Chapter 8
Power exchanges and market integration

While the focus of chapters 5, 6 and 7 is the power exchange spot market, i.e. power exchanges as national marketplaces, ignoring the question of market design, in this chapter and in chapters 9 and 10, we consider the role of power exchanges within the global design of a European electricity market, i.e. power exchanges as institutions. An important aspect of the creation of a common market is the opening up to competition of national electricity markets which are for most of them dominated by national monopolies. Since market structures in these markets are historically heavily concentrated in most European countries, the creation of a common market appears to be a good solution for diluting national market power. In this chapter we aim to test the level of market integration based on power exchanges prices. Two econometric analyses are done using power exchanges prices of major European electricity markets. The methodology used for estimating the level of market integration is described. Then an analysis based on simple price correlation is made. A second analysis is done to deal with the drawbacks of the above approach, using regression models. Finally, the empirical results are analyzed.

8-1 The creation of a common market

8-1-1 Introduction

The functioning of power exchanges as marketplaces defined for a limited area, mainly a national area, was analyzed in the previous chapters. However, keeping in mind the final objective of the European Commission is to create an integrated market international trade and a more generally European-wide market design needs to be considered (Smeers, 2001a). In such a context power exchanges can be considered as institutions that form part of the overall European market design. While in part 2 of the thesis the analysis focused on the functioning of electricity power exchanges as national market places, in this part the role of power exchanges within the general design of competitive wholesale electricity markets at the European level is analyzed. The clear objective of the liberalization process is "*to ensure that the implementation of the electricity directive does not result in 15 liberalized but separate and rather isolated electricity markets, thereby falling to create one common market*" (EC, 2002). The political and economical motives for the creation of a single European-wide electricity markets were presented in chapter 2. The purpose of this chapter is to test the existence of such integrated market, to do so we use power exchanges prices or more precisely the relationships between power exchanges' prices.

Spatial prices relationships constitute an important indicator for market integration. In economic theory, market definition is often based on such relationships. For instance, according to Cournot (1838) *"Economists understood by the term Market, not any particular market place in which things are bought and sold, but the whole of any region in which buyers and sellers are in such free intercourse with one another that the prices of the same goods tend to equality easily and quickly".* Similarly Stigler (1969) defines a market as an *"area within which the price of a good tends to uniformity allowances being made for transportation costs".* In practice, when analyzing price relationships price correlation is frequently used to determine whether two geographic areas are in the same economic market. In an integrated market, one would expect to find a high correlation between price levels. The concept of market integration is directly related to market efficiency. An efficient market is one where the prices always reflect all available information, hence the efficient market hypothesis implies that all publicly available information is fully reflected in prices at any location.

In this chapter we first discuss the limits of previous works on market integration. For this purpose we present in details the analysis of Bower (2002b) which can be considered to be a real primer on market integration in European wholesale electricity markets. Subsequently we discuss the limits of his analysis, which allow us to present the contribution of our work which represent a first attempt to estimate the level of market integration in 2002. Second, two econometric analysis are done using power exchange prices of five main European markets (UK, France, Germany, Netherlands, and Nordic countries). The first analysis is a simple price correlation analysis. Subsequently, due to the drawbacks of such an approach two others approaches, cointegration and regression analysis, are considered. Finally the results of our analysis are presented.

8-1-2 Previous analysis on market integration

Several studies in the literature have provided empirical evidences about market integration in Europe in different sectors. Amongst them a large number has been done for topics such as the European Monetary Union (Artis and Taylor, 1988; MacDonald and Taylor, 1991), the financial retails markets (Sander and Kleimeier, 2001; Schüler and Heineman, 2001) or natural gas (Asche *et al*, 2000). However, with the exception of Bower (2002b), little empirical work has been carried out with respect to the extent of the wholesale market for electricity in Europe. In this section we present the main findings and limits of the analysis of Bower (2002b) and present the contribution of our study.

The main results of Bower's analysis of European wholesale electricity prices in 15 locations by the end of 2001 are given in summary in table 8-1. Ten of these locations are within the Nordic countries area (zonal prices determined by Nord Pool for Finland, Denmark, Sweden and Norway[1]), one in UK, one in Spain, two in Germany and one in the Netherlands. Bower uses simple arithmetic daily prices averages. Two analytical techniques are used: simple correlation and cointegration.

Table 8-1: Main results of Bower's analysis

	Norway (Kristians)		Sweden (Stockholm)		Denmark (West)		Nord Pool (System)		UK (Pool/UKPX)		Spain (OMEL)		Germany (1) (EEX)		Germany (2) (LPX)	
	Cor	*Coi*	Cor	*Coi*	Cor	*Coi*	Cor	*Coi*	Cor	*Coi*	Cor	*Coi*	Cor	*Coi*	Cor	*Coi*
Norway	1	-														
Sweden	0,96	*-55,04*	1	-												
Denmark	0,78	*-27,02*	0,77	*-53,30*	1	-										
Nord Pool	0,99	*-159,2*	0,97	*-70,93*	0,78	*-26,53*	1	-								
UK	0,18	*-6,54*	0,19	*-7,25*	0,26	*-7,26*	0,18	*-6,78*	1	-						
Spain	0,29	*-1,33*	0,33	*-0,10*	0,37	*-2,38*	0,29	*-1,15*	0,4	*-1,1*	1	-				
Germany (1)	0,16	*-2,30*	0,20	*-4,15*	0,21	*-4,03*	0,19	*-2,91*	0,28	*-8,76*	0,26	*-9,05*	1	-		
Germany (2)	0,16	*-2,71*	0,25	*-4,78*	0,25	*-4,99*	0,19	*-3,26*	0,27	*-8,72*	0,34	*-8,3*	0,36	*-22,21*	1	-
Netherlands	0,14	*-2,49*	0,18	*-3,63*	0,22	*-5,78*	0,15	*-2,77*	0,26	*-5,42*	0,27	*-7,2*	0,60	*-14,61*	0,29	*-10,72*

Source: Bower (2002)

Note 1: Cor stands for correlation analysis, Coi for cointegration analysis
Note 2: Critical values for cointegration analysis are: 15 -3.944; 5% -3.363; 10% -3.064

The first contribution made by Bower was the development of a systematic and rigorous methodology for the analysis of wholesale spot prices in Europe. Based on wholesales prices provided by different "power exchanges"[2] this work represents a real primer regarding empirical evidences of market integration at the wholesale level. Such an analysis was not possible before 2001 as many organised wholesale markets did not start to operate until 2000 and 2001[3]. Bower's analysis reveals that there were significant prices differences between locations resulting in potential arbitrage opportunities. Bower concludes that within the Nord Pool area price correlation was high while correlation with other European market was low. Conversely, the prices in Spain were not correlated to other European electricity markets based on both techniques (correlation and cointegration). With regard to the other countries, UK, Germany and the

[1] See chapter 9 for details
[2] Except for Spanish market which cannot be considered as a power exchange (see chapter 2) and for the UK where data from the pool have been used until the 26th of March (UKPX started on the 27th of March)

Netherlands, Bower's conclusion is mitigated. Simple correlation analysis shows a very low level of correlation between these countries. However cointegration analysis shows relative cointegration between Germany, Sweden, Finland and Denmark and between Nord Pool, UK, Netherlands and Germany.

