The Relevant Market for Production and Wholesale of Electricity in the Nordic Countries: An Econometric Study*

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Abstract

We apply cointegration analysis to daily averages of Nord Pool prices covering the period 2001-2007 in order to empirically characterize the geographical dimension of the relevant market for production and wholesale of electricity. We reach the following econometric conclusions: (*i*) price areas Finland, Sweden and Norway 3 unambiguously belong to the same relevant market, (*ii*) Denmark 2 belongs to this same market except for the subsample 2004-2007, (*iii*) Norway 1 and Denmark 1 define separate markets on their own. We find that the stochastic trends in Nord Pool prices originate in countries abundant in capacity to generate hydro power.

Key words: Geographical market definition; Nord Pool; international transmission capacity; electricity prices; cointegration

JEL Classification: L94; L40; C32

I Introduction

Theoretical analysis in economics typically refers to the market as if its definition were self-evident. However, the implementation of competition law always requires that the relevant

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market is defined in a careful and systematic way. In this study we present an econometrically founded analysis of how to geographically define the relevant market with respect to production and wholesale of electricity in the Nordic countries. Do the seven price areas within Nord Pool, i.e. Finland, Sweden, Norway 1, Norway 2, Norway 3, Denmark 1 and Denmark 2, define separate relevant markets?[1] In particular, are the relevant markets national or is the relevant market perhaps so extensive so as to capture all the price areas in Nord Pool?

On a fundamental level, competition policy targets structural market imperfections with long-run effects. Consistent with this general perspective, a standard approach in European competition law for how to define the relevant market is the SSNIP test ("Small but Significant Non-transitory Increase in Price"). This test essentially asks whether a customer would switch to a competitor if confronted with a small but significant and persistent increase in price. The criterion of permanency or persistence should reasonably be determined in light of the prevailing mode of competition so as to match industry-specific factors, such as the required time to observe rivals' prices, to implement price responses, and possibly also to conduct capacity adjustments. The time required for unconstrained competition to discipline a price set above a level consistent with competition defines a lower bound for the horizon, below which an intertemporal definition of the relevant market would not be meaningful.

The crucial question when applying the SSNIP test to a Nord Pool price area is the following: Could a hypothetical firm with sufficiently strong market power in this price area profitably impose a non-transitory 5-10% price increase without being challenged by competition from Nord Pool producers located outside this price area? This issue is closely related to the empirical significance of restrictions (bottlenecks) in transmission capacity between areas, since the design of Nord Pool implies that prices across areas are equalized if there are no such bottlenecks.

From a strictly theoretical point of view the relevant geographic market should be determined on the basis of estimates of cross elasticities of demand across different price areas as well as estimates of marginal costs. However, such an approach typically imposes overly severe data restrictions for the purpose of antitrust implementation. For this reason the litera-

[1] When presenting the data in subsection IV we characterize these price areas more precisely.

ture has developed a number of empirical approaches that exploit the time series properties of area-specific prices as the basis for the definition of the geographical dimension of the relevant market. Prominent examples in this respect include Horowitz (1981), Slade (1986), Spiller and Huang (1986) and Uri and Rifkin (1985). These empirical approaches capture the basic idea that arbitrage will prevent prices in different price areas from moving independently of each other if these price areas belong to the same relevant market (Stigler and Sherwin (1985)). More recently, Walls (1994), Forni (2004) and Haldrup et al. (2008) have incorporated the notion of persistence associated with the SSNIP test into these price-based approaches by interpreting the market definition as implying cointegration between prices within the same relevant market.[2]

In this article, we apply a general cointegrated system approach to characterizing market delineation among Nord Pool price areas, using daily averages covering the period 2001-2007. The system approach is particularly valuable in that potentially conflicting results from mutually pairwise tests can be avoided. From a methodological point of view, Haldrup et al. (2008) is closely related to our study as they investigate the relevant market for salmon using a cointegrated system.[3] As a particular methodological novelty, we use a representation of the common stochastic trends to reduce the number of sequential tests needed for complete market delineation. Moreover, we test weak (long-run) exogeneity in order to explore whether the common stochastic trend originates in one particular area relative to the others within the same relevant market.

Our findings suggest that Nord Pool price areas Finland, Sweden and Norway 3 unambiguously belong to the same relevant market. The evidence also indicates that Denmark 2 belongs to this same market, but this result is sensitive to variations in the time horizon. Norway 1 and Denmark 1 define separate markets of their own. We also find that the common stochastic trends in Nord Pool prices originate in the Norwegian price areas. This suggests that price areas with a large capacity for generating hydro power tend to act as price leaders relative to other areas.

[2]A comprehensive review of price-based tests of market delineation can be found in Haldrup (2003).

[3]Haldrup et al. (2008) focus on both the product and geographical dimensions and compare a procedure with simultaneous market delineation with that of a sequential one.

The promotion of competition and efficiency in the European electricity markets has been a strong policy priority for the European Commission. Operational criteria for how to define a relevant market in a geographical sense serve as a precondition for economic assessments of the electricity industry regardless of whether a merger case or a case focusing on potential abuse of market dominance (Article 82) is evaluated (see, for example, Vandezande et al. (2006)). In its recent sector inquiry on the gas and electricity industries the European Commission (2007) presents a detailed discussion of the relevant market for production and wholesale of electricity in the Nordic countries. Relatedly, in the Sydkraft/Graninge[4] case the European Commission concludes: "…it is clear that Sweden has only constituted a separate geographic area during an insignificant period of time in each of the last years. At the same time the price correlation between Sweden and Finland and Sweden and Denmark seems to imply that the generation /wholesale market is likely to be larger than Sweden" (see, § 27 of the decision).

The geographical dimension of the relevant market for production and wholesale of electricity has also been subject to decisions at the national level in the Nordic countries. In a decision concerning Sweden and dated 7 May 2007, the Swedish Competition Authority concludes that the relevant market for production and wholesale of electricity is Nordic, or at least larger than the national market. In its 2006 evaluation of the recent acquisition of E.ON Finland by Fortum Power and Heat Oy, the Finnish Competition Authority (FCA) reached a different conclusion. It seemed to suggest an intertemporal separation according to which the relevant market would be the national Finnish market in phases when bottlenecks occur in the transmission of electricity between Finland and Sweden, whereas the relevant market would include both countries when such bottlenecks are not an issue. However, the definition of the relevant market suggested by the FCA was rejected by the Finnish Market Court in its ruling dated 14 March 2008. According to the Market Court, the relevant geographical market area consists of at least Finland and Sweden.

This paper is organized as follows. In Section II we present a cointegration-based approach for how to define the relevant market. The statistical model is presented in Section III. In Section IV we apply our econometric approach to daily averages of Nord Pool prices during the

[4]Case No COMP/M.3268 (30.10.2003).

period 2001-2007. In Section V we evaluate the policy option of an intertemporal separation in the definition of the relevant market. Section VI concludes.

