Volatility spillovers in EU electricity markets

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Abstract

Electricity markets have experienced considerable changes in the last decades. With increased deregulation, cross boarder trade and the consolidation of pricing mechanisms, markets have become more integrated. Previous research have shown that the introduction of renewable energy has impacted the market. In the literature there has been many articles investigating the price relationships between markets and the development of price volatility. However, few have studied volatility spillover effect between electricity markets. In this paper we investigate the level of price volatility spillover effects between 4 major European exchanges, EEX in Germany, EPEX in France, BPX in Belgium and APX in the Netherlands for the period 2007-2016. In our initial analysis we identify Germany and France as power exporting nations while the Netherlands and Belgium are import dependent. The results indicate that EPEX is the most influential in terms of transmitting volatility, while the APX and BPX are inclined to receive from external volatility effects. With France and Germany being the largest producers of electricity in Europe, this indicates that that price volatility origins from the more dominant market and is transmitted to minor market. We also notice that markets that are dependent on power imports are more susceptible to receive volatility effects from the exporting markets. In addition, time analysis indicate that our results are time-varying.

1 Introduction

This paper investigates the dynamics of price volatility transmission between major electricity markets in the Central-Western European (CWE) region. In the last decades, electricity markets have become increasingly deregulated. With the Norwegian market considered the most mature, dating its beginning of deregulation to 1991. With several initiatives since been promoted in the European Union (EU) to improve interconnection and integration (Sotiriadis et al. (2016)). With a goal to maximize the utility from renewables and increase social welfare in the EU. The target of integration of regional electricity markets and creation an single European market for electricity is still under progress with the EU setting a goal on 10% of power production being interconnected by 2020, and further 15% by 2030. This, in addition to the collaboration of power exchanges to schedule the exchange of power is referred to as market coupling. These market innovations have contributed in one-third reduction of wholesale electricity prices in the period 2008-2012

(EU Commission (2015)).

Motivated by such considerations, we investigate the transmission of power price volatility in the CWE region. More specifically the power exchanges APX in the Netherlands, BPX in Belgium, EEX Phelix in Germany and EPEX in France[1]. Different to integration of financial markets, when studying interconnected electricity market the transmission capacity between national markets is important. This cross boarder capacity is the actual MW that is possible to transmit at a certain time between countries and regions. This physical constraint denotes the transmission capability of the participant to exchange electricity and thus limits the level of integration (Sotiriadis et al. (2016)).

Figure 1: **Transimission capacity**

Indicative transport constraints, computed by extrapolation from standard situations. Winter 2010/2011 standard peak hours. Transport constraints in GWh.

The development of total cross border exchange in the European Union has been increasing markedly since the mid 90's, or from approximately 200 to 400 TWh in 2010. Where the leading nations in export of electricity, Germany and France have reached the 10% interconnection goal. Being the largest producers of electricity in EU each producing annually approximately 30% of all electricity in the EU. Consequently an important cross boarder exporters of electricity to neighbouring countries. The more import dependent neighbors Belgium and the Netherlands are currently at 17% interconnection level. With 18.9 % of power in Belgium being imported from the region and 22.5% in the Netherlands. A larger share of production in Germany and France are domestically consumed or imported from other countries, with only 2.4 and 7.8% respectively imported from the CWE region. With Belgium and the Netherlands importing 18.9% and

[1]EPEX spot was operated as Powernext in until december 2008

22.5% of its electricity consumption from the region and smaller market size, it can be expected that Belgium and the Netherlands are more susceptible to receive price changes from its larger neighbors. See table 1

Table 1: **Electricity production**

This table demonstrates the the portion of total consumption is imported from the CWE region. And the total proportion of production is exported to the region in the years 2007-2015.

Country	Consumption TWh	Import %	Production TWh	Export %
Belgium	781	18.9	719	9.5
France	4379	2.4	4884	11.2
The Netherlands	1032	22.5	923	12.9
Germany	4852	7.8	5147	11.5

Previous studies have analyzed the interrelationship between markets. An article by Sotiriadis et al. (2016) studied the price relationship between CWE countries and the Nordpool market, and provided evidence that there where to be found evidence of market integration within CWE region. But a weaker relationship to less interconnected Nordpool. De Jonghe et al. (2008) demonstrated in an earlier study with data from APX, Powernext and BPX that resulting market coupling increased price convergence. Reduction in volatility was only found on APX after market-coupling. However, found no price volatility reducing effect on Powernext or BPX. In addition to increased market coupling the promotion of renewables has impacted volatility levels. With the literature being conclusive that recent innovation in market coupling and in production of renewables resulted in lower wholesale prices, but more inconclusive on the effect of price volatility Rintamäki et al. (2017). Recently this has become a more popular research topic. There has been introduced a large amount of literature on the effect from renewables on price volatility and consequent interrelationship between markets, such as Mulder and Scholtens (2013), Dillig et al. (2016), and Mauritzen (2010)).