The second contribution of Bower's work is to show the inefficiency of the actual transmission pricing mechanism. Indeed by using the locational spot price model framework developed by Schweppe *et al* (1988)[4], he showed an important difference between theoretical prices of congestion and actual prices being charged by transmission system operators. The empirical evidences clearly shows large differences between prices in locations using explicit auctions for interconnector capacity while implicit auctions (Nord pool) appears to be quite efficient[5].

Finally the last part of Bower's analysis concerning the exercising of market power by generating firms and the solution suggested[6], although interesting, is less convincing. While the approach used (Lerner index) is certainly the most well recognised for its robustness, the estimation of generation costs is questionable (box 8-1). However for the purpose of this chapter we will not go into the details of the limits of the market power identification approach of Bower's analysis, here we will focus on the first part of Bower's work.

[3] See chapter 2
[4] See chapter 9
[5] This issue is discussed in details in chapter 9
[6] Breaking up dominant generators

Box 8-1: Limits of Bower's analysis with respect to market power

The first limit of the Bower's approach, found in the estimation of the Lerner index, is his use of the same generation cost for all countries (23,80$/MWh). Such an estimation overlooks the important differences between the generation cost structures in the countries studied. Norway relies almost exclusively on hydropower while Denmark in turn relies on conventional thermal power (Hjalmarsson, 2000). In contrast the market structure in generation for the UK, Spain and Germany is highly diversified with technologies ranging from nuclear, conventional thermal units, hydro plants and to less extent wind energy (Bergman *et al*, 1999). Finally the Netherlands relies mainly on gas-fired plants (Arentsen *et al*, 1997) which are strongly dependent on gas prices. Depending on type of generation, for instance on hydro conditions or on gas prices, generation cost between countries may vary widely. It is therefore not surprising that all the Lerner indexes for the Nordic countries are negative yet they are very high for the Netherlands. Bower argues that the 10 Euro/MWh range in mean locational prices *"is too wide to be explained by generation costs technologies"*, this is not totally true since the cost of a hydro plant and that of a gas power plant can easily exceed this range. Some differentiation in generation cost with respect to national generation structures is thus missing in Bower's work.

The second limit relates to using a simple figure as a benchmark for generation cost, this ignores dynamics, e.g. starting costs. This is especially important for hourly spot markets where flexibility of generation plays a fundamental role.

Finally when dealing with Germany, Bower concluded that prices did not indicate any exercise of market power. However due the network access conditions and "imperfect" unbundling, Brunekreeft (2001) has showed a specific type of exercise of market power where major utilities could compensate for low wholesale prices (the PX price) by charging high access charges to the network for third parties.

8-1-3 Shortcomings of Bower's analysis and corrective proposals

The Bower's analysis is confronted with three categories of limits. The first category is exogenous, mainly due to the availability of data for the year 2001. The second category is endogenous related to choices made by the author. Finally, the last limit is related to the assumption that electricity price time series are similar to other commodities, i.e. the price series are non-stationary. We discuss these three categories of limits in this section and suggest improvements that will be used for our analysis (for the year 2002) in the next section.

An important limit of Bower's analysis is related to the availability of data for three countries: France, Italy and UK. The absence of France in the analysis definitely represents the most important limits of this work, due essentially to the central geographical position of France and its interconnections with neighbouring countries, i.e. Spain, UK, Belgium, Germany, Switzerland, and Italy. The French power exchange started operation in November 2001. Trading volumes in the first months of operation of any exchanges are always low[7] due to the learning experiences of participants, it is thus perfectly understandable that it would not have been reasonable to include one month of French prices in the analysis. An important contribution of our work is the consideration of the French power exchange's prices for the year 2002.

The absence of Italy damages Bower's analysis because this market is the fifth largest one in Europe, after respectively Germany, France, the Nordic Region, and the UK but before Spain. Again this absence is due to the fact that no organised wholesale market in Italy was in operation in 2001. While the launch of an organised market was planned for 2002, this has been postponed and thus no figures are as yet available for 2002. Our analysis will therefore also ignore the Italian market. However this market is of less importance for our analysis as in contrast to France the geographical position of Italy is not central and interconnection with other main markets is limited.

The case of the UK is different from the two previous cases. The New Electricity Trading Arrangements (NETA) was introduced from 27 March 2001. NETA were introduced to address some of the fundamental weakness of the pool (OFGEM, 2001)[8]. Hence in Bower's analysis for the three first months of data pool prices

[7] See chapter 7
[8] See also chapter 2, box 2-1

were used while for the rest of the year UKPX prices were used. Due to the large difference between the two institutional arrangements, e.g. the pool was mandatory with no demand participation while UKPX is voluntary with demand participation, the time series for the UK does not appear to be consistent. This is not the case for the year 2002, when UKPX was in operation for the full year.

The second category of limits relates to choices made by the author. These limits are related to the choices of the wholesale locations, the absence of comparison with bilateral prices and the fact that Bower's analysis overlooks the important aspect of seasonality. First, two thirds (10 out of 15) of the prices are located in the Nordic countries which overestimate the importance of such market in Europe and add a lot of calculation for little supplementary information. For this reason in our analysis we will consider only four prices for the Nord Pool area. Second the choice of Spain is arguable for two reasons. The market design of the Spanish market might better be considered to be a pool rather than a power exchange[9] which make comparison with other market place difficult. Hence for consistency it appears worthwhile to not consider the Spanish market. Secondly, since Spain is only directly (and weakly) connected to France, the Spanish market is rather isolated from the rest of the European markets and, as shown in the results, arbitrage with other markets are unlikely to occur on a regular basis. For these two reasons, it is difficult to compare prices from the Spanish market with prices from other exchanges. However, to allow comparison, we will consider this market.

