Economics of Interconnection

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Abstract

The European policy of integrating national electricity markets to create a unified European electricity market necessities increased interconnection between the European countries. The potential benefits of a specific interconnection are important in order to decide which interconnections should be established (first). This paper addresses how especially the long term effects can be identified. It follows from the discussion in the paper that in order to cover all potential effects, a rather complex model will have to be employed, or one has to rely on various partial analyses.

This article was first motivated by a claim from the Dutch regulator DTe during the licensing procedure for NorNed that there would be no long term welfare effects from an interconnection. We strongly disagree.

Introduction

The aim of this article is to present the underlying economic foundations for an assessment of the value of interconnections between thermal and hydroelectric power systems. In particular, we are concerned with the long-term impact on welfare.

We will use two different approaches. First, we consider the short-term effects. Second, we consider the impact of interconnections on long-term equilibrium.

The impact of uncertainty is not included explicitly in the analysis. As a consequence, we have not analysed formally how an interconnection would affect the dynamics of investment decisions.

The article is to a large extent based on our experience from analyses of the NorNed project, which is a new 700 MW interconnection between Norway and the Netherlands.

Short-term Impacts

Assume two perfectly competitive electricity markets; one is a thermal based market, whereas the other is predominantly a hydro-based system. Without interconnection, the two markets are likely to have quite different price structures. When such markets are interconnected, the trade between them will, in the short term, have an impact on price formation, production and consumption in both regions. In hours with higher prices in the thermal system, there will be imports from the hydro market, and vice versa. Mobilising increased output from the hydro (thermal) suppliers would imply a certain price increase in the hydro (thermal) market. This price increase would then imply adjustments in consumption, and/or reduced hydro production during other periods, and/or reduced export to other neighbouring countries. These price changes will change producer and consumer surplus in the short term, and will also have distributional impacts across markets.

The size of these adjustments depends on the price elasticity of demand and supply in the regions in question, and to which extent the regions are interconnected with other markets as well.

A main benefit observed in a competitive model origins from the absolute value of the price difference between the new market prices, aggregated over the lifetime of the interconnection. This is often referred to as the Trading Margin. Newbery (2004) provides a brilliant overview of how the trading margin between a thermal and a hydro system is created.

Change in Local Consumer and Producer Surplus

It is fair to believe that the change of market prices in the hydro system will not change total output from the hydro power plants – reduced prices in one period will lead to increased production in other periods. Total output from the hydro system is constrained by precipitation, and is exogenous with respect to the interconnection. For the thermal market, reduced prices in one period will lead to reduced production for this period. Increased prices will similarly lead to increased production in other periods. However, there is no direct link between the reduction in one period and the increase in another period (unless the power plants face very strict market conditions for the contracted fuels or emission costs, e.g., if the opportunity cost of unused fuel is zero). A schematic illustration for a thermal market is thus slightly different from a corresponding illustration for a hydro market, as the short-term supply curve is not a horizontal line in the thermal market cases.

In the sketches below, it is assumed that the trade with neigh-

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See footnotes at end of text.

bouring countries remains unaffected by the price changes imposed from the trade via the interconnection studied.