Generally, electricity prices exhibit high volatility, strong mean-reversion, frequent spikes and seasonal patterns (Sotiriadis et al. (2016)). Electricity markets differ from conventional commodities market in the sense that electricity cannot be stored in a traditional way. This means that electricity has to be produced and consumed instantly, requiring the balance between supply and demand being constantly balanced in real time. As a breach in this supply demand equilibrium can lead to market failures resulting in extreme price movement and high price volatility. This is, in some instances caused by unexpected weather changes, failure in reliability or potential delivery constraint. Thus by improving the transmission capacity and trade between markets would indicate reduction in price volatility. The complexity of electricity markets has generated considerable research on models and tools to optimize the utility from electricity production.

Sophisticated models have been developed to model and analyze the dynamics of electricity prices. With univariate Generalized Auto Regressive Conditional Heteroskedasticity (GARCH) models, originally intro-

duced by Bollerslev (1990) and Engle (1982) being predominant in the literature when describing univariate series. Considering the interrelationship between time series the common econometric methodologies are the multivariate GARCH models (Malo and Kanto (2006), Worthington et al. (2005)), Regime Switching (RS) (Haldrup and Nielsen (2006), Weron (2009)) and Stochastic Volatility (SV) models. With the multivariate GARCH model is most commonly used by researchers. Departing from the methods above, Diebold and Yilmaz (2009) provided new measures of return and volatility spillovers of international stock markets based on forecast-error variance decompositions in a vector autoregressive framework (DY 2009). This method produces continuously-varying indexes which are statistically tractable even for very large numbers of assets. Diebold and Yilmaz (2012) discussed the return and volatility spillover among five American countries using this method. More importantly, Diebold and Yilmaz (2012) further improved the DY 2009 method and used the upgraded model (DY 2012) to explore the volatility spillover among major American financial assets including stocks, bonds, foreign exchanges, and commodities from 1999 to 2009. The DY 2012 model provides measures of both total and pairwise directional volatility spillovers.

The aim of this paper is to provide empirical evidence of transmission of wholesale electricity price volatility in the CWE region. In the light of recent innovations in the market, this paper is expected to elucidate the presence and characteristics of volatility spillovers between power exchanges in the CWE region by employing the DY 2012 approach. In our approach we use monthly net power exchange to visually investigate effects of volatility spillovers from interconnected power trade. To our best knowledge there is no empirical research available regarding this topic, we believe that the dissemination will provide of more insight and knowledge might enable improved decision-making.

2 Methodology

We base our investigation on a method introduced by Diebold and Yilmaz (2012). Which is based on autoregressive AR models, such from Engle III et al. (1988). We first consider the covariance stationary first-order two variable VAR

$$x_t = \sum_{i=1}^{p} \phi_i x_{t-i} + \varepsilon_t \quad \text{where } \varepsilon \sim (0, \sum) \text{ is a vector of IID errors.} \tag{1}$$

x_t is an N x 1 vector of endogenous variables, ϕ_i are N x N autoregressive coefficient matrices and ε_t is a vector of error terms. By using moving average coefficients $x_t = \sum_{i=1}^{\infty} A_i \varepsilon_{t-i}$ we are able to identify each variable's forecast error variances according to the various market shocks. Here, A_i are N x N coefficient matrices that follow the recursion $A_i = \theta_1 A_{i-1} + \theta_2 A_{i-2} + +\theta_p A_{i-p}$ and A_0 is an N x N identity matrix and $A_i = 0$ for i $<$ 0. The H-step-ahead forecast error variance decomposition can now be calculated as

$$\theta_{ij}^{g}(H) = \frac{\sigma_{ii}^{-1} \sum_{h=0}^{H-1} (e_i^{'} A_h \sum e_j)^2}{\sum_{h=0}^{H-1} (e_i^{'} A_h \sum A_h^{'} e_j)} \tag{2}$$

