electricity. Here we can set out in two different directions. We can take the observed total fuel-consumption (and related costs) of power plants and can project it on the quantity of electricity generated, or we can estimate the technology-based marginal cost of electricity generation from the energy conversion efficiency of generators and the fuel prices observed in the specific regions.

Although the first approach (using actual cost data) may seem more tempting theoretically, this method cannot be applied in practice – to the level of consistency required by the modelling example – due to the fact that such data is considered sensitive from a business perspective. On the other hand the advantage of the technology-based estimation is not only that significantly less data is required but also that there is a higher level of consistency inherent in the procedure: even if we are mistaken about the actual level of costs, the marginal costs of power plants in relation to one another remain consistent.[4]

We have aggregated the marginal cost curves resulting from technology estimation by country, as shown in *Figure 2.*

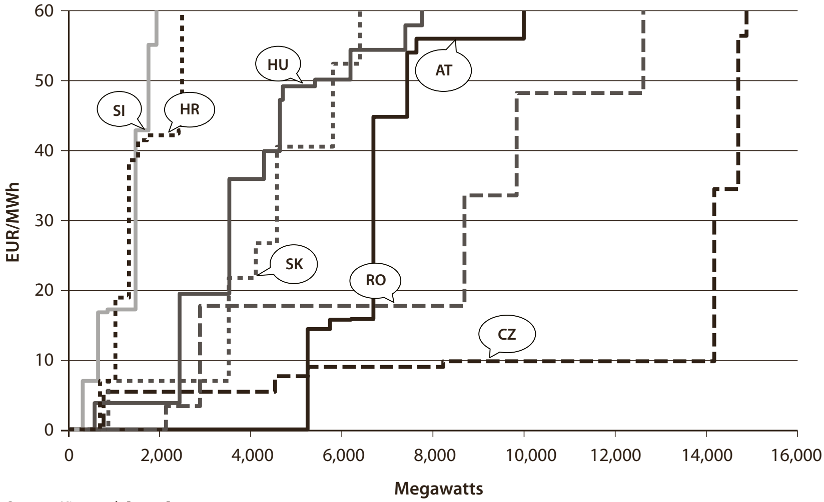
Figure 2 shows the available generating capacities and their costs as well as the load in peak periods. The bubbles with country codes indicate the point on the supply curve where the domestic demand can be met within the specific country (price elasticity has been ignored here). This way we can see the "international competitiveness" of the electricity sector of each country. The lower the bubble of a country is positioned, and the flatter the supply curve continues towards the right, the more the country's power plants are able to export cheaply to the regional market. In this regard the Czech and Romanian power plants are at an advantage.

Spatial structure

Since we are modelling quite a large regional market, the question arises whether the spatial structure has any significant effect on market equilibrium, and if so, how to take it into consideration.

Electricity is transmitted over long distances through high voltage transmission grids. The actual cost of transmission (the heat loss resulting from the resistance of power lines) are insignificant for the purposes of the model. However, the capacity

[4] In the case of hydropower we need to take a somewhat different approach, as the potential energy of water has no price as such. Of course it is true that we cannot generate electricity tomorrow with the water we use today, so we may not realise tomorrow's revenues this way. However, to estimate alternative costs we would need to have a fully dynamic market model, which is far beyond the scope of our study. As the second best solution we assume the marginal cost of hydro power to be zero; however, we reduce the amount of electricity that can be generated to the level of the annual average capacity utilization.



Source: Kiss et al. [2006].

FIGURE 2 • **Aggregate marginal cost curves**

constraints of power lines cannot be ignored: if the load exceeds the capacity limit, the lines simply burn (which the transmission system operators do not allow to happen).

The structure of transmission networks had to be simplified for the purposes of the model. In our model all parts of the transmission network, within each country, were simplified to a single node, and between two neighbouring nodes (countries) there are no more than one cross-border link drawn. Every consumption and generation takes place at the nodes and the transmission of electricity (trade) occurs through the limited capacity lines connecting them. By marking countries with a single node, we assume that congestion can only occur on the interconnectors.[5] *Figure 3* shows a stylized drawing of the modelled region. We will concentrate on the interconnectors denoted by solid lines (and the countries located at the end of these lines) explicitly.