It is worth noting that Bower does not refers at all to prices from bilateral markets (OTC) whereas these markets represent the largest share of European electricity trading. For this reason and for the sake of completeness it appears important, before drawing any conclusion on the level of market integration, to realise some analysis based on bilateral market prices. Such an analysis is by definition difficult because prices from bilateral markets are usually not available and are

[9] See chapter 2

difficult to compare. However some indexes are regularly published. Therefore, we will use these indexes for two purposes. First they will allow us to estimate the level of integration at a national level between national bilateral markets and national power exchanges. Second, they will allow us to compare the level of market integration, based on power exchanges, with the one based on bilateral markets.

The use of daily averages for the full period though providing a workable proxy for the analysis, suffers from ignoring price variations with respect to seasonality within the week (weekdays/ week-end). Seasonality is a cyclical factor that occurs on a regular basis and it can strongly influence the result of an analysis. As showed in chapter 7 prices on power exchanges present important seasonality aspects. Indeed price differs in average by 35% between weekdays and weekends. Hence, it is likely that a large part of the correlation between locations in Bower's analysis is related to seasonal components rather than real integration between markets. This aspect has been totally overlooked and represents a serious limitation. In order to eliminate the seasonal component we only consider prices during weekdays. Thus a question that is not addressed deals with the possible different levels of integration of markets with respect to levels of demand. The point here is that, the level of demand directly influences the level of congestion which in turn has an impact on market integration. Thus, in our analysis we will first use daily averages, which will allow us to compare our result with Bower's results, but we will also use "peak prices" indexes to reflect the different level of demand.

While the use of cointegration is one of the most commonly used methods for testing market integration in applied economics, from an econometric point of view such an approach requires specific time series properties of the data. In this respect Bower's analysis is limited due to the fact that he did not test the properties of the data but assumed that electricity prices time series were non-stationary. If this assumption appears to be wrong, the cointegration approach makes little sense and others approaches should be considered. For this reason we will first test the properties of the data so we can choose the most appropriate method.

In sum, our analysis contributes to the discussion by extending the analysis of Bower made for the year 2001. Our analysis will make four new contributions to the literature:

- An analysis of the year 2002, first year where exchanges in France and in the UK where operational
- Include France, central geographic position
- Reduce the impact of seasonality, weekdays/weekends; baseload/peakload
- Compare power exchanges prices with bilateral markets, national and international integration

8-2 Test for market integration

8-2-1 Data and hypothesis

The data used in this study consists of hourly prices from five power exchanges, APX, LPX, Powernext, Nord pool, and UKPX, previously presented in chapter 7, one power pool, Omel, and daily prices from the bilateral market for the whole of year 2002. Power exchanges prices were taken directly from power exchanges' website and OTC spot prices from *Platts European Power Daily*[10] publication. For the Nordic countries we use the "system price"[11] and three regional prices: Denmark West, Norway-Kristiansand and Sweden. Over this period, there are 365 days with 24 observations per day (8760 prices) for the five power exchanges considered. Daily average prices for the different markets were calculated for the purpose of this work, since seasonality is an important characteristic of hourly prices[12] and since bilateral prices are only quoted on a

[10] Research assistance with collecting data from Nathalie De Barstch from the French Energy Regulatory Commission (CRE) and from Sylvia de Hoop from the Dutch Energy Regulatory office (DTe) is gratefully acknowledged.
[11] The "system prices" is an equilibrium price for the global Nordic countries regardless to bottlenecks and capacity restriction on the grid.
[12] See chapter 7

daily basis. Moreover due to the important difference in demand between weeks and weekends we only consider weekdays which represents 261 observations for each of the six organized markets. The two types of price series utilised are summarized in table 8-2.

Table 8-2: Data collected

Location	Source	data	Website
UK			
	UKPX	Hourly price/volume	www.ukpx.co.uk
	OTC	Base/peak	www.Platts.com
France			
	Powernext	Hourly price/volume	www.powernext.fr
	OTC	Base/peak	www.Platts.com
Germany			
	LPX	Hourly price/volume	www.lpx.de
	OTC	Base/peak	www.Platts.com
Netherlands			
	APX	Hourly price/volume	www.apx.nl
	OTC	Base/peak	www.Platts.com
Nordic countries			
	System	Hourly price	www.nordpool.no
	Denmark West	Hourly price	www.nordpool.no
	Norway-Kristiansand	Hourly price	www.nordpool.no
	Sweden	Hourly price	www.nordpool.no
Spain			
	Omel	Hourly price	www.omel.es

There is not just one price for the bilateral market, since these transactions consist of taylor-made contracts traded bilaterally when contrasted to power exchanges. First bilateral trade by definition is achieved between two players and the prices are only known by the parties involved. Second in these markets contracts are not standards which makes aggregation a difficult exercise: How does one aggregate a six month baseload contract with a two weeks peak hours contract? Prices on this market can only be estimated by using an aggregated index. In Europe traders then usually use the prices provided by *Platts*. This company contacts a subset of different market participants which provide them the price of their bilateral transactions. Specific transactions involving names of companies, quantities and price are confidential, so they are aggregated to build an anonymous index. Based on this information *Platts* publishes an average price which is recognized by most professionals as a good indicator of bilateral prices. The prices are broken down into many categories: peak prices, baseload prices, week ahead and year ahead. For each category a high and a low price are reported. Whereas Platts report a high and a low price for each market for each day, in this work we use a simple arithmetic average of high and low price for base and peak[13] to give a spot bilateral price.

Summary statistics of power exchanges prices were presented in table 7-11. More details statistic for both power exchanges and bilateral electricity prices including baseload and peak prices are given in table 8-3. As can been seen, the properties of bilateral prices are similar in some ways to those of power exchanges. For example the average power exchange prices are comparable in magnitude to the averages of bilateral prices for most countries. Nevertheless, the standard deviations of bilateral prices are generally lower than the corresponding standard deviation of power exchanges prices. This implies that bilateral prices tend to be less volatile than power exchanges prices. In particular, maximum and minimum prices are typically respectively lower and higher in the bilateral market than on power exchanges.