where $\sum$ is the variance matrix for the error ε,σ_{ii} is the standard deviation of the error term for the ith element and ϵ_t is the selection vector with one as the ith element and zeros otherwise. This produces a spillover index of N x N matrix, where each element represents the contribution in the forecast error variance from market i to market j. Since the sum of the variance contribution to the forecast error may deviate from 1, we normalize the found error decomposition by dividing by the row sum:

$$\sum_{j=i}^{N} \theta_{ij}^{g}(H) \neq 1 \tag{3}$$

We are now able to calculate the total volatility spillover index:

$$\tilde{\theta}_{ij}^{g}(H)) = \frac{\theta_{ij}^{g}(H)}{\sum_{j=1}^{N} \theta_{ij}^{g}(H)} \tag{4}$$

Based on Equation 2-4 five different measures directional volatility of interest can be derived: total volatility index, gross directional volatility spillover (to and from), net volatility spillover and pairwise spillover.

Equation 5 shows the total volatility index ($S^g(H)$), which shows the average amount of volatility caused by spillover between the markets. Total volatility index is calculated as the relation between the sum of off-diagonal column sums of directional volatility spillover from each market and the sum of the directional volatility spillover from each market.

$$S^g(H) = \frac{\sum_{\substack{i,j=1 \\ i \neq j}}^{N} \tilde{\theta}_{ij}^{g}(H)}{\sum_{i,j=1}^{N} \tilde{\theta}_{ij}^{g}(H)} \cdot 100 = \frac{\sum_{\substack{i,j=1 \\ i \neq j}}^{N} \tilde{\theta}_{ij}^{g}(H)}{N} \cdot 100 \tag{5}$$

Then, equation 6 shows the gross directional volatility spillover ($S_{i\cdot}^{g}(H)$) to market i from all other markets j.

$$S_{i\cdot}^{g}(H) = \frac{\sum_{\substack{j=1 \\ i \neq j}}^{N} \tilde{\theta}_{ij}^{g}(H)}{\sum_{j=1}^{N} \tilde{\theta}_{ij}^{g}(H)} \cdot 100 = \frac{\sum_{\substack{j=1 \\ i \neq j}}^{N} \tilde{\theta}_{ij}^{g}(H)}{N} \cdot 100 \tag{6}$$

Further, equation 7 shows the gross directional volatility spillover ($S_{\cdot i}^{g}(H)$) from market i to all other markets j.

$$S^g_{\cdot i}(H) = \frac{\sum\limits_{\substack{j=1 \\ i \neq j}}^{N} \tilde{\theta}^g_{ji}(H)}{\sum\limits_{j=1}^{N} \tilde{\theta}^g_{ji}(H)} \cdot 100 = \frac{\sum\limits_{\substack{j=1 \\ i \neq j}}^{N} \tilde{\theta}^g_{ji}(H)}{N} \cdot 100 \tag{7}$$

In addition, equation 7 shows the net spillover ($S^g_i(H)$) between market i and all other markets j.

$$S^g_i(H) = S^g_{\cdot i}(H) - S^g_{i \cdot}(H) \tag{8}$$

Finally, equation 7 shows the pairwise ($S^g_{ij}(H)$) spillover between market i and market j.

$$S^g_{ij}(H) = \left(\frac{\tilde{\theta}^g_{ij}(H)}{\sum\limits_{k=1}^{N} \tilde{\theta}^g_{ik}(H)} - \frac{\tilde{\theta}^g_{ji}(H)}{\sum\limits_{k=1}^{N} \tilde{\theta}^g_{jk}(H)} \right) \cdot 100 \tag{9}$$

3 Data

A total of four electricity spot markets are considered in this study: Brussels Power Exchange (BPX) operating spot price trading in Belgium; European Power Exchange (EPEX) operating in France; Amsterdam Power Exchange (APX) operating in the Netherlands; and European Energy Exchange (EEX) operating in Germany. All data utilized in this article was extracted from Datastream and are assumed of high quality. Electricity base prices for the Belpex, APX and EEX markets are evaluated with a weighted daily average frequency between 01.01.2007 and 31.12.2015.

Table 2: **Descriptive statistics:**

This table show descriptive statistics for the returns in the electricity prices for the European markets Belpex, Powernext, APX and EEX Phelix. The number of observations, statistical moments and p-values for Jarque-Bera normality test and the Sup Wald structural break test is included. The Sup Wald test is tested for an AR regression where the number of lags are based on the Hanna-Quinn information criterion.