Our capacity constrained electricity transmission model is further „complicated" by the laws of physics pertaining to current: Kirchhoff's junction and loop rules. The former is interpreted in a relatively intuitive way from an economic aspect in our model: the sum of all electricity flowing to a node (generation + import) is equivalent to the electricity flowing from the node (consumption + export). However, the loop rule is not in compliance with the general view on transportation of goods: free route choice does not apply to electricity!

[5] In the case of Austria for instance this assumption is not always true; therefore it cannot be considered a perfect approximation of the real situation.

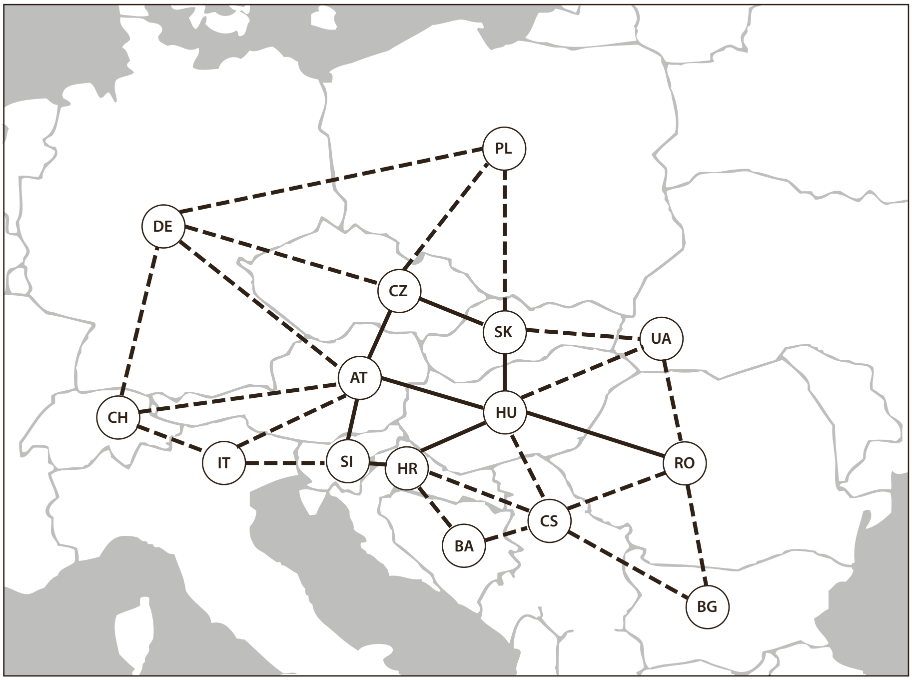


FIGURE 3 • **The spatial structure of the regional market**

On a network with parallel paths between two nodes, electricity flows along all parallel paths between the two nodes. Furthermore, the amount of electricity flowing through the specific network lines is distributed (roughly) in inverse proportion to the resistance of each path.

Let us take the transaction of 100 MW from Hungary to Austria as an example. If we want to consider its actual physical effect on the specific cross-border lines, we find that only one third of the 100 MW actually flows through that line from Hungary to Austria, the rest takes parallel routes through Slovakia, the Czech Republic, Croatia and Slovenia before reaching Austria – but if we look at the map we can see that the transaction also effects the Polish-German, or the Swiss-Italian borders as well. Of course the further the route is the less electricity flows through there.