II An Econometric Approach to Market Delineation

Within a market operating under conditions of competition, the demand faced by one firm is dependent on the prices set by the other firms. This interconnectivity of demands implies that exogenous shocks, even if they are firm-specific, trigger price reactions among all firms in the market. In other words, prices in the same market internalize the same set of shocks and cannot, therefore, persistently deviate from (some) market equilibrium. Such deviations can survive only as a temporary phenomenon, which implies that the observed prices within the same relevant market should display a high degree of correlation. This feature can be exploited for empirical market delineation. However, prices in separate markets can also display a high degree of correlation due to, for instance, common exogenous factors.[5] Hence, a high degree of correlation between prices alone is not, in general, sufficient to delineate markets. Market delineation requires that prices be highly correlated even when all exogenous factors have been taken into account. In addition, there should be no significant deterministic deviations between prices.[6]

In a non-stationary price environment, the condition placed on the evolvement of prices belonging to the same market is more stringent: the prices must share the same stochastic trends in the same relative proportions, i.e. they must be cointegrated. If they are not, permanent deviations between them are possible. Such a feature would be inconsistent with equilibrium under conditions of interconnected demands, and would also violate the persistency requirement of the SSNIP test. In contrast, even in the unlikely case where prices in separate markets share precisely the same stochastic trends, there is no reason why the composition of these trends should be proportional. Hence, prices in separate markets will not, in general, be cointegrated.

[5]For example, consider the price of flight tickets and taxi fares in the face of an oil price shock.

[6]There is no objective benchmark as to what constitutes a significant deterministic deviation with respect to market delineation. For example, in some cases a significant difference in the mean of the prices may be sufficient for them to belong to separate markets (*e.g.* homogeneous goods markets), whereas this may not be sufficient in other cases.

Specifically, let the (logs of) prices in areas i and j behave according to

$$\begin{aligned} p_{i,t} &= c_i' \sum_{h=1}^{t} \varepsilon_h + c_i^{*\prime}(L)\varepsilon_t, \\ p_{j,t} &= c_j' \sum_{h=1}^{t} \varepsilon_h + c_j^{*\prime}(L)\varepsilon_t, \end{aligned}$$

where $\varepsilon_t = (\varepsilon_{1t}, ..., \varepsilon_{wt})'$ is a vector of w exogenous shocks, c_i and c_j are parameter vectors, and $c_i^*(L)$ and $c_j^*(L)$ are vector polynomials in the lag operator, L, with all roots outside the unit circle. The first right-hand term in each equation captures permanent price shocks, whereas the second term captures transient shocks.[7] A necessary condition for areas i and j to belong to the same market is that $c_i = \lambda c_j$, where $\lambda \neq 0$ is a scalar. This means that the permanent shocks enter prices proportionally. If this condition holds, prices are cointegrated with cointegration vector $\beta = (1, -\lambda)'$, whereas they differ by a stochastic trend otherwise. This condition holds trivially when prices are stationary. When prices are non-stationary it constitutes a significantly more stringent requirement for market delineation than merely requiring a high degree of price correlation. In fact, the cointegration condition enables market delineation without first accounting for all common exogenous long-run shocks, since it restricts the underlying shock structure.

Cointegration does not require that $\lambda = 1$. For example, λ may very well differ from unity if the products are not perfect substitutes (see Haldrup et al. (2008)). However, if the products are perfect substitutes the price areas define the same market only if $c_i = c_j$, implying the cointegration vector $\beta = (1, -1)'$. In this case, long-run price homogeneity is said to hold. Walls (1994) applies precisely this pairwise condition to all areas in his sample when characterizing the relevant geographical market for the U.S. natural gas industry.[8] In this study we advocate the general view that cointegrated price series constitute a necessary condition for two areas to define the same market. The acceptable deviation from unity in the proportion of

[7] In the present paper we limit the discussion to $I(1)$ trends, although the general framework can easily be extended to higher order stochastic trends. To ensure applicability we also tested the Nord Pool price data for the presence of $I(2)$ trends using the test described in Johansen (1996). We found no evidence of $I(2)$ trends in the data. These results are available upon request.

[8] Related conditions for both product and geographical market delineation are tested in Horowitz (1981) and Forni (2004).

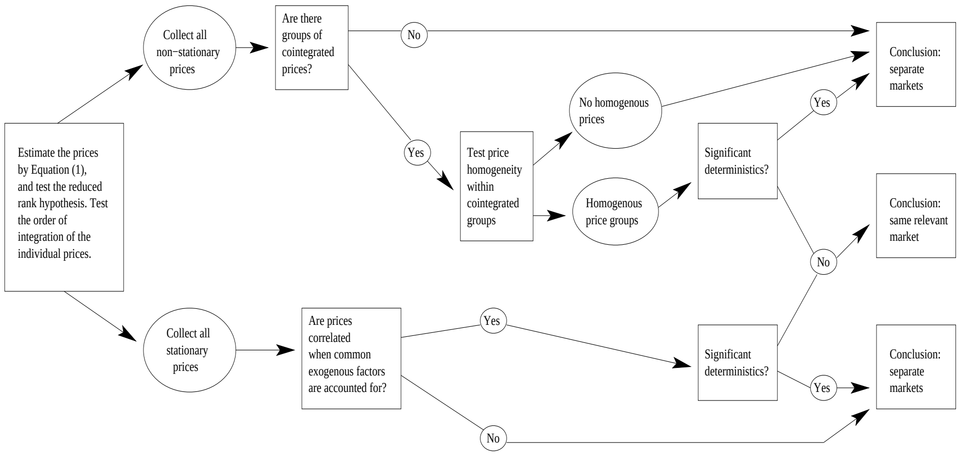

Figure 1: Flow chart of the econometric procedure.

the loadings is industry-specific and determined by the degree of substitutability between the products.

In the case of homogeneous goods and difference-stationary prices, the issue of market delineation can be econometrically broken down into three separate questions.

(i) Can we reject the hypothesis of cointegration between the prices?

(*ii*) Can we reject the hypothesis of long-run price homogeneity?

(*iii*) Are there significant deterministic differences between the prices?

If the answer to any of these questions is affirmative, we must reject the hypothesis that the firms belong to the same relevant market. If, on the other hand, the answer to all questions is negative, we conclude that the firms belong to the same relevant market. Figure 1 summarizes this econometric procedure for defining the relevant market in a logical sequence of steps. (In the figure, the stationary case is included for completeness.) We apply this procedure in Section IV.

III The Statistical Model

The implementation of the econometric approach outlined in the previous section requires a statistical framework for analyzing the integration and cointegration properties of a vector of prices. A natural choice is the vector auto-regressive (VAR) model in error correction form

$$\Delta X_t = \sum_{i=1}^{k-1} \Gamma_i \Delta X_{t-i} + \Pi X_{t-1} + \Psi D_t + \varepsilon_t, \tag{1}$$

where k is the lag-length, D_t is a $p \times f$ matrix that collects the deterministic components, and $\varepsilon_t \sim N_p(0, \Sigma)$. The parameter matrices are Γ_i, Π, Ψ, and Σ respectively.