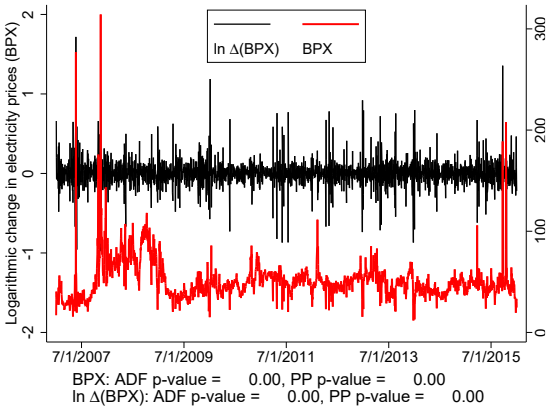
Electricity:	**Obs:**	**Mean:**	**Std dev:**	**Skew:**	**Kurt:**	**Jarque-Bera:**	**Sup Wald:**
BPX	2348	0.00	0.18	0.06	18.86	0.00	1.00
EPEX	2348	0.00	0.23	0.21	8.25	0.00	0.55
APX	2348	0.00	0.13	0.07	27.30	0.00	0.98
EEX	2348	0.00	0.20	0.51	17.86	0.00	0.51

Committing to the log-returns, Figure 2 shows the price and returns of each electricity market between 01.01.2007 and 31.12.2015. Unlike most financial prices, the augmented Dickey-Fuller test reveals that BPX, EPEX, APX and EEX prices does not contain a unit root, and consequently neither does the returns. A visual inspection of the prices seems to indicate a great deal of co-variation between the markets. For instance, the prices appears to increasing from 2007 to 2008 before reverting back to normal levels. Inspecting the returns, there appears to be volatility clustering present in the data. A more formal ARCH lm test confirms this suspicion.

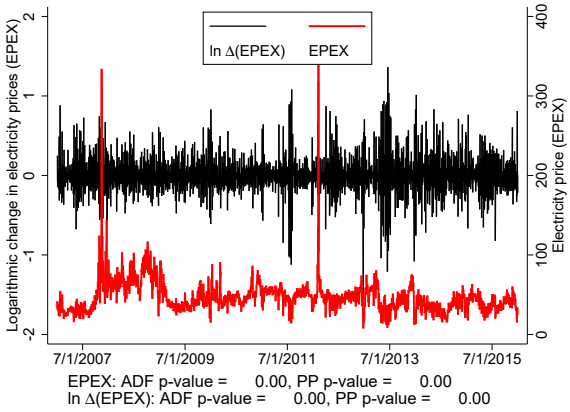
Figure 2: **Electricity prices and returns:**

This figure show the price and logarithmic return for the European electricity markets BPX, EPEX, APX and EEX.