The effect that electricity transmission between two nodes has on a line can be described using so called PTDF matrices, which are used on a regular basis by transmission system operators.[6] The current European cross-border capacity dis-

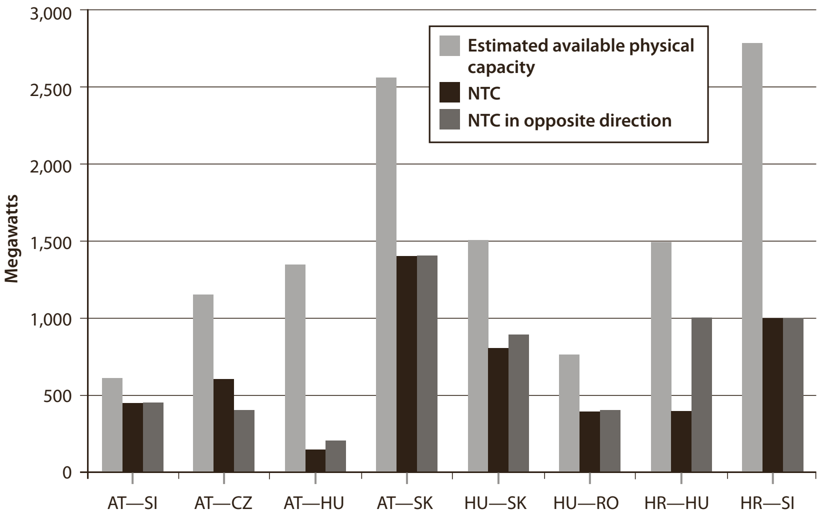
[6] PTDF stands for Power Transfer Distribution Factor. It shows the size and direction of physical flows generated by the transfer of one unit of electricity between two control zones connected directly and indirectly.

tribution mechanisms do not take into consideration the effect of non-direct (loop) flows, which has an adverse consequence: the bilateral transmission agreements generate negative external effects on lines that connect nodes indirectly. (They reduce available capacities elsewhere, which are not paid for.)

The existing continental capacity distribution mechanism (bilateral or coordinated auctions) „solves" the issues caused by externalities by reducing the actually available cross-border capacities by the amount of loop flows. This solves the problem of system security, but does not eliminate the basic welfare losses caused by external factors.

In tightly integrated systems, the effect of loop flows is explicitly taken into consideration during capacity allocation, and so called nodal pricing is applied.[7] In our model – in order to simplify the modelling of strategic behaviour – we assumed such an effective capacity allocation mechanism. However, we are aware that for the region under study this is far from the current practice. As a matter of fact, tighter regional integration could be interpreted as a shift to a more effective capacity allocation system. However, our model cannot be used to evaluate such a measure.

Figure 4 shows the size of cross-border capacities taken into account. As a starting point we can assume that the values of the so called NTC (net transfer capacity),[8]



Source: UCTE, ETSO, own calculations.

FIGURE 4 • **Estimated network capacity values available with regional nodal pricing and current net transfer capacity (NTC) values**

[7] See for example, the PJM market on the Eastern coast of the United States (www.pjm.com).

[8] NTC, or Net Transfer Capacity is the maximum capacity for exchange of power between two control zones.

known from the bilateral capacity allocation system, determine the maximum amount of electricity that can be transmitted between two nodes (countries). Since we use nodal pricing in the model, this is only a rough estimate. Therefore we also present an "integration" scenario in our model as well, where we determine the size of cross-border capacities available by subtracting the effect of average loop flows (and a 20 percent reserve margin) coming from countries that are outside the region from the physically available network capacity.[9]

As one can see, the available capacities estimated by us (based on the simplified network model) in each and every case exceed the NTC values actually published. The average difference is almost double.

Corporate behaviour

During the running of the model we distinguish two behavioural patterns by (the owners of) generators. The more basic assumption is price-taking behaviour (perfect competition). Every power plant assumes that their decision to generate electricity has no effect on market prices or the usage of cross-border capacities (and consequently their prices).

As a result, companies will keep increasing their electricity generation until the local market price exceeds their marginal costs (of course within the specific generating capacity constraints).

The first welfare theorem of economics states that perfect competition leads to efficient allocation in the market: competition maximises complete welfare attainable on the regional market given the existing constraints (including generating and transmission constraints). Of course, if we loosen these constraints – for instance, by assuming tighter integration, implying larger cross-border capacities – we can achieve a higher welfare level in the new equilibrium than previously.