Cointegration in (1) can be tested by the likelihood ratio (LR) test for the rank of Π (Johansen (1996)). If the rank, r, is equal to p, then X_t is stationary, i.e. $X_t \sim I(0)$. If $0 < r < p$, then $X_t \sim I(1)$ is cointegrated with r cointegration vectors and $p - r$ common trends. In this case, $\Pi = \alpha\beta'$, where α and β are two $(p_1 \times r)$ matrices of full column rank and $\beta' X_{t-1}$ describes the cointegration relationships. If $r = 0$, then $X_t \sim I(1)$ and the process is not cointegrated. A testing sequence that ensures correct power and size starts from the null hypothesis of rank zero and then successively increases the rank by one until the first non-rejection.

Given $0 < r < p$, general linear hypotheses on β can be tested in the form

$$\mathcal{H}_\beta : \beta = (H_1\varphi_1, ..., H_r\varphi_r), \tag{2}$$

where $H_i(p \times (p - m_i))$ imposes m_i restrictions on β_i, and $\varphi_i((p - m_i) \times 1)$ consists of $p - m_i$ freely varying parameters. The likelihood ratio test of the hypotheses is asymptotically χ^2. Two linear hypotheses are particularly interesting from the perspective of market delineation. Firstly, is the g:th element of X_t stationary? Secondly, is the proportion of the stochastic trends between the g:th and f:th elements of X_t unity? The former hypothesis can be formulated by setting H_1, say, to be a unit vector, e_g, while leaving the remaining cointegration relationships unrestricted. The latter hypothesis can be formulated by setting $H_1 = e_g - e_f$, while again leaving the remaining cointegration relationships unrestricted. The joint hypothesis of long-run price homogeneity between $n \in \{2, ..., r+1\}$ elements of X_t can be formulated in an similar way using $H_i = e_{g_i} - e_{g_{i+1}}$, where $i = 1, ..., n-1$ and g_i indicates the elements of the group.

Another hypothesis of special interest is whether one or several rows in α consist of zeros, which can be tested in the same way as linear hypotheses on β. A variable with a zero row in α is said to be weakly exogenous. A weakly exogenous variable generates a common stochastic trend, but it is not affected by the other stochastic trends in the system. In this sense, a weakly exogenous variable can be viewed as a forcing variable in the long run.

When $p > 2$, it will sometimes be more convenient to obtain a representation of the $p-r$ common stochastic trends rather than the stationary relations β. The reason is that the common trends representation contain the same statistical information as α and β, but relieves us from testing $p(p-1)/2$ cointegrating combinations between the prices. Instead, the cointegrating combinations can be directly read from the common trends representation. Given $0 < r < p$, the inverse of (1), provided by the Granger-Johansen representation theorem is

$$X_t = C\sum_{i=0}^{t-1}(\varepsilon_i + \Psi D_i) + C(L)(\varepsilon_t + \Psi D_t) + X_0, \tag{3}$$

where $C = \beta_\perp\left(\alpha'_\perp\left(I - \sum_{i=1}^{k-1}\Gamma_i\right)\beta_\perp\right)^{-1}\alpha'_\perp$, $C(L)$ is a stationary matrix lag-polynomial with zeros outside the unit circle, X_0 summarizes the initial condition, and $\alpha_\perp$ and $\beta_\perp$ denote the orthogonal complements to α and β. The matrix $\alpha'_\perp$ exhibits the common stochastic trends, whereas $\beta_\perp\left(\alpha'_\perp\left(I - \sum_{i=1}^{k-1}\Gamma_i\right)\beta_\perp\right)^{-1}$ provides the loadings of the common stochastic trends into each element of X_t.

IV Application to Nord Pool price data

In this section we apply the econometric approach to price data from the Nordic market for production and wholesale of electricity, Nord Pool. Within a given Nord Pool price area, wholesale prices of electricity are perfectly equalized among firms. Thus market delineation within Nord Pool primarily involves comparisons between price areas.[9]

Data, Frequency and Averaging

The data consists of hourly observations of prices from the following Nord Pool price areas: Finland, Sweden, Norway 1 (South Norway, the Oslo area), Norway 2 (mid-Norway, the Trondheim area), Norway 3 (North Norway, the Tromsö area), Denmark 1 (East Denmark, the

[9] On a general level Amundsen and Bergman (2007) have argued that the Nordic wholesale markets are well integrated. They conclude that no significant differences exist between area prices, except for during periods with an exceptional supply of hydro power.

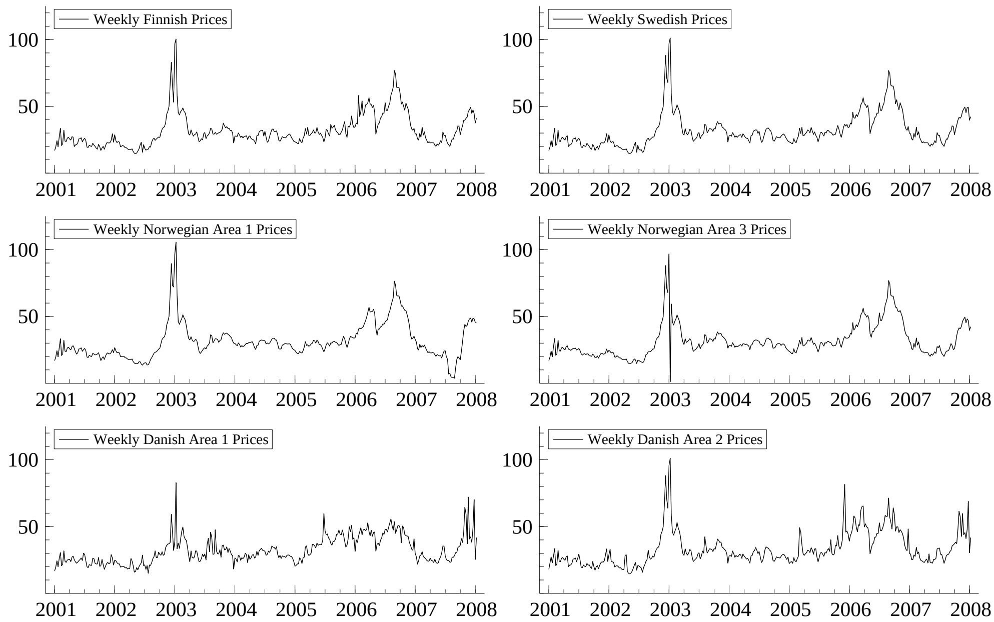

Figure 2: Weekly price averages (in Euro/MWh) for Nord Pool price areas Finland, Sweden, Norway 1, Norway 3, Denmark 1 and Denmark 2.

Copenhagen area), and Denmark 2 (West Denmark, the Odense area). Due to the almost complete correlation between Norway 2 and Norway 3, we only consider Norway 3 in the analysis in order to avoid severe multicollinearity problems.[10] The price observations cover the period 2001:01:01:00-2007:12:31:23, which means that the sample consists of 61337 observations in total. Figure 2 depicts the area-specific prices (using weekly averages to facilitate the exposition). Table 1 presents descriptive evidence on price convergence between the Nord Pool price areas for the period 2001-2007. The table shows that the correlation between price areas Finland, Sweden, and Norway 3 is typically very high, above 0.9, whereas the correlation between the Danish areas and the other price areas is much lower, between 0.5-0.7. Moreover, the correlation is generally higher for neighboring areas compared to areas located further apart. A similar pattern is visible in the means of the price differences.