[13] Peak: 7h00-19-00 (or hour 8 to hour 19), Base 0h00-0h00 (or hour 1 to hour 24)

Table 8-3: Summary statistic power exchanges and bilateral markets (2002)

	Mean	Median	Maximum	Minimum	Std. Dev.
APX BASE	34,60	27,98	220,85	7,84	24,24
APX PEAK	44,93	35,10	324,53	9,80	35,85
DK BASE	27,38	24,44	88,47	9,06	11,32
FRA OTC BASE	23,92	22,75	65,00	7,50	6,37
FRA OTC PEAK	30,66	28,35	110,00	10,00	9,45
GER OTC BASE	25,39	23,88	70,00	7,73	7,07
GER OTC PEAK	33,34	31,55	110,00	9,75	10,64
LPX BASE	25,26	23,94	61,00	3,47	8,06
LPX PEAK	32,44	29,95	89,81	4,14	12,25
NL OTC BASE	32,28	26,63	177,50	8,25	18,79
NL OTC PEAK	44,15	35,50	255,00	12,75	27,41
NORDPOOL BASE	27,38	20,85	93,43	11,75	16,96
NORWAY BASE	26,91	20,50	94,17	12,26	17,31
OMEL BASE	41,03	40,65	106,97	5,66	12,87
POWERNEXT BASE	23,49	22,83	55,85	6,24	6,30
POWERNEXT PEAK	29,26	27,76	76,99	7,00	8,84
SWEDEN BASE	28,36	23,06	93,32	11,48	16,42
UK OTC BASE	26,58	24,92	56,04	16,71	7,07
UK OTC PEAK	33,88	29,51	100,16	19,61	12,06
UKPX BASE	23,05	21,72	61,77	15,17	5,73
UKPX PEAK	26,08	23,76	82,75	17,72	7,65

Using the above data, the two tests developed below are based on the idea that in a fully integrated European-wide electricity market, price between locations should only differ due to transmission constraints and arbitrage should safeguard that prices move in tandem. Hence, if two markets are integrated, prices in the two regions should move quite closely in tandem. This means that any shock of supply or demand in one location should be transmitted to the other regions because electricity coming from abroad can be considered as a perfect substitute for national production within the limit of transmission constraints. Two econometric approaches for testing time series relationships are in common use, the correlation and the “regression/cointegration” approach. We use these two different methods to test the level of integration of European electricity markets. The methodology used and results of these two approaches are given in the rest of this chapter.

8-2-2 Methodology: Correlation analysis

The most widely used measure of market interdependence is “simple” (or linear) correlation analysis. Even in a perfectly integrated market, prices can differ because of transport costs or transaction costs or because of temporary demand or supply or demand shocks, so correlation will be less than one. However, correlation analysis is especially well-suited as a starting point for estimating the level of market integration. Indeed the correlation coefficient between two time series price data can be used to determine whether these two markets are integrated (Stigler and Sherwin, 1985). Two variables are said to be correlated if a change in one variable is associated with change in the other. If two series have a correlation of 1, they are perfectly correlated: as one moves up, the other one moves up. If they have a correlation of –1, as one moves up, the other moves down. If two sets of numbers have a correlation close to zero, they are said to be non-correlated. Coefficients were calculated according to equation 8-1 for the first analysis correlation:

$$\rho_{x,y} = \frac{Cov(X,Y)}{\sigma_x \cdot \sigma_y} \qquad (8\text{-}1)$$

where

$$-1 \leq \rho_{x,y} \leq 1 \qquad (8\text{-}2)$$

and

$$Cov(X,Y) = \frac{1}{n}\sum_{i=1}^{n}(x_i - \mu_x)(y_i - \mu_y) \qquad (8\text{-}3)$$

Concerning electricity markets, the classical weaknesses of correlation analysis are (or can be) avoided. For instance, one drawback of correlation analysis is that a misleadingly low correlation coefficient can arise because one price series responds to another with a significant lag. Since electricity is non-storable such a lag problem cannot occur in electricity markets, e.g. a price spike on one market at 12.00 due to unusual weather conditions is unlikely to affect prices on another market later on. A misleading high correlation can occur if the prices in two locations are subject to a common influence. This is the case in electricity markets because intra-day and week seasonality is important[14]. We partially eliminated the impact of such seasonality by using weekdays data and daily averages rather than hourly prices.

While Bower's analysis only used this method for power exchanges' prices, including weekends, we have applied this method both to power exchanges and bilateral markets. This allows us to estimate three level of market integration: the national levels between power exchanges and bilateral markets, the international level between power exchanges, and finally between the different national bilateral markets. The results of this analysis are presented in section 8-3.

8-2-3 Methodology: classical regression and cointegration analysis?

An alternative method to simple correlation analysis can be use to test the level of market integration of electricity market based on the locational spot price framework developed by Schweppe *et al* (1988) and extended by Hogan (1992), and used in Bower's analysis. This method uses a rather simple standard model of an integrated market. The underlying idea is that in an integrated market prices between locations should equal prices in other location plus the price of transmission. Such model can be defined as follows:

$$Y_t = T_t + X_t \qquad (8\text{-}4)$$

where Y_t is the price at location Y at time t, X_t the price at location X at time t, and T_t the price for transmission between X and Y at time t. Estimation of this model is straightforward and can be realized using regression models according to standard ordinary least square (OLS) method:

[14] See chapter 7

$$Y = c + bX \qquad (8\text{-}5)$$

where

$$b = \frac{n\sum XY - (\sum X)\cdot(\sum Y)}{n\sum X^2 - (\sum X)^2} \qquad (8\text{-}6)$$

$$c = \frac{\sum Y}{n} - b\frac{\sum X}{n} \qquad (8\text{-}7)$$

n= total number of observations in the sample

Regression models are commonly used as a quantitative way to determine underlying trend and price relationships. A linear regression trend line uses the OLS method to plot a straight line through prices to minimize the distances between the prices and the resulting trend line. Such an estimation makes sense only if the data are stationary time series, i.e. contain a constant mean, variance, and autocovariance. If the different time series are stationary OLS can be use to estimate the level of interdependence between prices. However, in the presence of non-stationary time series[15] classical OLS regressions may lead to spurious or nonsense regressions. In other words, if a variable contains a unit root it is non-stationary and unless it combines with other non-stationary series to form a stationary cointegration relationship, a simple regression of the series can falsely imply the existence of a meaningful economic relationship. For instance if two time series grow with time they can be correlated even if there is absolutely no relationship between them[16]. Such regressions often include important autocorrelation as indicated by a low Durbin-Watson[17] statistic.

[15] A non-stationary time series posses unit root which mean that the effect of shocks persit indefinitely.

[16] Examples of spurious regression characterized by high correlation coefficient but a low Durbin Watson: Egyptian infant mortality rate, annual data on gross aggregate income of American farmers and total Honduran money supply (1971-1990); US Export Index and annual data on Australian males' life expectancy (1960-1990); US Defense Expenditure and annual data on Population of South African (1971-1990). (source: http://halweb.uc3m.es/esp/Personal/personas/jgonzalo/teaching/jgonzalo.html)

[17] The Durbin-Watson test is used to measure autocorelation which occurs when the disturbances in one period are correlated from one or more of the preceding periods (see appendix 2 for details).