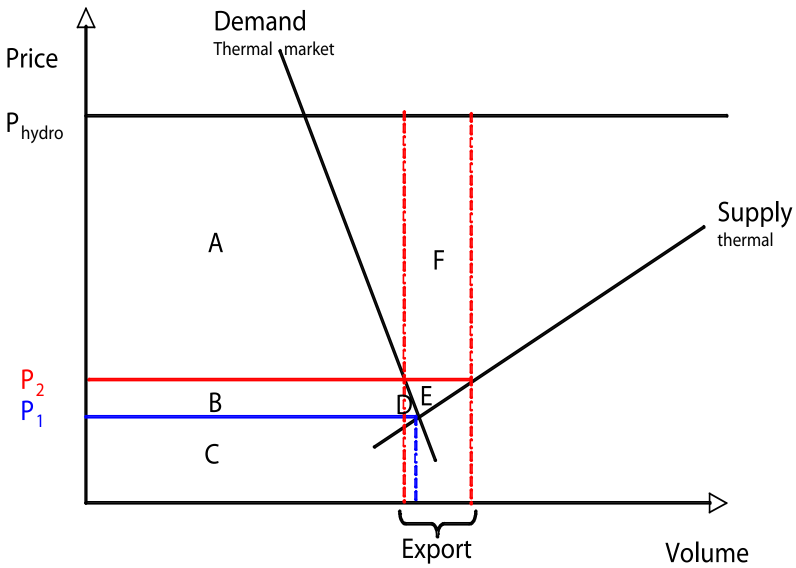

Figure 1
Thermal Market Exports to Hydro Market

Thermal Market During Low Load Periods[1]

Let us first consider the export from the thermal market. Figure 1 pictures a typical off-peak situation with a relatively low price in the thermal market. Hence, off-peak trade would typically imply increased thermal production, potentially reduced consumption and export to the hydro system. The price difference between the two markets will be reduced somewhat because of the trade. Thus part of the potential trading margin will be shifted to producers in the thermal market, instead of the owner of the capacity.

The consumers will experience increased prices, from P_1 to P_2, and the consumer surplus will change from areas A, B and D to just A. The producers will see their producer surplus increasing from C with B, D and E. We assume that the thermal market's share of the trading margin is γ, and the share of the costs for the interconnection is β. Thus the thermal country will receive γF, F being the trading margin. Finally, we let X be the operation and maintenance costs plus annuity of the fixed costs, discounted with the correct (societal) interest rate. The welfare accounts for the thermal market will then be as follows:

- Change consumer surplus: -B-D
- Change producer surplus: +B+D+E
- Change trading margin: +γF
- Cost of interconnection: -βX
- **Total change: +E+γF-βX**

We note that the size of E depends on how steep the supply and demand curves are. The area will be larger the less elastic (steeper) the demand and supply curves are. We note that the smaller E turns out, the larger will F be. Whereas F is the trading margin, E is the part of the potential trading margin that is shifted to the participants in the thermal market.

The assumption that an increase in interconnector capacity will not affect the trade with other countries is typically not true. The changes in domestic prices will tend to influence the volumes traded (and thereby also the prices in the other countries), or the trading margin on other interconnectors. These changes will in general not have important effects on total welfare, but will lead to a redistribution of income between the countries involved.

An important question is whether it is possible to say anything ex ante about the slope of the supply curve and the demand curve during peak and off-peak situations. We note that in addition to cost functions of thermal power plants, this also depends on producer behaviour in the thermal market during off-peak situations. How do the producers behave in a specific hour when spot price is insufficient to cover marginal costs, but stop and start costs makes it unprofitable to stop the plant? It is commonly observed that thermal power plants are kept running despite variable costs above the prevailing spot price. Due to start and stop costs, this might also be optimal for the plant.

SKM (2003), which takes supplied volumes under peak and off-peak into consideration, and thereby calculates volume weighted average prices, reports a significant transfer of wealth from producers to consumers. This corresponds to a statement that area B during import (transfer from producers to consumers) is significantly higher than B+D under export.

The European Inter-TSO compensation scheme (ITC) implies a redistribution of income between TSOs affected by international trade. ITC does not directly influence market prices and trade, but the trade patterns influence the amounts paid/received by the TSOs. It should, therefore, be accounted for in cost-benefit analyses of new interconnectors.

Other Short Term Effects

In the short term, there are also other sources of potential benefits:

- Increased competition and improved market liquidity.
- Interconnection with a hydro system will tend to stabilise demand towards the thermal system. This will increase the expected operation time and thus improve the investment climate for base-load generation as well as the average fuel efficiency.
- Security of supply can be improved. As shown in the next section, the results with respect to security of supply in the long run are ambiguous and depend on the assumptions applied in the models.
- Interconnection with hydro systems will also give the thermal market access to hydroelectric balancing services.

Long-term Analysis

Competitive market players handle production investment and operation, while transmission investment and operation is handled by TSOs (and regulators). Both production and transmission assets will be part of the long-term equilibrium. In this respect, it is important to bear in mind that if the TSOs do not implement profitable grid investments, the long-term equilibrium will be less efficient than it should have been. One cannot expect the market players to invest in grid assets if TSOs don't.