The second possible assumption is that companies with large generating capacities recognize what effects their own decisions on their electricity output have on market prices. In extreme cases they may know perfectly well the demand curves as well as the reaction of the price-taking corporate sector (the „competitive fringe") and strategic competitors. To solve the model we are applying the so called Cournot-assumptions, meaning that when making their output decisions strategic companies assume that other large, strategic players do not react to the output changes of competitors, but the competitive fringe adapts to the new market price in a price-taking manner. In addition, strategic companies need to be able to forecast, which interconnectors will be congested. Equilibrium will occur where all

[9] It should be kept in mind that this calculation method ignores the effect the flows within a country have on cross-border lines.

these assumptions are in line with the generating decisions companies have made based on their forecasts.[10]

The ability to decide who the *strategic players* are, provides some decisive freedom in the course of modelling. Having examined several variations, we selected (non-state-owned) companies, which have strategic generating capacities that are significant both regionally and at a national level, but do not have full coverage of the sector. We have identified three such companies: CEZ (the Czech Republic), SE (Slovakia) and Verbund (Austria). Including such companies as MVM (Hungarian Electricity Ltd), AES-Tisza Power Plant Ltd, Electrabel Hungary Ltd or RWE Energy Hungary Ltd. which are regionally small (although significant in Hungary) in our study does not affect our findings greatly. Such a great part of the Romanian, Slovenian and Croatian generating capacities was state-owned at the time of modelling (and still are) that it would be more reasonable to expect a price-taking (or from a different perspective: optimally regulated) market behaviour from them than to think they would go for profit-maximisation.

OUTCOMES OF PERFECT COMPETITION

Having presented the model and input data, let us now look at the results. *Figure 5* shows the main scenario characterized by perfect competition and low level of regional integration.

There are two values corresponding to each country in the figure. The top box shows the equilibrium market price (EUR/MWh), while the box at the bottom displays the net export position of the country. A positive value in a white field means that the country is a net exporter (in MWh); while a negative value in a black field means that the country is a net importer.

Arrows crossing the borders indicate the direction and the strength of electricity flows (the stronger the flow the thicker the arrow). The tone of the arrow indicates whether the interconnector is congested (i.e. if the capacity of interconnectors is an effective constraint on further trade). Lines using 100 percent of their capacity are marked in black, while those marked in grey are not used to the full.

[10] For a detailed, formalized description of the model and the solution concept, see the paper of *Barquín–Vázquez* [2005]. Numerous studies have been conducted about the strategic modelling of electricity market competition, which for the most part differ in their assumed market mechanisms, the type of strategic game, the degree, to which they cling to the physical characteristics of electricity flow, or their equilibrium calculation methods (see *Cardell et al.* 1997], *Smeers* [1997], *Wei–Smeers* [1999], *Hobbs et al.* [2000], *Joskow–Tirole* [2000], *Day et al.* [2002], and *Metzler et al.* [2003]) A great overview of electricity market strategic competition modelling literature is given by *Neuhoff et al.* [2005] and *Ventosa et al.* [2005].

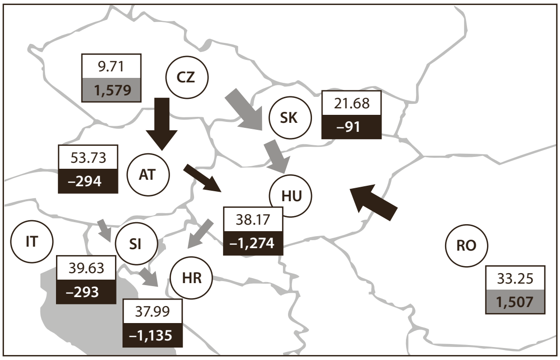


FIGURE 5 • **Competitive market, moderate integration**
(cross-border capacity = NTC value)

We can make the following observations about the diagram. There are large price differences between equilibrium prices in the countries as a result of severe congestion on three interconnectors (from the Czech Republic to Austria, from Austria to Hungary, from Romania to Hungary).