The concern about spurious regressions in time series gave rise to the concept of cointegration (Granger and Newbold, 1974; Phillips, 1986). Spurious regression happen when time series are dominated by long term trends or important seasonal components. The concept of cointegration was first introduced in the econometric literature by Granger (1981) and was further extended by Engle and Granger (1987). This concept is based on the idea that, although economic time series exhibit non-stationary behaviour, an appropriate linear combination between trending variables can remove the trend component and, hence, the time-series can be cointegrated. In economic terms, cointegration implies that there is an equilibrium prices relationship toward which prices gravitate. The interest of cointegration lies in the fact that it allows to look for the existence of an equilibrium relationship among time series even if each series is individually non-stationary. The Engle-Granger residual based test is one of the most commonly used for testing cointegration. This test contain two steps: estimation of a cointegrating regression by applying Ordinary Least Squares (OLS) on the levels of the variables included, and testing for stationarity of the residuals using Augmented Dickey-Fuller (ADF) tests[18].

The choice between the two methods involves a primary analysis to figure out if the series are stationary or not, using unit root tests. If the series are stationary OLS regression can be used, if the series are non-stationary cointegration should be used. Concretely, before testing for cointegration, it is necessary to test for the existence of a unit root in each price time series. If the time series are non-stationary cointegration analysis can be used. Subsequently if the prices studied are found to be co-integrated it will mean that prices will be tied in the long run. It is worth noting that the primary test for unit root was not conducted by Bower because he assumed that the behaviour of electricity prices is comparable to other commodity or financial markets which are mainly non-stationary. Such an assumption represents an important shortcoming because electricity markets

[18] ADF tests of stationarity of residuals are different from ADF tests of whether a variable is stationary. In the case of ADF test of residuals these residuals are generated by regression. Hence, critical values are

have many peculiarities which might involve electricity prices behaving differently from others markets. From an econometric perspective, appropriate definition of the nature of price series is a vital issue because misspecification of a random walk as a stationary process, or the other way around, has a major effect on the statistical analysis of the data (Perron, 1989; Hamilton 1989). Concretely, it is necessary to figure out if the series are stationary or not because cointegration analysis cannot be used if any series is stationary.

The second method of our study is as follows.

1) Establish the time series properties of the individual series, using ADF tests (box-8-2), to determine the use of the appropriate method.
2) Consider the price relationships, regression if the data are stationary, cointegration if the data are non-stationary, between pairs of locations.
3) Compare with the result of correlation analysis and Bower's analysis
4) Conclude on the level of integration of the "European electricity market"

The results of this analysis are presented in section 8-4.

different from those used for ADF tests for stationarity of a variable.

Box 8-2: The ADF Test

The issue of trend stationarity versus difference stationarity is critical for the analysis of time series. The theory of cointegration emphasises the need for pre-test time series for unit roots (Hendry and Juselius, 2000). There is a large literature on testing for unit root theory (McKinnon, 1994; Hamilton, 1994; Stock, 1994; Lardic and Mignon, 2002). For the purpose of this work we consider the approach suggested by Dickey and Fuller (1979; 1981).

Consider the case in which the price series Y_t can be described by the following equation:

$$Y_t = \alpha + \beta t + \rho Y_{t-1} + \varepsilon_t \qquad (8\text{-}8)$$

Where Y is the variable under investigation, t is a linear time trend, and ε_t is a random error term. The Augmented Dickey Fuller (ADF) test is carried out by expanding equation (8-8) to include lag, *p* is the number of lag, changes in Y_t as follow:

$$Y_t = \alpha + \beta_t + \rho Y_{t-1} + \sum_{j=1}^{p} \lambda_j \Delta y_{t-j} + \varepsilon_t \qquad (8\text{-}9)$$

Using OLS, one first runs the unrestricted regression:

$$Y_t - Y_{t-1} = \alpha + \beta t + (\rho - 1) Y_{t-1} + \sum_{j=1}^{p} \lambda_j \Delta Y_{t-j} \qquad (8\text{-}10)$$

and then the restricted regression

$$Y_t - Y_{t-1} = \alpha + \sum_{j=1}^{p} \lambda_j \Delta Y_{t-j} \qquad (8\text{-}11)$$

Then a standard *F* ratio is calculated to test whether the restriction (β=0, ρ=1) hold using the distribution.

Source: Pindyck and Rubinfeld (1998)

8-3 Results of linear correlation analysis

In an integrated electricity market, one would expect to find a high correlation across the market between prices. A really integrated market should provide price correlation in the individual underlying markets. The price differences should only reflect physical congestion between markets. Many correlation calculations between different prices were done as a test. These correlation calculations were done between different locations and between different types of contracts from January 2002 to December 2002. The different physical markets under study are directly or indirectly physically interconnected (ETSO, 1999). One would expect to see a high level of correlation between the prices on these markets. However the simple correlations reported in table 8-4 do not support the idea of a single integrated European electricity market but rather the existence of different regional markets. Several interesting conclusions emerge from these results with respect to the level of market integration at the national levels between power exchanges and bilateral markets, at the international level between power exchanges, and finally between the different national bilateral markets.

First in general, a high correlation (80% in average including both base and peak periods) has been found at the national level between OTC prices and power exchanges for the four markets where OTC prices were computed (France, Germany, Netherlands and UK). Such a result is consistent with the analysis given in part 2 of this thesis (chapters 5-6-7) which has showed that power exchanges have been developed and designed at national levels. Furthermore, it shows that despite a relatively small traded volume, power exchanges prices are representative of the overall wholesale market since change in one market is associated in change in the other market. In other words, at national level arbitrages between the two markets safeguard that prices move together. Moreover no significant differences in correlation were found at the national level using base or peak prices for OTC and power exchanges, 82% of correlation between “base OTC” and “base power exchanges” and 79% between “peak

OTC" and "peak power exchanges" on average. We can thus conclude that **the level of integration at the national level is high** between power exchanges and bilateral markets.

Second, at the international level, this analysis reveals the existence of two "supra-national" markets, Norway-Sweden-Denmark, and France-Germany, and three rather isolated markets, Spain, Netherlands, and UK. Similar to Bower we found evidences that prices between Norway and Sweden were almost perfectly correlated (99%) and to less extent that all prices within the Nord pool locations were also highly correlated as indicated by correlation coefficients above 70%, 74% between Norway and Denmark, 77% between Sweden and Denmark. This means that supply or demand shocks in any Nord pool location have a direct impact on other Nord pool locations. This result is consistent with the general idea that the Nordic market is highly integrated[19]. In contrast, locational prices within the Nord pool area appear to be totally isolated from the other European power exchanges prices. Surprisingly the Nord pool system price is more correlated with the UKPX price (35%) than with the LPX price (7%) in spite of no cross-border transmission capacity between UK and Nord pool and the existence of interconnection between Nord pool and Germany, through Denmark and Sweden, but this coefficient remain too low to be significant. Similar correlation with France (6%) and Netherlands (7%) are also very low. Finally, the negative correlation with Spain (-45%) shows a total separation between these two markets. Hence these results indicates that there was a high level of integration between Norway, Sweden, and Denmark in 2002 forming an **integrated Nordic market**. However, this market was rather isolated from all other locations outside the Nordic countries.