The large number of observations associated with the hourly frequency increases the power of virtually all statistical tests (see, for example, Otero and Smith (2000)), which is beneficial as long as size remains unaffected. However, with hourly observations it is difficult to account

[10]The correlation between prices in Norway 2 and Norway 3 is 0.998. Moreover, price data on Norway 2 is not available until 2003:07:23:00.

Correlations, Means of Prices and Price Differences							
		Fin	Swe	Nor1	Nor3	Dk1	Dk2
	$\bar{p}_i$				$\overline{p_i - p_j}$		
Fin		31.72	-0.158	0.259	-0.249	-0.490	-1.508
Swe		0.957	31.88	0.417	-0.091	-0.332	-1.349
Nor1		0.881	0.929	31.46	-0.507	-0.748	-1.766
Nor3	$\rho(p_i, p_j)$	0.931	0.974	0.958	31.97	-0.241	-1.259
Dk1		0.560	0.561	0.493	0.527	32.21	-1.018
Dk2		0.671	0.690	0.624	0.661	0.616	33.23

Table 1: Correlations, means of prices, and means of price differences for Nord Pool price areas (in Euro/MWh). The lower left half of the table shows the correlation between the area in column i and row j, denoted by $\rho(p_i, p_j)$. The upper right half shows the arithmetic mean of the price difference between area i and j, denoted by $\overline{p_i - p_j}$, whereas the diagonal shows the arithmetic mean of area i.

for all symmetric additive outliers in the price series potentially caused by exogenous events.[11] Such additive outliers tend to create a bias towards cointegration or even stationarity (see Bohn Nielsen (2004) and Franses and Haldrup (1994)). This could be problematic if one wants to avoid defining markets too broadly.

Temporal averaging offers a potential solution to this problem since it preserves the integration and cointegration properties (see, Marcellino (1999)) of the data, while it makes the problem with outliers manageable. For this reason, we will mainly conduct our analysis with daily averages. The number of observations for each price area at the average daily frequency is 2556. However, we have conducted robustness checks with weekly and monthly averages. We also experimented by letting one (peak) hour represent each daily observation. The results obtained by these robustness checks were not substantially different and are available upon request.[12]

Generally speaking, the area prices are to a large extent equalized, as can be seen in Figure 3. When differences between area prices occur, they are typically one-sided with some extreme outliers. This suggests that the price differences may not be perfectly modeled with linear processes. More elaborate alternative ways of modeling electricity prices can be found in Haldrup and Ørregaard Nielsen (2006) and Koopman et al. (2007), among others. The former

[11]In general, it is almost impossible to distinguish from the data whether the source of extreme price realizations is exogenous or endogenous. Presumably, the only way to make such distinctions is to investigate the particular incidents in detail. For example, the price outliers dated 19 January 2006 and 11 June 2007 were both caused by Svenska Kraftnät's maintenance service of the power system, and thereby were clearly exogenous in nature.

[12]Some additional results are reported in Juselius and Stenbacka (2008).

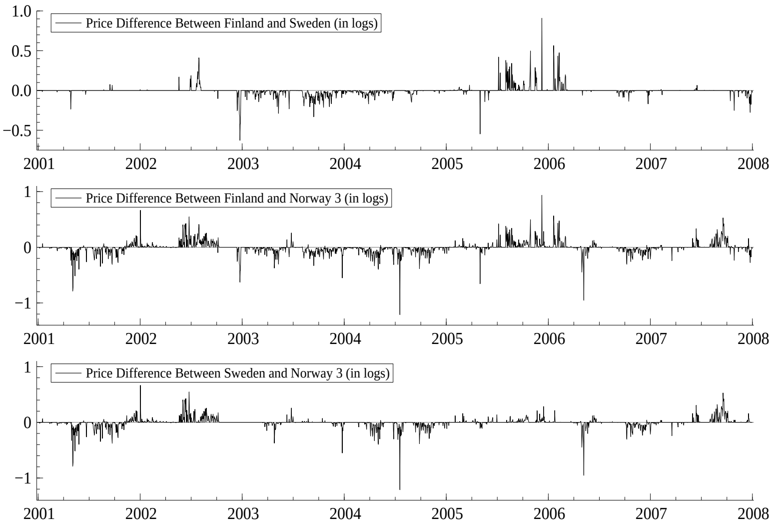

Figure 3: Differences between area prices in Finland, Sweden and Norway 3 (in logs).

apply a long memory regime-switching model to separate periods when prices are perfectly equalized from periods in which prices are not equalized. They find that the regime-switching models outperform alternative models for forecasting purposes. Koopman et al. (2007) estimate the relative importance of regression effects, periodicity, long memory and volatility in electricity prices within a periodic seasonal Reg-ARFIMA-GRACH model. Although these approaches undoubtedly offer improvements in terms of model fit and forecasting, the cointegration approach adopted in our paper seems to be sufficient for market delineation. The reason is that empirical market delineation primarily requires estimates of the long-run components of the price series, whereas detailed descriptions of short-run adjustments, such as periodicity and volatility, seem less important.

Empirical market delineation of Nord Pool price areas

We apply the procedure outlined in Section II to (the logs of) the Nord Pool area-specific prices (excluding Norway 2), denoted by p_t^{FIN}, p_t^{SWE}, p_t^{NOR1}, p_t^{NOR3}, p_t^{DK1} and p_t^{DK2}, respectively. We report the results from the full sample, the latter-half sample (2004-2007), and the full sample excluding year 2007 (i.e. the sample 2001-2006).[13] We do not report individual years, but emphasize that the yearly samples follow similar patterns. The reason for separately

[13]The results from the first-half sample (2001-2003) are very similar to those obtained from the sample 2001-2006 and hence are not reported in order to conserve space.

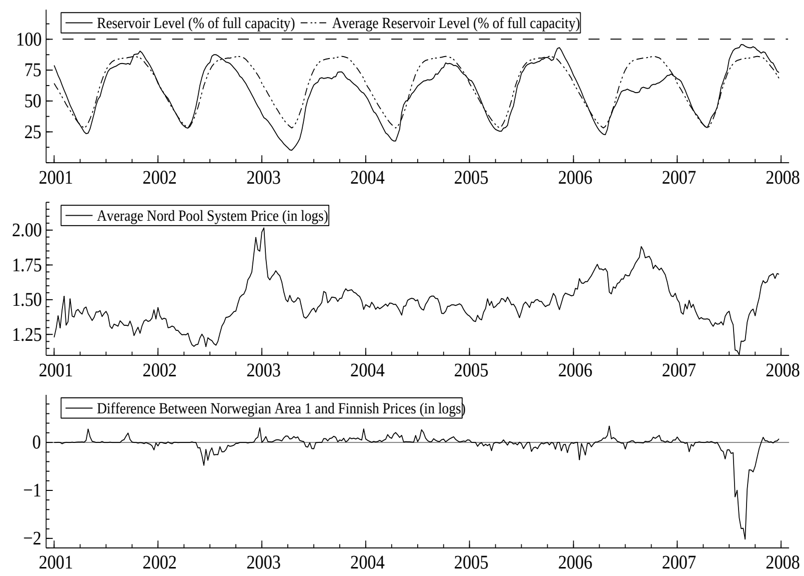

Figure 4: Norway 1 hydro reservoir content (% of full capacity) compared to the average level for 1990-2000 (upper panel), the (log) average Nord Pool system price (middle panel), and the difference (in logs) between the area prices in Norway 1 and Finland (lower panel).

reporting the results excluding year 2007 is that the hydro reservoir level in Norway 1 was exceptionally high in 2007, thus inducing a very high supply of electricity generated by hydro power in order to avoid waste. This production exceeded the export transmission capacity of Norway 1, thereby leading to substantially lower prices in this area compared to the other Nord Pool areas (see Figure 4). Thus excluding 2007 from the full sample as a separate case allows us to assess the effect of this particular year on the overall results.