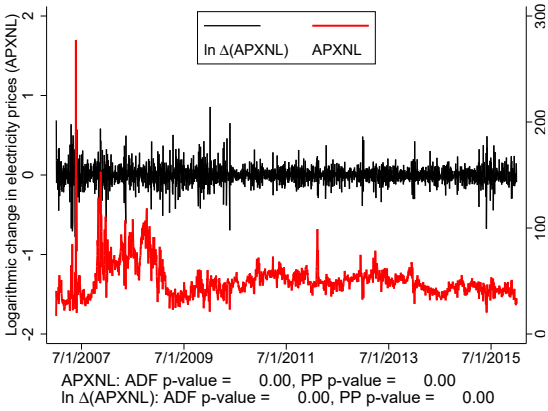
(a) **BPX**



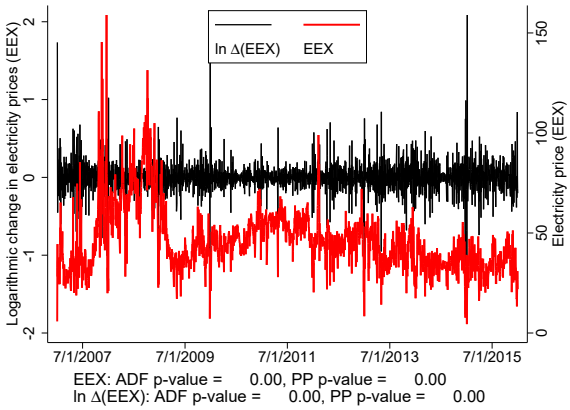
(b) **EPEX**



(c) **APX**



(d) **EEX**



In the interpretation of our results we consider monthly aggregated power exchange data between the individual countries in the CWE region. The data is gathered from European Network of Transmission System Operators for Electricity (ENSTSO-E). As we are interested in knowing how much electricity is being imported and exported between individual countries[2] In figure 3 we see that incresingly, Belgium imports more electricity from France than it exports. In the meantime Belgium exports more to APX than it receives. Figure 4 shows that the Netherlands is increasingly becomming more dependent on Germany as a source of power while exporting much less. Finally, we observe that at a stable rate France mainly export to Germany while importing less.

Figures 3 and 4 shows the amount of power is transferred monthly between the countries. The positive area shows how much i exports to j and the negative shows how much is imported from j to i. The red regression shows the direction of the monthly net exchange of power. That is, export subtracted by import.

Figure 3: **Net pairwise exchange of power:**

(a) **(BPX,EPEX)** (b) **(BPX,APX)**

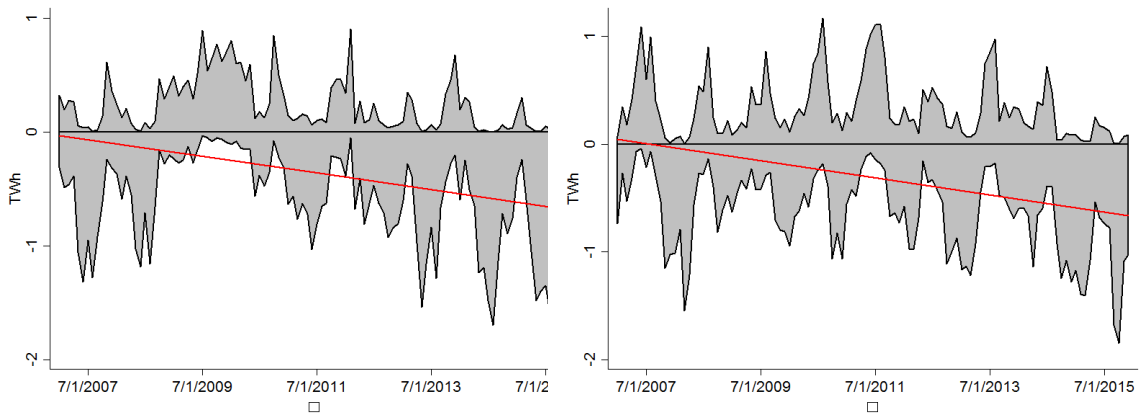
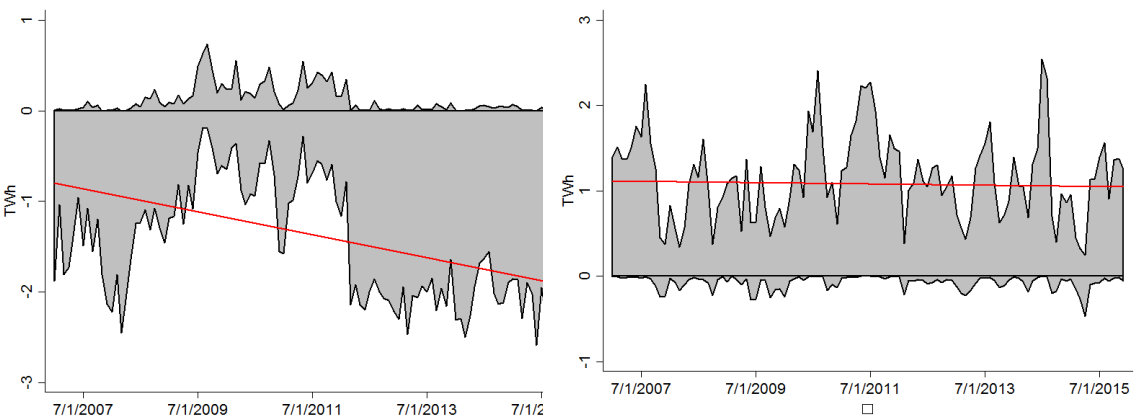


Figure 4: **Net pairwise exchange of power:**

(a) **(EEX,APX)** (b) **(EPEX,EEX)**



[2]We only include import and export from the CWE region.