A second "supra-national" market can be identified that is made up of France and Germany, based on power exchanges prices and bilateral prices. These two markets show high correlation, 75% on average. Such correlation shows that

[19] See chapter 9 for more details on Nord pool

important arbitrages exist between these two countries. As they are directly connected such result appears to be logical[20]. However it is worth noting that the interconnections between France and Germany have historically been a one-way connection for EDF to export cheap (nuclear) electricity to Germany. Furthermore the low level of liquidity in the French market make it difficult for any company other than EDF to take advantage of arbitrage possibilities between the two markets. In conclusion, this analysis highlights an **important level of integration between France and Germany** but the possible domination of EDF on the arbitrage remains an open question.

The analysis also highlights that for all the other locations there is little correlation for either power exchange prices or bilateral prices during the period in focus, with correlation between locations generally below 40%. For instance, despite the central geographic position of France and beyond the correlation between France and Germany, electricity prices on the French power exchange appear to be weakly correlated with prices from neighboring exchanges: 51% with Omel, 41% with UKPX, 29% with APX. Similarly correlation between the UK markets and all others location are mainly below 40%. Therefore, this analysis shows a **very low level of integration between most European locations**.

In summary, several interesting facts emerge from this first analysis. First a high level of integration at the national level between power exchanges and bilateral markets has been observed. Second, two “supra-national” markets have been identified. Finally the more general conclusion that can be drawn from this analysis is that with some regional exceptions, European electricity prices are not correlated which shows inefficiency of arbitrage mechanisms and a low level of market integration.

[20] See chapter 9 for a presentation of the allocation mechanism of interconnector capacity between France and Germany

Table 8-4: Results of correlation analysis

	FraOTC base	Powernex base	FraOTC peak	Powernex peak	GerOTC base	LPX base	GerOTC peak	LPX peak	NLOTC base	APX base	NLOTC peak	APX peak	UKOTC base	UKPX base	UKOTC peak	UKPX peak	Omel base	Nordpool base	DK-West base	Norway base	Sweden base
FraOTC base	1,00																				
Powernext base	0,87	1,00																			
FraOTC peak	0,96	0,81	1,00																		
Powernext peak	0,83	0,97	0,80	1,00																	
GerOTC base	**0,90**	**0,81**	**0,88**	**0,78**	1,00																
LPX base	**0,76**	**0,75**	**0,69**	**0,73**	0,83	1,00															
GerOTC peak	**0,84**	**0,73**	**0,85**	**0,74**	0,97	0,80	1,00														
LPX peak	**0,67**	**0,66**	**0,63**	**0,67**	0,78	0,97	0,78	1,00													
NLOTC base	0,31	0,33	0,34	0,36	0,37	0,35	0,39	0,36	1,00												
APX base	0,25	0,29	0,28	0,33	0,33	0,32	0,35	0,33	0,89	1,00											
NLOTC peak	0,27	0,28	0,31	0,33	0,35	0,32	0,38	0,34	0,96	0,90	1,00										
APX peak	0,23	0,27	0,26	0,30	0,30	0,29	0,32	0,31	0,89	0,99	0,90	1,00									
UKOTC base	**0,52**	0,48	**0,55**	0,48	0,37	0,27	0,34	0,23	0,25	0,18	0,21	0,17	1,00								
UKPX base	0,41	0,41	0,42	0,39	0,29	0,25	0,26	0,20	0,20	0,12	0,16	0,12	0,72	1,00							
UKOTC peak	0,45	0,42	0,49	0,45	0,33	0,25	0,33	0,23	0,26	0,20	0,25	0,20	0,95	0,68	1,00						
UKPX peak	0,39	0,38	0,41	0,38	0,27	0,24	0,26	0,21	0,23	0,14	0,19	0,14	0,70	0,99	0,68	1,00					
Omel base	0,47	**0,51**	0,40	0,44	0,42	0,38	0,38	0,33	0,01	0,01	-0,03	-0,01	0,12	0,15	0,05	0,12	1,00				
Nordpool base	0,11	0,06	0,17	0,11	0,06	0,02	0,06	0,02	0,09	0,07	0,12	0,08	0,42	0,35	0,41	0,34	-0,45	1,00			
DK-West base	0,32	0,31	0,34	0,37	0,33	0,34	0,32	0,34	0,36	0,29	0,37	0,28	0,42	0,35	0,45	0,36	-0,30	0,75	1,00		
Norway base	0,11	0,06	0,16	0,11	0,06	0,01	0,05	0,00	0,08	0,06	0,10	0,07	0,42	0,35	0,41	0,34	-0,45	0,99	**0,74**	1,00	
Sweden base	0,12	0,06	0,18	0,12	0,08	0,05	0,09	0,05	0,12	0,09	0,15	0,10	0,40	0,34	0,41	0,33	-0,45	0,99	**0,77**	**0,99**	1,00

LEGENDA

>0.5	National integration
> 0,5	International integration
< 0,5	No integration

8-4 Results of regression analysis

8-4-1 Unit root test

In Bower's analysis the assumption was made that the data were non-stationary time series. While such a characteristic has been observed for most economic variables, it is a fundamental prerequisite to test such hypothesis for electricity prices to choose the appropriate method to use for an analysis. Indeed, due to the peculiarities of electricity markets such hypothesis may be non-suitable for electricity prices. Hence, before any econometric analysis can be carried out, it is necessary to investigate the time series properties of the data. We need to distinguish between the stationary and stochastic component, for this purpose, the Augmented Dickey-Fuller test was performed for each price series[21]. The results are reported in table 8-5. To save space in this section, the details of all test results are displayed in appendix 2.

Table 8-5: Summary of ADF unit root tests

Serie	ADF Test Statistic	Unit root* (5%)
Powernext	-6,837230	No
LPX	-7,164452	No
APX	-8,182311	No
UKPX	-7,607387	No
OMEL	-3,135941	No
DK-West	-6,419316	No
NORDPOOL	1,152283	Yes
NORWAY	1,786610	Yes
SWEDEN	0,056822	Yes

*MacKinnon critical values for rejection of hypothesis of a unit root.