The price series were modeled by (1), where a trend was included in the cointegration space. We added 6 centered seasonal dummies to account for daily seasonal variation within the week, and 11 centered seasonal dummies to account for monthly seasonal variation within the year. Initial results indicated that 32 additional dummy variables are needed to account for additive outliers that affected at least two or more areas *symmetrically*.[14] These outliers *do not* reflect any significant and systematic price differences between the affected areas.

The choice of lag-length, k, was based on the Schwarz and Hannan-Quinn information criteria which indicated that between 4 and 7 lags are needed in order to account for the variation in the data. We chose a lag structure with 7 days to capture potential systematic weekly patterns. However, any lag k above 4 days yields virtually identical results as those reported

[14]The initial analysis also revealed a number of idiosyncratic shocks to all price series. These were not blocked out by dummy variables.

The LR test for the rank of Π						
	$r=0$	$r=1$	$r=2$	$r=3$	$r=4$	$r=5$
Full sample, 01-07	0.000	0.000	0.000	0.000	0.003	**0.437**
Half sample, 04-07	0.000	0.000	0.000	0.000	**0.187**	**0.734**
Full sample, 01-06	0.000	0.000	0.000	0.000	0.000	**0.682**

Table 2: The likelihood ratio test for cointegration rank between Nord Pool prices. The numbers are p-values of the null hypothesis of the ranks given in the columns. Bold numbers indicate non-rejection at the 5% significance level.

below. Further, the seasonal dummies accounting for monthly variation were all insignificant, and therefore were excluded.

The likelihood ratio test for the rank of Π is shown in Table 2. The table indicates that the rank in the full sample is five, whether 2007 is excluded or not. This implies that all non-stationary Nord Pool prices are cointegrated, because they share the same stochastic trend. Moreover, there were no significant deterministic long-run deviations between the price series. In particular, long-run exclusion of restricted linear trends and constants could not be rejected regardless of the sample or the choice of rank.[15] Hence, non-stationary area-specific prices cannot evolve independently of each other. In other words, each price area imposes competitive discipline on the others. Table 2 also shows that the rank is four in the half sample. Given that the area-specific prices are non-stationary, the case with a rank $r=4$ facilitates an interpretation according to which Nord Pool can be decomposed into at least two separate relevant markets. We demonstrate below that the additional unit-root originates in the exceptional conditions in Norway 1 during 2007.

Table 3 reports the results of testing stationarity on all area-specific prices in the samples. Table 3 shows that stationarity can be rejected for all area-specific prices, regardless of sample (time horizon) or choice of rank. Thus for 2001-2007 and 2001-2006 the prices in *all* Nord Pool areas are cointegrated. Furthermore, in 2004-2007 the Nord Pool area prices can potentially be divided into three groups according to whether they exclusively share one of the two stochastic trends or whether they contain both.

Table 3 also reports tests of weak exogeneity. Interestingly, p_t^{NOR3} is weakly exogenous in the full sample when 2007 is included, whereas p_t^{NOR1} is weakly exogenous when 2007 is

[15]These results are available upon request.

Tests of stationarity and weak exogeneity								
Sample	r	Test	p_t^{FIN}	p_t^{SWE}	p_t^{NOR1}	p_t^{NOR3}	p_t^{DK1}	p_t^{DK2}
Full sample, 01-07	5	Stat	0.000	0.000	0.000	0.000	0.000	0.000
		Exo	0.000	0.000	0.004	**0.532**	0.000	0.000
Half sample, 04-07	4	Stat	0.000	0.000	0.000	0.000	0.000	0.000
		Exo	0.000	0.000	**0.197**	**0.316**	0.000	0.000
Full sample, 01-06	5	Stat	0.000	0.000	0.000	0.000	0.000	0.000
		Exo	0.000	0.000	**0.112**	0.014	0.000	0.000

Table 3: Tests of stationarity and weak exogeneity of daily Nord Pool prices. The null hypotheses are that of stationarity and weak exogeneity, respectively, and the numbers are p-values of the null hypotheses. Bold numbers indicate non-rejection at the 5% significance level.

excluded. Both p_t^{NOR1} and p_t^{NOR3} are weakly exogenous in the half sample. These results suggest that Norway 1 acts as the price leader under normal conditions, like those prevailing when year 2007 is excluded. However, during the abnormal year 2007, when the export transmission capacity of Norway 1 was exceeded, the role of price leader was taken over by Norway 3. Under all circumstances, the two Norwegian areas serve as price leaders relative to all other Nord Pool price areas.

The system approach allows for simultaneous tests of long-run price homogeneity between two or more Nord Pool price areas. It seems natural to begin by conducting pairwise tests and to subsequently extend the tests by successively adding more areas. However, much effort can be saved by investigating the loadings of the common stochastic trends (see equation (3)) prior to formally testing price homogeneity, since price pairs that are very far from homogeneity are in this way easily detected.

Given the weak exogeneity results, we know that the common stochastic trends, $\alpha_\perp' \sum_{i=1}^t \varepsilon_i$, consist of the two Norwegian prices. We label these as $\sum_{i=1}^t \varepsilon_i^{NOR1}$ and $\sum_{i=1}^t \varepsilon_i^{NOR3}$, respectively. Table 4 reports the loadings to each trend. The table reveals that prices in the Nord Pool areas Finland, Sweden, Norway 3 and Denmark 2 have similar loadings in the full sample, 2001-2007. For instance the relative loading between Finland and Sweden is $c_{FIN}/c_{SWE} = 0.523/0.544 = 0.96$ (see Section II). Denmark 2 and Norway 3 have the smallest relative loading within this group, $c_{DK2}/c_{NO3} = 0.85$, which is rather far from unity. Norway 1 and Denmark 1 each have significantly different loadings from the rest. Based on these observations, the tests of long-run price homogeneity within the subset $\{p_t^{FIN}, p_t^{SWE}, p_t^{NO3}, p_t^{DK2}\}$ are