4 Result

Based on the innovation terms obtained from the VAR(5) model, we proceed by applying a forecast error variance decomposition following the methodology of Diebold and Yilmaz (2012). The aim is to analyse the characteristics of the relation between the European electricity markets in regards to volatility spillover. Specifically, we look at the total volatility spillover ($S^g(H)$), gross directional volatility spillover both to ($S^g_{i\cdot}(H)$) and from ($S^g_{\cdot i}(H)$) market i, net directional volatility spillover ($S^g_i(H)$) and pairwise directional volatility spillover ($S^g_{ij}(H)$) for both the full and rolling-sample.

Table 3 (a) shows the level of spillover between the BPX, EPEX, APX and EEX electricity market based on the full sample. As indicated, Table 3 (a) shows the directional and total spillover. For instance, BPX has a self-caused variance of 50.03, but receives a directional spillover of 28.79 from EPEX, 13.23 from APX and 7.95 from EEX. Hence, the total directional spillover to BPX would thus be 49.97. On the contrary, BPX is transmitting a spillover of 5.45 to EPEX, 19.77 to APX and 7.60 to EEX. The total amount of volatility spillover from BPX to all other markets is then 32.82. Based on the observed findings, APX received the highest amount of volatility spillover (50.36) while EPEX (12.89) receives the least from all other markets. As EPEX only imports 2.4% of its consumption, this is not that suprising. Being the most import dependent (22.5%) APX receives highest amount of volatility. APX is also transmitting the least amount of volatility (23.33). As suggested by Diebold and Yilmaz (2012), it is better to give than receive. In that sense APX is getting a raw deal. Contrary to APX, but not that suprisingly EPEX is not only receiving least, it is also the market spreading the highest amount of volatility (65.04). Further, the total volatility spillover index is 36.30%, which indicates that on average almost two-fifths of the electricity markets volatility is caused by spillover from other markets. The total volatility is obtained from dividing the total row sum excluding diagonal entries by the total column sum including diagonal entries.

Table 3 (b) shows the net spillover for all markets, i.e. difference between the volatility transmitted by a given market to all others and the volatility received from all other markets. Seemingly, only EPEX is able to give more than it receives as the net spillover is positive ($52.15 = 65.04 - 12.89$). The three remaining markets are receiving more than they transmit, where APX (-27.03) has the worst trade-off followed by BPX (-17.15) and EEX (-7.97). In Table 3 (c) the difference between giving and receiving is disaggregated to bivariate relations. For instance, the pairwise spillover between BPX and EPEX is -23.34 ($= 5.45 - 28.27$). This implies that BPX transmit far less volatility to EPEX than BPX receives from EPEX. Considering the absolute value of the pairwise spillover, the highest amount of difference in volatility transfer is between BPX and EPEX. The pairwise spillover between BPX and EEX (-0.35) is the lowest difference.

Table 3: **Spillover in electricity prices:**

(a) **Total and gross directional volatility spillover**:

Europe (2007 - 2015)		From BPX	EPEX	APX	EEX	Sum (excl. own)
To	BPX	50.03	28.79	13.23	7.95	49.97
	EPEX	5.45	87.11	3.07	4.37	12.89
	APX	19.77	18.87	49.64	11.72	50.36
	EEX	7.60	17.38	7.02	67.99	32.01
Sum (excl. own)		32.82	65.04	23.33	24.04	
Sum (incl. own)		82.85	152.15	72.97	92.03	**36.30 %**

Contribution to forecast error variance of market i from error term of market j obtained from a VAR(5) model specified through SBIC.

(b) **Net directional volatility spillover**:

BPX	EPEX	APX	EEX
-17.15	52.15	-27.03	-7.97

(c) **Pairwise volatility spillover**:

(BPX,EPEX)	(BPX,APX)	(BPX,EEX)	(EPEX,APX)	(EPEX,EEX)	(APX,EEX)
-23.34	6.54	-0.35	15.8	4.49	-4.7

4.1 Net spillover

By studying the full sample we ignore any temporal changes within the relations between the European electricity markets. This can be remedied by redoing the analysis on a rolling-sample. Figures 5-8 (a) shows the net directional volatility spillover for each market, which is the difference between the gross directional spillover from market i and to market j. If the net spillover is greater than zero, then the market is transmitting more volatility than it receives. Figures 5-8 (b) shows the net power exchange from interconnection in the CWE region. That is, export subtracted by import, which is then regressed to show in which trend direction the time series is going.