1% Critical Value	-3,4571
5% Critical Value	-2,8728
10% Critical Value	-2,5727

If the ADF statistic is not significant we fail to reject the null hypothesis of stationarity and can conclude that the series are non-stationary. Surprisingly, according to the ADF test for unit root, the hypothesis of stationarity can be rejected only for three series, Nord pool, Norway, and Sweden, while for the six other series, Powernext, LPX, APX, UKPX, Omel, and Denmark, this hypothesis cannot be rejected. Hence most prices series were found to be stationary. These results of unit root tests are of primary importance because they show that electricity spot prices do not behave like most others economic time series which are generally non-stationary. As such cointegration analysis will be invalid, because in the presence of stationary series cointegration analysis will always find prices to be cointegrated.

Based upon the above results the alternative approach to test for market integration is regression analysis, i.e. regressing price series on each other using the standard OLS method. This approach appears well suited because due to the nature of these markets, short-term, and the nature of electricity, non-storable, the relationship between prices should be instantaneous rather than containing lags (e.g. ARMA models[22]).

8-4-2 Results of regression

Since the data are stationary time series, estimation of our model (equation 8-5) can be done using the standard OLS method. In order to focus on the most important relationships, the regression analysis only considers markets which are directly connected, e.g. France-Spain as opposed to Germany-UK, assuming that markets are better integrated when they are closer. The results of the regression analysis ranging R-squared in decreasing order are given in table 8-6[23]. This statistic is important because it measures the strength of the association between the two variables by indicating the percentage of variation in one location that is explained by the other location.

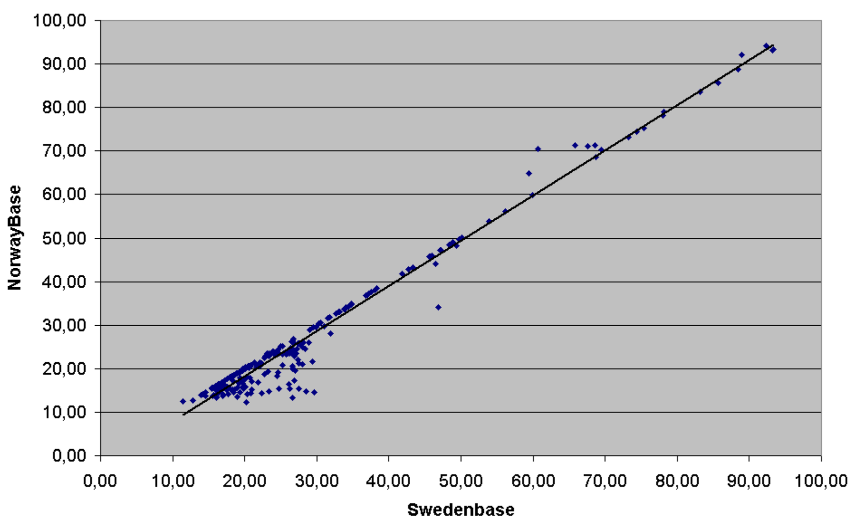
[21] Two different numbers of lags (zero and four) have been used. They both end up with similar results. For the sake of brevity only the results of the first estimation are presented.
[22] AutoRegressive Moving average see Box and Jenkins (1970)

Table 8-6: Summary of regression analysis

Dependent variable (Y)	Variable (X)	Constant (c)	Coefficient (b)	R-squared	Durbin-Watson
NORWAYBASE	SWEDENBASE	-2,57755	1,039818	0,972605	0,625035
DKWESTBASE	SWEDENBASE	12,33978	0,530569	0,592542	1,196392
POWERNEXTBASE	LPXBASE	8,76749	0,583019	0,555816	1,380904
DKWESTBASE	NORWAYBASE	14,39116	0,482891	0,545649	1,140531
POWERNEXTBASE	OMELBASE	13,28181	0,248835	0,258207	0,816145
POWERNEXTBASE	UKPXBASE	13,12157	0,449886	0,167365	0,841305
LPXBASE	DKWESTBASE	18,62080	0,242315	0,115740	0,665690
APXBASE	LPXBASE	10,42515	0,957349	0,101347	0,950483
POWERNEXTBASE	APXBASE	20,84045	0,076639	0,086854	0,698207

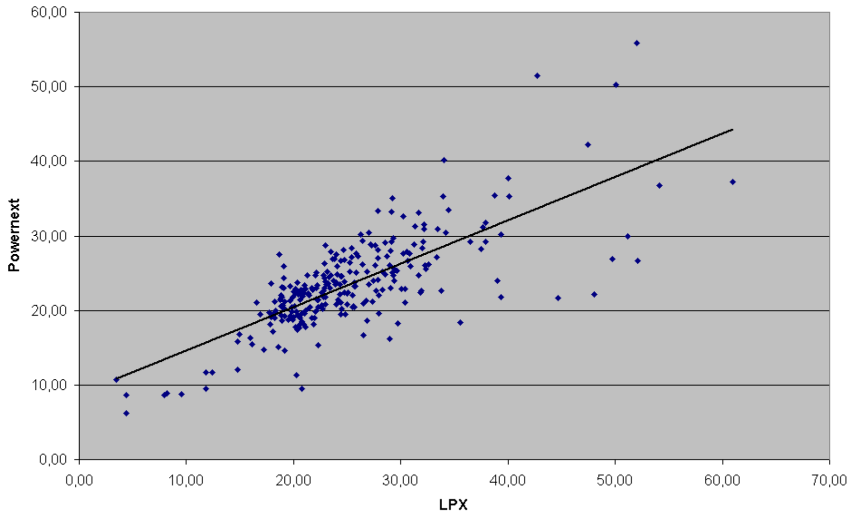
The R-Squared allows us to separate the results in three categories: very high relationships, high relationships and no relationships. First, as in the previous analysis, the regression between Norway and Sweden prices (figure 8-1) indicates a very high level of integration between these two markets. Indeed the estimated R-squared indicates that 97% of price variation at one location is explained by price variation at the other location. Moreover the slope of the regression is close to one which demonstrate a high level of arbitrage between these two markets.