The lowest priced country is the Czech Republic, followed by Slovakia and Romania. The prices in Hungary, Croatia and Slovenia are higher, and they are relatively close to each other. The quite high price observed in Austria is probably the result of two effects: firstly, the limited import capacity existing from the direction of the Czech Republic, and secondly, the limitation of the capacity of storage power plants to average available capacity. (With less careful assumptions we would probably allow much a higher level of capacity usage for storage plants, which would lead to significant inexpensive extra capacity – and lower prices.)

Only the Czech Republic and Romania are in net exporting position. The most severe power deficit occurs in Croatia and Hungary.

Figure 6 shows what happens in a model assuming perfect competition, if, by increasing cross-border capacities, a tighter regional integration is achieved (for the degree of capacity increase see *Figure 4*).

The striking difference between *Figure* 5 and *Figure* 6 is the dramatic increase in the Czech export position towards both Austria and Hungary. The net exporting position of Romania has slightly decreased, but it is still very positive. Both Austria and Hungary have greatly increased their dependence on imports, while the export-import balance of all other countries has only slightly worsened.

The effect of tighter market integration is clearly visible in the equilibrium prices: market prices have converged considerably. In the case of the Czech Republic, this implies a two-fold increase in the system price; nevertheless, the Czech market remains the lowest priced country in the region. Slovakia comes in second place, followed by Romania, Hungary,

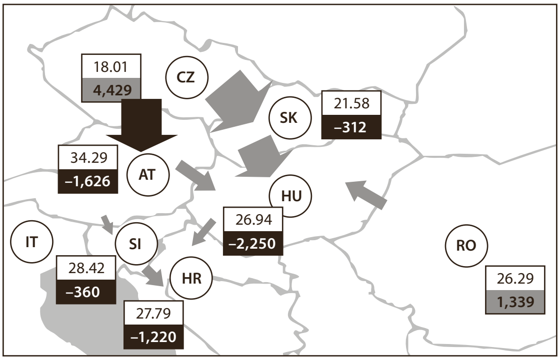


FIGURE 6 • **Competitive market, tight integration**
(cross-border capacity = estimated available physical capacity)

Croatia and Slovenia. Austria still has the highest electricity price, but proportionately it has had by far the largest price decrease of all countries.

Correspondingly, congestion still exists between the Czech Republic and Austria, but line limits from Austria to Hungary and Romania to Hungary are no longer binding.

THE EFFECT OF MARKET DOMINANCE IN THE REGION

We already covered the assumptions and effects that lie behind strategic behaviour, so now we will simply present and interpret the modelling results. *Figure 7* shows the market outcomes resulting from the strategic use of market dominance with moderate regional integration.

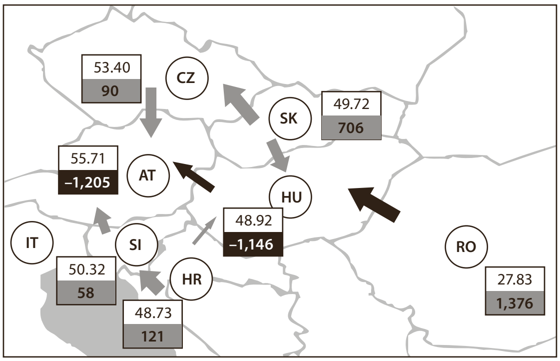


FIGURE 7 • **Oligopolistic market, moderate integration**
(cross-border capacity = NTC value)

To understand the effects of market dominance, compare *Figures 5* and *7*. Regarding the net export positions, the most striking is how much production in the Czech Republic was cut back. Numerical results show that as an oligopolistic company CEZ decreased generation by almost 3,400 MW (44 percent), which is only partly substituted by the 525 MW (14 percent) increase in Czech fringe production. There is also a sizeable decrease in power generation by Verbund (–1,019 MW) and SE (–809 MW). As a result, prices have gone up considerably throughout the whole region (except Romania, where competitive companies prevail).