Stochastic trends and their loadings				
	Full sample, 01-07	Half Sample, 04-07		Full sample, 01-06
	$r=5$	$r=4$		$r=5$
	$\sum_{i=1}^{t}\varepsilon_i^{NOR3}$	$\sum_{i=1}^{t}\varepsilon_i^{NOR3}$	$\sum_{i=1}^{t}\varepsilon_i^{NOR1}$	$\sum_{i=1}^{t}\varepsilon_i^{NOR1}$
p_t^{FIN}	0.523 (4.250)	0.469 (6.568)	0.020 (0.793)	0.381 (4.969)
p_t^{SWE}	0.544 (4.250)	0.485 (6.709)	0.010 (0.388)	0.403 (4.969)
p_t^{NO1}	0.729 (4.250)	−0.182 (−1.243)	0.768 (14.530)	0.436 (4.969)
p_t^{NO3}	0.566 (4.250)	0.489 (6.487)	0.028 (1.027)	0413 (4.969)
p_t^{DK1}	0.335 (4.250)	0.221 (4.288)	0.116 (6.239)	0.191 (4.969)
p_t^{DK2}	0.489 (4.250)	0.381 (6.214)	0.039 (1.770)	0.355 (4.969)

Table 4: Loadings to the stochastic trends originating in the Norwegian price areas. The numbers in parenthesis are *t*-values.

Tests of price homogeneity in the sample 2001-2007			
$\{p_t^{FIN}, p_t^{SWE}\}$	$\chi^2(1)=6.43$ (**0.011**)	$\{p_t^{FIN}, p_t^{SWE}, p_t^{NO3}\}$	$\chi^2(2)=10.10$ (0.006)
$\{p_t^{FIN}, p_t^{NO3}\}$	$\chi^2(1)=6.31$ (**0.012**)	$\{p_t^{FIN}, p_t^{SWE}, p_t^{DK2}\}$	$\chi^2(2)=10.92$ (0.004)
$\{p_t^{FIN}, p_t^{DK2}\}$	$\chi^2(1)=3.09$ (**0.079**)	$\{p_t^{FIN}, p_t^{NO3}, p_t^{DK2}\}$	$\chi^2(2)=8.84$ (**0.012**)
$\{p_t^{SWE}, p_t^{NO3}\}$	$\chi^2(1)=2.07$ (**0.150**)	$\{p_t^{SWE}, p_t^{NO3}, p_t^{DK2}\}$	$\chi^2(2)=8.38$ (**0.015**)
$\{p_t^{SWE}, p_t^{DK2}\}$	$\chi^2(1)=6.51$ (**0.011**)	$\{p_t^{FIN}, p_t^{SWE}, p_t^{NO3}, p_t^{DK2}\}$	$\chi^2(3)=11.86$ (0.008)
$\{p_t^{NO3}, p_t^{DK2}\}$	$\chi^2(1)=6.62$ (**0.010**)		

Table 5: Tests of price homogeneity between Finland, Sweden, Norway 3 and Denmark 2 for the sample 2001-2007. The *p*-values are reported in parenthesis below the test statistic. Bold numbers indicate non-rejection of price homogeneity at the 1% significance level in the respective price areas.

reported in Table 5.[16] As the table shows, none of the pairwise tests were rejected at a 1% significance level, although several price pairs came close to rejection. For larger groups of prices, the only non-rejections occur for the subsets $\{p_t^{FIN}, p_t^{NO3}, p_t^{DK2}\}$ and $\{p_t^{SWE}, p_t^{NO3}, p_t^{DK2}\}$. However, long-run price homogeneity was rejected by a very narrow margin for the other subsets of prices. Overall, we view this evidence as supportive of price homogeneity between Finland, Sweden, Norway 3 and Denmark 2 in the full sample, 2001-2007.

For 2004-2007, Table 4 reveals that Finland, Sweden and Norway 3 share the same stochas-

[16]The homogeneity tests for other price pairs or groups were rejected. Detailed results are available upon request.

Tests of price homogeneity in the sample 2001-2006			
$\{p_t^{FIN}, p_t^{SWE}, p_t^{NO1}\}$	$\chi^2(2) = 15.78$ (0.000)	$\{p_t^{SWE}, p_t^{NO3}, p_t^{DK2}\}$	$\chi^2(2) = 6.86$ (**0.033**)
$\{p_t^{FIN}, p_t^{SWE}, p_t^{NO3}\}$	$\chi^2(2) = 7.31$ (**0.026**)	$\{p_t^{NO1}, p_t^{NO3}, p_t^{DK2}\}$	$\chi^2(2) = 19.90$ (0.000)
$\{p_t^{FIN}, p_t^{SWE}, p_t^{DK2}\}$	$\chi^2(2) = 8.87$ (**0.012**)	$\{p_t^{FIN}, p_t^{SWE}, p_t^{NO1}, p_t^{NO3}\}$	$\chi^2(3) = 19.19$ (0.000)
$\{p_t^{FIN}, p_t^{NO1}, p_t^{NO3}\}$	$\chi^2(2) = 18.19$ (0.000)	$\{p_t^{FIN}, p_t^{SWE}, p_t^{NO1}, p_t^{DK2}\}$	$\chi^2(3) = 16.61$ (0.001)
$\{p_t^{FIN}, p_t^{NO1}, p_t^{DK2}\}$	$\chi^2(2) = 16.57$ (0.000)	$\{p_t^{FIN}, p_t^{SWE}, p_t^{NO3}, p_t^{DK2}\}$	$\chi^2(3) = 9.03$ (**0.029**)
$\{p_t^{FIN}, p_t^{NO3}, p_t^{DK2}\}$	$\chi^2(2) = 6.98$ (**0.031**)	$\{p_t^{FIN}, p_t^{NO1}, p_t^{NO3}, p_t^{DK2}\}$	$\chi^2(3) = 20.05$ (0.000)
$\{p_t^{SWE}, p_t^{NO1}, p_t^{NO3}\}$	$\chi^2(2) = 14.79$ (0.001)	$\{p_t^{SWE}, p_t^{NO1}, p_t^{NO3}, p_t^{DK2}\}$	$\chi^2(3) = 20.32$ (0.000)
$\{p_t^{SWE}, p_t^{NO1}, p_t^{DK2}\}$	$\chi^2(2) = 14.87$ (0.001)	$\{p_t^{FIN}, p_t^{SWE}, p_t^{NO1}, p_t^{NO3}, p_t^{DK2}\}$	$\chi^2(4) = 21.34$ (0.000)

Table 6: Tests of price homogeneity between Finland, Sweden, Norway 1, Norway 3 and Denmark 2 for the sample 2001-2006. The *p*-values are reported in parenthesis below the test statistic. Bold numbers indicate non-rejection of price homogeneity at the 1% significance level in the respective price areas.

tic trend with similar loadings. Denmark 2 shares the same stochastic trend with these areas, but with a significantly different loading. The price in Norway 1 develops according to a separate stochastic trend, whereas Denmark 1 shares both these stochastic trends. The joint test of price homogeneity between the prices in Finland, Sweden and Norway 3 generate $\chi^2(2) = 7.37$ and a *p*-value of 0.025, i.e., a non-rejection of price homogeneity at the 1% significance level. Thus we can draw the conclusion that these three areas belong to the same relevant market in the half sample.[17]

Table 4 reveals that the price in Denmark 1 has a significantly different loading from other prices in the sample covering 2001-2006. Accordingly, Table 6 reports the results from testing price homogeneity in all groups of three or more Nord Pool prices from the set $\{p_t^{FIN}, p_t^{SWE}, p_t^{NO1}, p_t^{NO3}, p_t^{DK2}\}$, which excludes Denmark 1. Interestingly, Table 6 reveals that price homogeneity *cannot be rejected* in any such group which excludes the price in Norway 1. On the other hand, price homogeneity *is always rejected* in all groups containing the price in Norway 1. Thus we have reason to draw the conclusion that Nord Pool price areas Finland, Sweden, Norway 3 and Denmark 2 belong to the same relevant market in the sample 2001-2006.