Theoretical Analysis

In the long run, transmission and production investments are to some extent substitutes. This is in fact one of the reasons why transmission capacity is attractive from a welfare perspective – it may be an efficient way of providing power when local production is expensive.

We have based the analysis on three different approaches, where we compare the equilibrium in a thermal system with and without an interconnection to a hydro system[2]:

- A two period, one technology model, with constant marginal costs
- A four period, four technologies model
- A two period, one technology model, with variable marginal costs

Two Periods, One Technology, Constant Marginal Costs

The simplest two period model assumes a production technology with a per unit capacity limit and constant marginal costs up to that limit. For simplicity, demand is assumed to be independent of prices (no price elasticity, D_B and D_H). It is also assumed that base load and high load periods have the same duration. The long-term equilibrium is shown in the figure below:

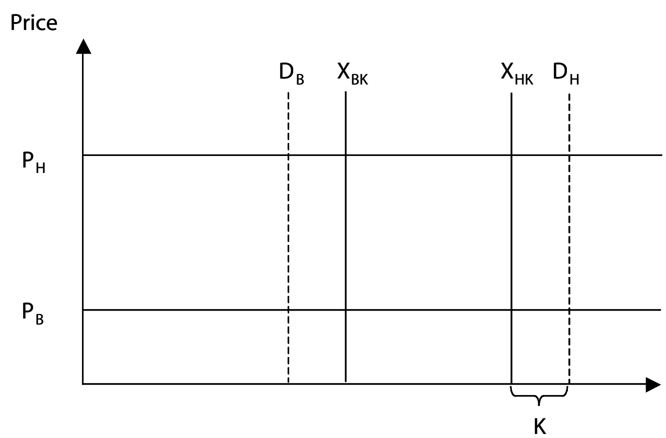

Figure 2
Interconnection in a Single Technology Model

Without interconnection, production equals demand in both periods. In base load, the price will be equal to short run marginal costs (SRMC), as capacity is not a scarce resource in this period. The peak load price must then be such that it covers both the SRMC as well as the capital costs of the production units. That is, peak load price must equal SRMC + a, a = capital costs / production. If the price is lower, producers will in the long run not be able to cover their full costs and will go out of business. If the price is higher, new production units will be attracted to the market.

Assume then that the price difference makes it profitable to build an interconnection. Imports will then replace some of the high load production (X_{HK}), leading to a reduction in production capacity equal to the capacity of the interconnection (K). In base load, production will increase by the volume exported (X_{BK}). Domestic production costs are reduced by the capital cost of K production units. The reduction in operational costs during high load is exactly offset by an increase in operational costs during base load. Prices, and thereby the consumer surplus, is not affected. The owner of the interconnection will then capture all of the gain from reduced production costs (a*K).

The interconnection can be seen as a storage for electricity, making it possible to produce power during base load and consume it during high load. This kind of storage should be expanded until the price difference between base and high load exactly covers the costs of storage. With the assumptions used in this model, the long-term equilibrium including storage (or interconnections) implies that production capacity is replaced by interconnections until the production capacity is fully utilized in both base and high load.

Four Periods, Four Technologies

von der Fehr and Sandsbråten (1997) present a power market model with four periods (base load, medium-run, high-run and peak load) and four thermal production technologies. Each of the technologies is the marginal technology in each of the periods, both with and without the introduction of an interconnection.

With respect to production capacities, an interconnection with a "one unit" capacity implies that (in their day-night power exchange):

- Peak load capacity is reduced by two units
- High-run capacity is increased by two unit
- Medium-run capacity is reduced by two units
- Base load is increased by one unit

The interconnection then implies that the new optimal level of installed capacity is one unit less than the initial equilibrium. Prices and consumer surplus are not affected. Again, the owner of the interconnection captures the gain from reduced production costs – in the form of a trading margin.

The results from both this and the previous model are driven by the model assumptions, particularly the assumption that there is no change in which technology is the marginal one in each period. From this assumption, it follows that prices are unaffected by the interconnection. As will be demonstrated below, it is quite easy to develop a numerical example with different conclusions.