Some countries (most notably Croatia and Slovenia) have turned from net importers to net exporters. Generally, the destination of electricity trade is still Hungary and Austria, but the Czech Republic is no longer the main source. Consequently, the direction of the flow of electricity has also changed at some interconnectors. The line from the Czech Republic to Austria is no longer congested, and the Austrian-Hungarian line is now congested in the other direction, towards Austria. Assumed price-taking behaviour in the Romanian power sector ensures that Romania remains a strong net exporter, as a result of which the flow on the Romania → Hungary interconnector has not decreased.

Finally, let us examine what effect tighter regional integration has in a market dominant position on the equilibrium *(Figure 8)*.

Relative to the corresponding scenario under the competitive setting *(Figure 6)*, we can make the following observations.

- Capacity withholding has decreased trade in the region and taken the load off the interconnectors. All congestions have been eliminated (although Romania-Hungary is still very close to being congested, using almost 100 percent of its capacity).
- As a result, all prices have converged to 41.23 EUR/MWh, which is much higher than any of the market prices under the perfect competitive market setting with tight integration.

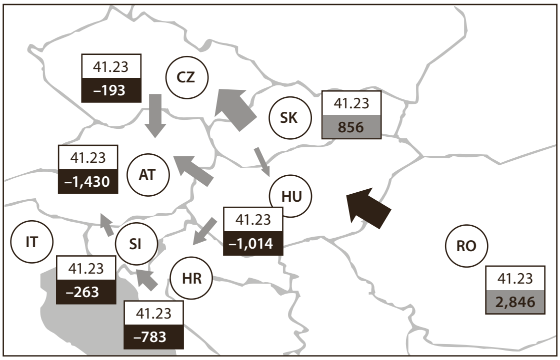


FIGURE 8 • **Oligopolistic market, tight integration**
(cross-border capacity = estimated available physical capacity)

- Slovakia has taken over the role of main regional exporter from the Czech Republic. Romania exports almost twice as much as in the competitive environment.
- If one takes advantage of market dominance, the average regional price level will still be higher under tight integration than with price-taking behaviour without integration.

Finally, let us see what effect regional market integration has on market dominance *(Figures 7 and 8)*.

- With the exception of Romania, prices in all of the countries dropped by an approx. average of 20 percent after the integration.
- The direction of flows remained the same.
- The Czech Republic, Croatia and Slovenia have turned from net exporters to net importers. The export-import balance of Austria has slightly worsened, while that of Hungary and Slovakia got better.
- The "missing" energy is provided by price-taking firms in Romania, which increases the local price there to regional levels as well.

SENSITIVITY ANALYSIS

Of the input data of our model – not taking into consideration structural assumptions – the information about the demand function are the most ad hoc. As a result, we have looked at some other scenarios regarding the level of demand and its price elasticity.

Looking at the results, we can say that the characteristics of the changes in demand and under competitive and strategic behaviour were qualitatively alike. So we only present the results about the oligopolistic market structure.

Figure 9 shows what happens if we reduce the demand to different extents on regional markets The specific cases (10–50 percent drop in demand) can be interpreted in two ways.

As we know, the demand for electricity fluctuates according to the time of the day, from week to week and seasonally. With the changes in the level of demand according to the first interpretation, we are examining how sensitive our results are to normal fluctuations in demand. (The ratio of peak period and off-peak period consumption can be as much as 2:1.)

In the second interpretation, sensitivity to changes in demand also affects one of our structural assumptions: the insularity of the region towards cheap and competitive import coming from outside (e.g. Poland or Ukraine). If some inexpensive and price-taking import electricity comes from over the borders of the region, we expect residual demand to drop. However, taking import capacities into consideration this decline in demand can be no more than 10-20 percent.