[17] Pairwise tests between these prices support this conclusion. Price homogeneity was rejected for all combinations between p_t^{DK1} or p_t^{NO1} and other prices. These results are available upon request.

There seems to be a strong empirical relationship between Nord Pool system prices and deviations of the Nordic (mostly Norwegian) hydro reservoir levels compared with the norm for the year. More precisely, strong reductions of the reservoir level relative to the norm for the year seem to have driven the visible incidents of price increases since 2001 (see Figure 4).[18] Due to restrictions in transmission capacity between price areas, this price effect is stronger in areas with a higher proportion of hydro power.[19] The price effects are weaker for areas not directly connected to Norway or for areas with a low transmission capacity for imports from Norway. The pattern is clearly visible in Table 4, where the relative loadings to the stochastic trends are highest for the Norwegian areas, followed successively by Sweden, Finland, and Denmark. This also seems to explain the instances and patterns of deviation from complete price homogeneity. Interestingly, these results bear resemblance to the result obtained by Walls (1994) concerning the effects of pipeline bottlenecks on prices in the U.S. natural gas industry.

To summarize, we can report the follow findings. (*i*) All area-specific prices are difference-stationary. (*ii*) During time horizons 2001-2007 and 2001-2006, the prices in the Nord Pool areas Finland, Sweden, Norway 3, and Denmark 2 share the same stochastic trends with relative loadings of unity, indicating that these areas belong to the same relevant market. (*iii)* During the time horizon 2004-2007 the price areas Finland, Sweden, and Norway 3 belong to the same relevant market, whereas areas Norway 1, Denmark 1, and Denmark 2 define separate markets on their own. (*iv*) There is a clear tendency for the price areas rich in hydro power to serve as price leaders relative to other areas in the same relevant market. Restrictions in international transmission capacity tend to generate higher price volatility in these areas relative to the other areas. During phases with normal hydro power conditions (the period 2001-2006), the stochastic trend in prices originates in price area Norway 1. However, if we include the year 2007, this role is taken over by price area Norway 3.

Some of the price areas in Nord Pool are also interconnected to geographic areas outside the Nordic countries. Strictly speaking, we have not investigated whether these interconnections could justify conclusions that the relevant markets extend beyond the borders of Nord

[18]This argument has also been advocated by, for example, Amundsen and Bergman (2007).

[19]Hydro power constitutes 98% of the electricity capacity in Norway, 48% in Sweden, 18% in Finland, and 0% in Denmark, at the end of 2006 (see Nordel annual report and Nord Pool).

Pool. From a purely econometric point of view the cointegration vectors are invariant to extensions in the information set. In other words, price series which are cointegrated based on Nord Pool price data are also cointegrated if prices from additional price areas outside of Nord Pool are added. Thus the relevant markets may potentially be more extensive, but not smaller, if price areas outside of Nord Pool are considered.[20]

V Bottlenecks in the Transmission Capacity between Finland and Sweden

As our analysis has made clear, the geographical market delineation within Nord Pool is closely related to the empirical significance of bottlenecks in the transmission capacity between different price areas. We now turn to a detailed investigation of bottlenecks in the transmission capacity between two particular price areas, namely Finland and Sweden. The export capacity from Sweden is in total 9210 MW, out of which 2230 MW is directed to Finland and 5780 MW to the other Nordic countries. Similarly, the export capacity from Finland is in total 2280 MW, out of which 1830 MW and 100 MW are to Sweden and the other Nordic countries, respectively. The total import capacities for Sweden and Finland are 9470 MW and 4240 MW, respectively. In particular, Finland's import capacity substantially exceeds its export capacity.

Figure 3 (upper panel) presents a coarse graphical representation of the frequency of those hours when the international transmission capacity has been insufficient to induce price equalization between Finland and Sweden. Table 7 presents a descriptive yearly account of the number and proportion of hours when there has been a bottleneck in the transmission capacity between Finland and Sweden. During the period 2001-2007 a price difference existed between Finland and Sweden for 11.47% of the hours. When a bottleneck occurred in the transmission capacity between Finland and Sweden the price difference has predominantly, for 9.35% of

[20] Data limitations impose severe restrictions on the possibilities to extend our study to price areas outside of Nord Pool. This is exemplified by the interconnection between Finland and Russia. In Russia there is no power exchange with price information comparable to Nord Pool. Delivery is based on bilateral contracts, and the associated prices are not observable. Furthermore, the interconnection between Finland and Russia currently only allows for imports to Finland, but no exports from Finland. Imports from Russia to Finland are in the order of magnitude 10-11 TWh/a, which could be compared with a yearly consumption of approximately 90 TWh/a in Finland.

Bottleneck Statistics (hours)								
	2001	2002	2003	2004	2005	2006	2007	2001-2007
$\#\{P_t^{FIN} > P_t^{SWE}\}$	30	262	0	0	739	227	44	1301
$\#\{P_t^{FIN} < P_t^{SWE}\}$	66	177	2561	2092	77	375	385	5733
$\#\{P_t^{FIN} \neq P_t^{SWE}\}$	96	439	2561	2092	816	602	429	7035
$\#\{P_t^{FIN} = P_t^{SWE}\}$	8663	8320	6198	6691	7943	8157	8330	54302
T	8759	8759	8759	8783	8759	8759	8759	61337
$\frac{\#\{P_t^{FIN} > P_t^{SWE}\}}{T}$	0.34%	2.99%	0.00%	0.00%	8.44%	2.59%	0.50%	2.12%
$\frac{\#\{P_t^{FIN} < P_t^{SWE}\}}{T}$	0.75%	2.02%	29.24%	23.82%	0.88%	4.28%	4.40%	9.35%
$\frac{\#\{P_t^{FIN} \neq P_t^{SWE}\}}{T}$	1.09%	5.01%	29.24%	23.82%	9.32%	6.87%	4.90%	11.47%
$\frac{\#\{P_t^{FIN} = P_t^{SWE}\}}{T}$	98.91%	94.99%	70.76%	76.18%	90.68%	93.13%	95.10%	88.53%

Table 7: Bottleneck statistics between Finland and Sweden. $\#\{\cdot\}$ denotes the number of the set and T is the total sample size.

the hours, been to the advantage of buyers in Finland.