Inspecting the net spillover for BPX it is clear that this market predominantly receives more volatility compared to what it is able to transmit. However, regressing the net spillover over time it is clear that there is an upward sloping trend. As such the discrepancy between spillover from and to BPX is decreasing. This happening in spite increased dependence on import. In the case of APX the net spillover is chiefly negative and appears to posses a negative trend, with imports slowly increasing in the period. For EPEX the net spillover is primarily positive and accompanied by an upward sloping trend. In the meantime, exports are increasing. Finally, EEX appears to differ from the preceding markets in the sense that EEX spillovers oscillates between being negative and positive on a frequent basis. The same trend can be noticed in the net power exchange.

Figure 5: **Net spillover:**

(a) **BPX** (b) **Belgium net power exchange**

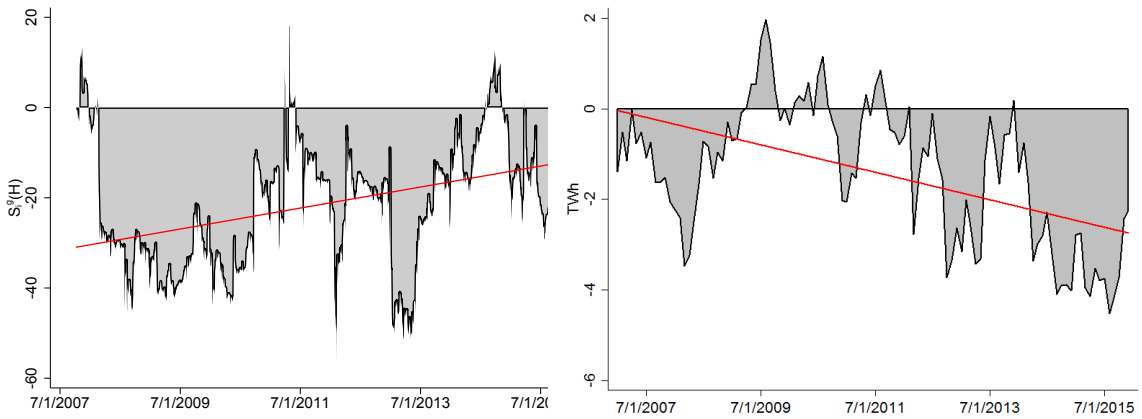