Two Periods, One Technology, Variable Marginal Costs

The purpose of this model is to examine the effects of an interconnection in a situation with a more continuous supply function, as opposed to the stepwise linear functions in the previous two models. The model is equal to the constant marginal cost model, except that each production unit has no capacity limit, but instead an increasing marginal cost function. The number of units and their production during high load is determined by costs and the difference between high and base load consumption. For computational convenience, a rather simple cost function is assumed:

$$C(Z, X_H, X_B) = A \cdot Z + \frac{X_H^2}{Z} + \frac{X_B^2}{Z}$$

Here, Z is generation capacity, A is the fixed (capital) costs associated with Z, and X_H and X_B is actual production during High and Base load.

With this model, it turns out that prices are affected by interconnection, such that an interconnection reduces high load prices and increases base load prices. In sum, the interconnection implies an increase in consumer surplus. This result has a rather intuitive explanation. As shown by the previous models, the interconnection leads to a reduction in production costs, as producer surplus is always zero in the long run. A reduction in the difference between high and base load prices then means that some of the potential income for the owners of the interconnection is transferred to the consumers. This result is in fact the same as described in the section about short-term effects. Although the change in producer surplus in the long run, due to an interconnection, will be zero, the change in consumer surplus will not be zero.

The model also has some interesting features with respect to production capacity. In a numerical example, an interconnection with a capacity of 17% of high load consumption leads to only 2% reduction in the production capacity. This is a quite different result from the one obtained in the other models. We arrive at this result as we have departed from the commonly used and simplifying assumption that prices will not be affected by the interconnection.

Concluding Remarks

Using simple models of perfect competition with realistic assumptions, we have demonstrated that interconnectors will create persisting benefits for consumers and producers, in addition to the trading margin.

The models arrive at different conclusions regarding security of supply, measured by available production and interconnection capacities. In the models where prices are assumed unaffected, the increase in interconnection capacity is offset by a similar reduction in production capacity. In the model where the interconnection affects prices, the numerical example shows a substantial increase in available capacity.

In real life, the production technologies are arguably more diverse and flexible than assumed in the first two models. Interconnections will most likely improve security of supply, by increasing total available capacity.

Our analysis has focused on the benefits of interconnection related to the spot market. In principle, similar benefits can be obtained if the interconnector capacity is used for trading balancing power and system services.

Many countries have ambitious targets related to developing renewable power. Linking a thermal market to a hydro system improves the ability to increase the market share of green, but inflexible generation, such as windmills.

We believe that interconnector investments will be most efficiently provided for by considering them as part of the core business of the TSOs. In such as setting, interconnections, as well as all other transmission investments, should be evaluated from their welfare effects.

Given the complexity of a real electricity market, a very complex model will have to be employed in order to capture all the potential benefits. Alternatively, one has to rely on several partial analyses. This approach though, has the disadvantage that one cannot really be sure to which extent the "partial" benefits/costs are additive or not.

Footnotes

[1] During peak load, the thermal market will typically be importing from the hydro market, but the welfare impact will be similar.

[2] The hydro system is characterized by less intra day price volatility than the thermal system, meaning that the interconnection will be used for imports to the thermal system during high load and exports during base load.

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[3] In 2007, Czech power prices (CZ) almost reached Western European levels for a number of reasons. CO_2 certificate prices fell dramatically during 2007, nuclear production decreased in the Czech Republic and more cross-border capacities became available due to a reduction in long-term contracts between Germany and the Czech Republic.

[4] Clearly, some "new" renewable energy sources are associated with high variable costs (e.g. biomass). Nevertheless, from a wholesale market point of view, these technologies – in the short run – decrease residual load which has to be met on the conventional markets (see also Sensfuss et al. (2007)).

[5] The figures for the trend in generation capacities are based on existing capacities, approved new capacities, decommissioning of nuclear according to IAEA and a limited lifetime of fossil plants of 40 years. Load forecast is based on an earlier study of the authors.

[6] In 2005, on the Czech Austrian border 60-70% of interconnector capacity was reserved for long-term contracts (EC, 2007).

[7] See www.auction-office.at for results of cross-border auctions at the Austrian borders.

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