With a definition of the relevant market as national, it would be logically inconsistent to refer to structural competition problems during bottleneck phases in the transmission of electricity between Finland and Sweden. The presence of bottlenecks is an issue unrelated to whether the Finnish (Swedish) market performs well as a national market given the constraints imposed by the national production technology. Bottlenecks constrain the ability to efficiently exploit the joint supply in the two countries, but do not imply any type of abuse of market power or other types of strategically induced distortions in the national markets. By logical necessity, arguments identifying the bottlenecks of electricity transmission between Finland and Sweden as the core of potential structural competition problems imply that the underlying relevant market incorporates at least Finland and Sweden. This inconsistency could potentially be reconciled by introducing an intertemporal separation of the relevant market into two phases: a phase where there is no congestion in the transmission of electricity between Finland and Sweden and a phase where there is congestion of interconnections between these countries.[21] In most markets such an intertemporal separation could not easily be applied, but the remarkable transparency of the Nord Pool market for electricity with prices determined regularly and with high frequency might at least theoretically make such an intertemporal separation possible. Apparently, the idea behind such an intertemporal separation could then be

[21] As pointed out in our introduction, such an intertemporal separation has been suggested by the Finnish Competition Authority.

that the behavior of a potentially dominant firm in Finland (Sweden) would not be constrained by the competitive dynamics of the Swedish (Finnish) market during those hours when there is congestion of interconnections.

Based on hourly area-specific prices, one can draw some further descriptive conclusions regarding the nature of the bottlenecks. The duration of bottlenecks has predominantly been very short, typically one hour or at most a few consecutive hours. There is no significant relationship between the hour of the day or the weekday and the incidence of a bottleneck. Furthermore, there is no evidence that the bottlenecks would occur more frequently during the winter months with the yearly regular peak in demand. Thus available data does not support the view of bottlenecks emerging as a demand-driven phenomenon. Instead, the variations in hydro inflow and the complexity associated with the intertemporal reservoir management together with other stochastic disturbances in the power generation or distribution seem to be the primary explanations for the emergence of bottlenecks. In view of our detailed bottleneck statistics it does not seem credible that the states with bottlenecks emerge in a way which is predictable to the market participants. Overall, in the light of our cointegration analysis, the frequency of bottlenecks is not sufficient to classify Finland and Sweden as separate markets.

An intertemporal separation in the definition of the relevant market would have far-reaching consequences for the implementation of competition law and for competition policy more generally. The same argument in support of an intertemporal separation of the definition of the relevant market could then be applied in all markets characterized by a combination of demand fluctuations and capacity constraints. Such a policy would easily give incentives for firms to establish excess capacity so as to avoid the risk of being accused of abusing a dominant position in a phase where a bottleneck occurs, i.e. a phase where demand exceeds the available capacity. For that reason, such a competition policy would induce distortions with excess capacity and thereby not promote efficient investments. In this respect such an intertemporal separation of the electricity market into an hour-by-hour market would most likely counteract the overall goal of competition policy as a structural microeconomic policy tool having the objective of promoting efficiency in the long run.

VI Concluding Comments

In this study we applied cointegration analysis to daily averages of hourly price observations during the period 2001-2007 in the Nord Pool price areas with the objective of empirically characterizing the geographical dimension of the relevant market for production and wholesale of electricity in the Nordic countries. We established econometrically that the price areas Finland, Sweden and Norway 3 unambiguously belong to the same relevant market. Furthermore, we found that the price area Denmark 2 belongs to this same market when evaluated over the periods 2001-2007 or 2001-2006, but defines its own market over the period 2004-2007. Norway 1 and Denmark 1 define separate relevant markets of their own for each of the time periods studied. We also found a clear tendency for the price areas rich in hydro power to serve as price leaders relative to other areas in the same relevant market. During normal hydro power conditions (the period 2001-2006), the stochastic trend in prices originates in price area Norway 1. However, if we include the year 2007, this role is taken over by price area Norway 3.

We presented detailed hourly statistics of bottlenecks in the international transmission capacity between Finland and Sweden in order to evaluate the competition policy option of an intertemporal separation in the definition of the relevant market into two phases depending on whether restrictions in the international transmission capacity prevents competition. We argued that such an intertemporal separation of the electricity market into an hour-by-hour market would most likely counteract the overall goal of competition policy to promote efficiency in the long run. In light of the econometric evidence such an intertemporal separation of the relevant markets is not consistent with the persistency requirements imposed by the SSNIP test.

In general, it is almost impossible to distinguish from the data whether the source of bottlenecks in the international transmission capacity is exogenous or endogenous, i.e. whether strategic behavior on behalf the producers generates these bottlenecks. The price-based cointegration approach is not able to distinguish between these exogenous and endogenous reasons. Presumably, the only way to distinguish bottlenecks emerging for exogenous reasons from those emerging for endogenous ones is to investigate the particular incidents in detail.

As Werden and Froeb (1993) emphasize, market delineations based on price correlation tests can reach erroneous conclusions if the correlation originates from common factors with no relationship to competitive forces. As stressed by Haldrup (2003), the cointegration approach applied in our study can be viewed as an econometric technique to minimize the risk of erroneous market delineations based on spurious correlations. Furthermore, as we have emphasized, the cointegration criterion imposes restrictions on the underlying structure of the long-run shocks, thereby making it robust to common exogenous factors. Coe and Krause (2008) recently conducted a simulation study to evaluate the performance of price-based tests of market delineation within the framework of a static oligopoly model with difference-stationary exogenous cost shocks. They found that cointegration tests cannot correctly determine the relevant markets when applied to their simulated data. However, due its static nature, their model does not ensure that the exogenous shocks enter prices within the same relevant market proportionally, implying that price differences can become infinitely large over time. Hence, their static model seems insufficient for evaluating the cointegration approach to market delineation.

The frequency of bottlenecks in the transmission of electricity between countries is largely determined by the capacity of interconnections between these countries. A proper structural assessment of the relevant market should not be restricted to past and present market performance, but should also take the likely and foreseeable future development of the relevant industry into account. In particular, the significance of the problem with bottlenecks should also be evaluated in light of existing commitments and plans for future capacity expansions of the interconnections between countries. Borenstein et al. (2000) present an interesting and relevant theoretical analysis, designed primarily with the Californian market in mind, of the transmission capacity necessary for two local markets to achieve the benefits of competition within the framework of an integrated market. It is also an overall goal of European energy policy to promote an expansion of international interconnections in order to ultimately create a European market for production and wholesale of electricity.

Discussions of international interconnection capacity are easily biased towards a view according to which higher interconnection capacity always generates benefits. However, it should be kept in mind that it is not socially optimal to establish such an extensive interconnection capacity that the probability for the emergence of a bottleneck would be reduced to zero. As always, the socially optimal capacity is determined by the condition that the expected marginal social benefit of an additional incremental unit of capacity is equal to its marginal social cost. Our characterization of the relevant markets within the framework of Nord Pool identifies those price areas for which an extended transmission capacity might have particularly high benefits. From an overall Nordic perspective high export transmission capacities from Norway seem particularly valuable, in light of our study.

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