No matter which interpretation we chose, it becomes obvious that the decline in demand will result in lower equilibrium prices. The degree of price decrease is

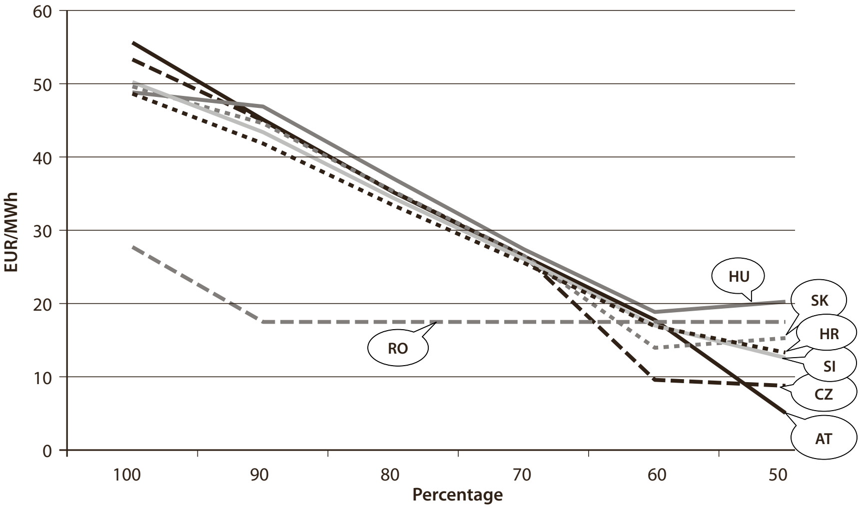


FIGURE 9 • **The effect decline in demand relative to peak demand (100 percent) has on equilibrium prices under an oligopolistic market structure and moderate integration**

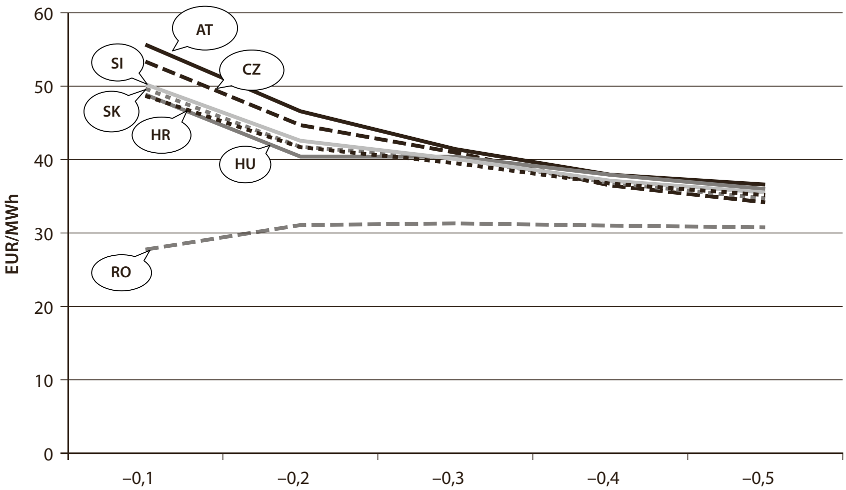


FIGURE 10 • **The effect greater demand elasticity has on equilibrium prices under oligopolistic market structure and moderate integration**

significant (it can drop to half of the market price); however it corresponds to the difference between peak and off-peak prices of power exchanges.

Figure 10 shows the effect the increase of demand elasticity has on equilibrium prices. Here our expectations inspired by economic theory are met: greater demand elasticity reduces price raising by strategic companies, since with the price increase companies can expect a sharper drop in demand, which makes the increasing of prices less profitable. However, the *Figure* also shows that even major changes in demand elasticity do not have such a strong reducing effect on prices as the daily fluctuation of consumption does.

CONCLUSIONS

We have now seen that large electricity generators have considerable market power in the modelled regional market environment, which raises market prices above competitive levels across the region. Using current NTC values as available cross-border capacity, this mark-up can range from 2 EUR/MWh (Austria) to 44 EUR/MWh (Czech Republic), with a typical value around 12-14 EUR/MWh. In percentages, the margin averages between 25-40 percent.

At the same time, two interconnectors are very heavily used. Congestion on the lines from Romania to Hungary and from Hungary to Austria reflects the effect of the competitive electricity supply coming from the Eastern end of the region and trying to reach the Western part of the region, where capacity withholding creates a shortage of supply.