Figure 8-1: Regression Norway-Sweden



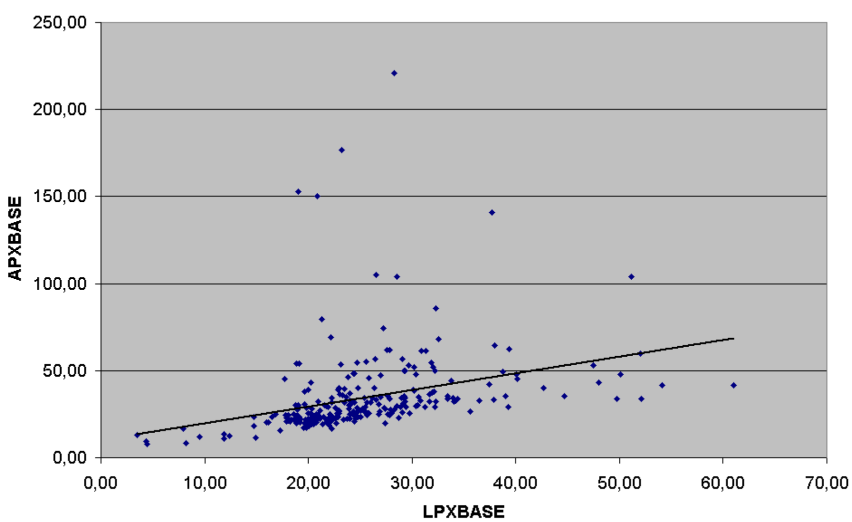
[23] See appendix 2 for details of regression analysis

Figure 8-2: Regression Powernext-LPX



Second, to a lesser extent Denmark appears to be relatively well integrated with Norway and Sweden while France and Germany also present a high R-squared (>55%). However compared to the previous case (Norway-Sweden) which can be considered as an example of effective integration, these markets appears has imperfectly integrated.

Figure 8-3: Regression APX-LPX



Finally, the other regression results suggest that no real relationships exist between numerous locations since none of the estimated coefficients are significant although these markets are physically connected (figure 8-3). For instance the estimated R-squared is lower than 20% for four relationships, France-UK, Germany-Denmark, Netherlands-Germany, France-Netherlands. It appears that price variations in several locations do not affect prices in neighbouring locations (figures 8-4, 8-5). In conclusion, just as with the correlation analysis the OLS estimation results based on power exchanges prices are unambiguous. There seems to be very few relationships between the different markets. These results indicate that so far there exists no single European electricity market although there is some evidence for local integration.

Figure 8-4: Regression Powernext-UKPX

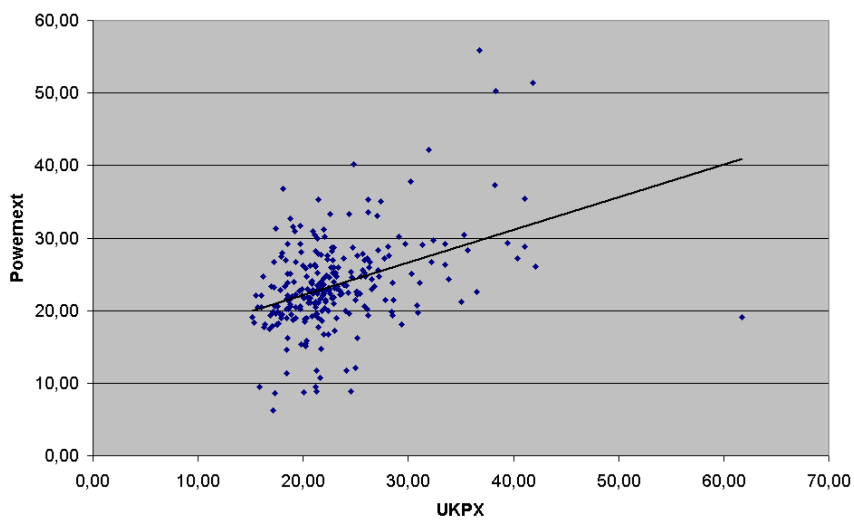
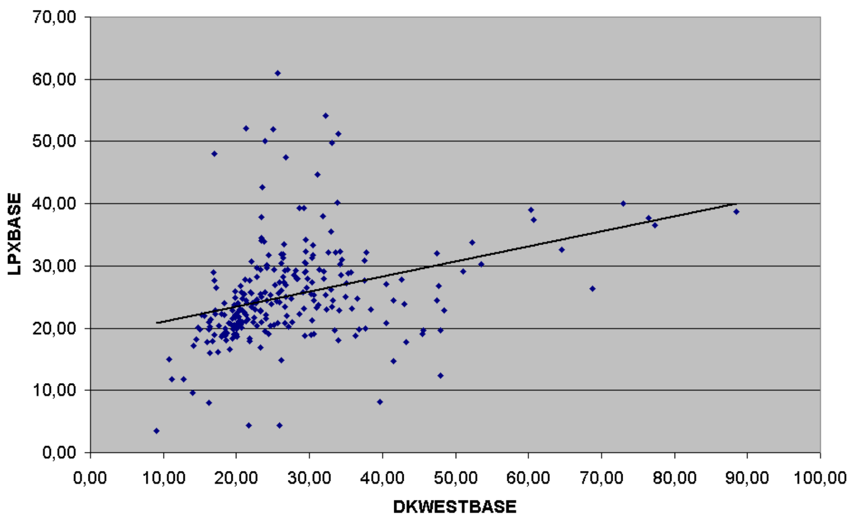


Figure 8-5: Regression LPX-Denmark



8-5 Conclusion

The extent to which electricity prices in the different countries are related is of considerable interest from a market definition perspective. In this chapter we have considered prices in several European locations during the year 2002 to test the level of market integration of electricity markets in accordance with the objective of the liberalization process to create a single European market. In principle, in an integrated electricity market, one would expect to find a high correlation across the market between prices. However the results presented here give limited support to this assumption of a single "European electricity market".

Taken together, our econometric evidence points in one direction: the European electricity market is not integrated. In particular it has been possible to identify different markets. While in theory strong relationships should exist between these markets, the present sets of tests with the present set of data have provided only weak support for this theory. First, correlation analysis between prices considered in location pairs proved to be low in general. This holds true for both types of spot market, i.e. power exchanges/bilateral markets, and for both types of periods, i.e. base/peak. However, this analysis has allow us to demonstrate a high level of integration at the national level between power exchanges and bilateral markets and to identify two regional markets and three isolated markets.

Second, while cointegration analysis is the most commonly used method for measuring market integration, the nature of the data did not allow us to use this method because this test requires non-stationary time series. Indeed, primary tests on time series properties have showed that electricity price behaviors are different from classical commodity prices which are usually non-stationary. Hence, classical regression has been used and this provided primary evidences that although the goal of the liberalization process is to create an integrated European-wide market, the process so far has resulted in the creation of different national markets that still need to be integrated.

From this analysis, a question emerges: What are the reasons for this lack of integration? In the following chapter we try to answer this question and argue that the lack of market integration which mean a lack of efficient arbitrage between markets is directly related to market design and especially to the existence of inefficient transmission pricing for cross-border trading.