We can observe that the modelled tighter regional integration does indeed reduce the price increasing power of dominant market players. The primary reason for this is also that the competitive supply coming from Romania is allowed to compete with strategic supply in Western markets. This result is of course not independent from the assumption (exogenous in our model) that electricity generators in Romania behave in a price-taking way.

On the other hand we have to note that large regional electricity generators have significant dominance even in a tightly integrated market. (Figure 8 shows the tightest integration that can be achieved, as there are no congestions at any borders in the region, and the same price applies to every market.) Even if we consider the effect of competitive supply coming from the east, we find that short-term equilibrium prices will be around 1.5-2 times the prices observed in the integrated competitive scenario.

Thus, it is fair to say that closer integration mitigates market power relative to a *more segmented market structure*, but it is not nearly sufficient to eliminate it altogether or to realize the potential welfare gains of market competition. (Indeed, the price mark-up of strategic players is barely dented by integration.) To draw our main conclusions we should not forget the original assumptions we worked with and their limitations.

The most important ones are: the static nature of the model, the idealized nature of the capacity allocation mechanism used, somewhat arbitrary drawing of the borders of the region under study, the isolation of the region, and the optimistic assumptions about the motivations of state controlled market players. It is hard to evaluate the practical importance of our modelling results until these limiting simplifications have been overcome.

REFERENCES

Barquín, J.–Vázquez, M. [2005]: Cournot equilibrium in power networks. Mimeo, Instituto de Investigación Tecnológica, Universidad Pontificia Comillas, Madrid, http://www.iit.upcomillas.es/docs/IIT-05-007A.pdf.

Cardell, J.–Hitt, C. C.–Hogan, W. W. [1997]: Market power and strategic interaction in electricity networks. Resource and Energy Economics. Vol. 19, No. 1–2, pp. 109–137.

Day, C. J.–Hobbs, B. F.–Pang, J.-S. [2002]: Oligopolistic competition in power networks: a conjectured supply function approach. IEEE Transactions on Power Systems, Vol. 17, No. 3, pp. 597–607.

Hobbs, B. F.–Metzler, C.–Pang, J.-S. [2000]: Calculating equilibria in imperfectly competitive power markets: an MPEC approach. IEEE Transactions on Power Systems, Vol. 15, No. 2, pp. 638–645.

Joskow, P.–Tirole, J. [2000]: Transmission rights and market power on electric power networks. RAND Journal of Economics, Vol. 31, No. 3, pp. 450–487.

Kiss, András–Barquín, J.–Vázquez, M. [2006]: Can closer integration mitigate market power? A numerical modeling exercise. In: Towards More Integration of Central and Eastern European Energy Markets. Regionális Energiagazdasági Kutatóközpont, Budapest, http://rekk.uni-corvinus.hu/c3em/pdf/modeling_study.pdf.

Metzler, C.–Hobbs, B. F.–Pang, J. S. [2003]: Nash–Cournot equilibria in power markets on a linearized DC network with arbitrage: formulations and properties, Networks and Spatial Economics, Vol. 3, No. 2, pp. 123–150.

Neuhoff, K.–Barquín, J.–Boots, M. G.–Ehrenmann, A.–Hobbs, B. F.–Rijkers, F. A. M.–Vázquez, M. [2005]: Network-constrained Cournot models of liberalized electricity markets: the devil is in the details. Energy Economics, 27, pp. 495–525.

Smeers, Y. [1997]: Computable equilibrium models and the restructuring of the European electricity and gas markets. Energy Journal, Vol. 18, No. 4, pp. 1 –31.

Ventosa, M.–Baíllo, Á.–Ramos, A.–Rivier, M. [2005]: Electricity markets modeling trends. Energy Policy, Vol. 33, No. 7, pp. 897–913.

Wei, J.-Y.–Smeers, Y. [1999]: Spatial oligopolistic electricity models with Cournot generators and regulated transmission prices. Operations Research, Vol. 47, No. 1, pp. 102–112.