Figure 6: **Net spillover:**

(a) **APX** (b) **The Netherlands net power exchange**

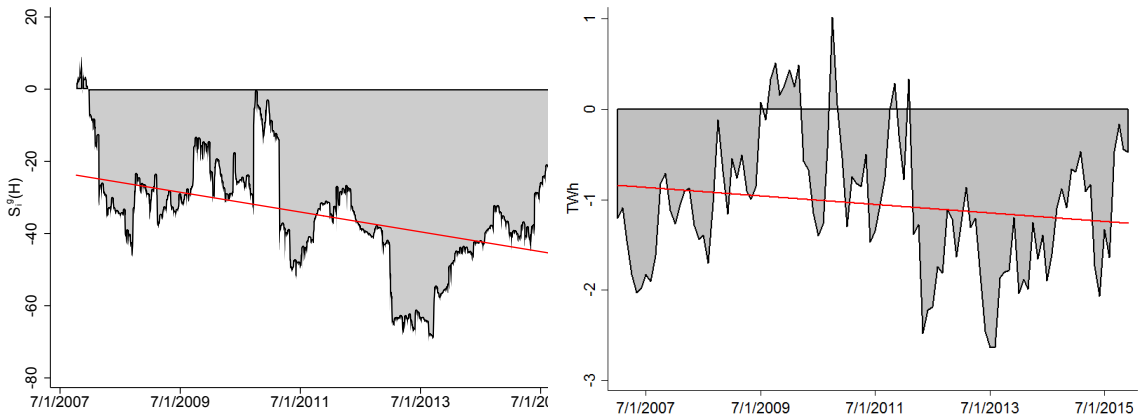


Figure 7: **Net spillover EPEX (France):**

(a) **EPEX** (b) **France net power exchange**

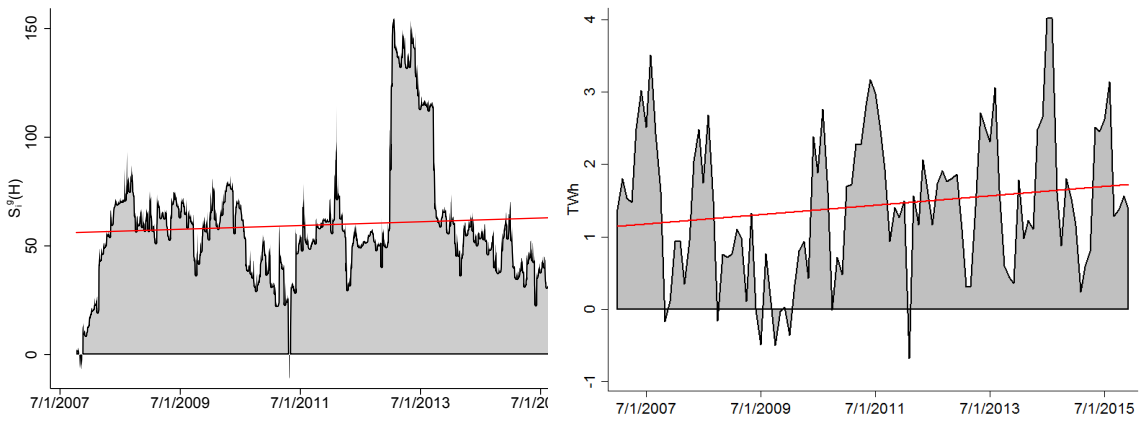
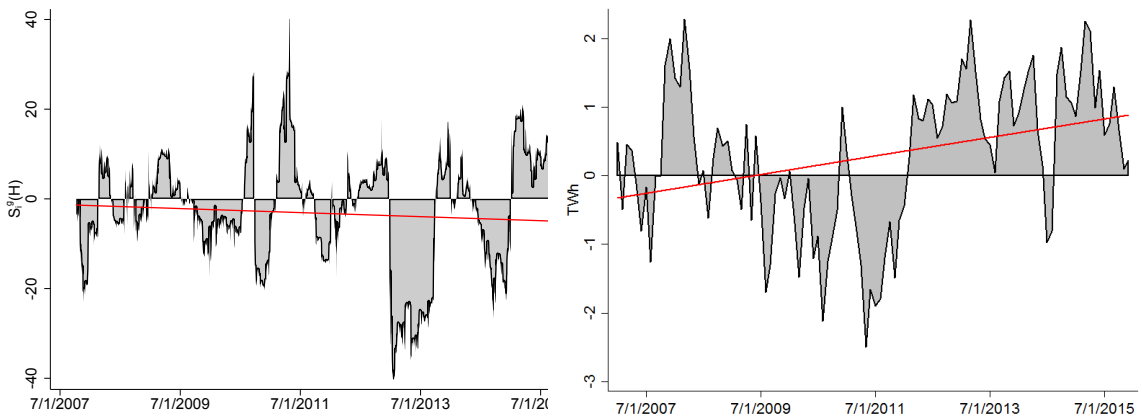


Figure 8: **Net spillover EEX (Germany):**

(a) **EEX** (b) **Germany net power exchange**



4.2 Net pairwise spillover

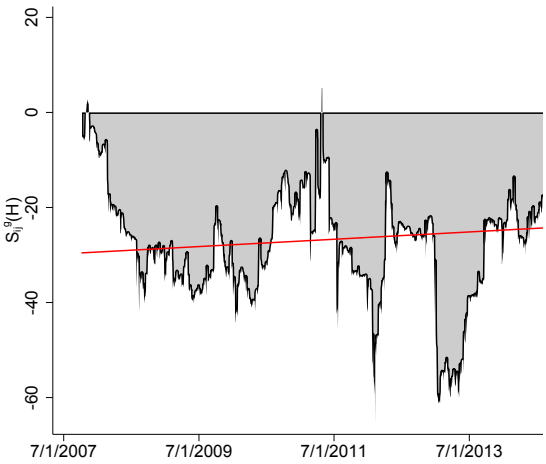
In this section we investigate the the pairwise volatility spillover, i.e. the difference between the volatility transmitted by market i to market j and the volatility transmitted back to market i from market j. When the pairwise volatility spillover exceeds zero we have a case where market i transmits more volatility than what it receives from market j. With four electricity markets we obtain six different pairwise volatility spillover plots. Specifically we get $\{\text{BPX}, \text{EPEX}\}$, $\{\text{BPX}, \text{APX}\}$, $\{\text{BPX}, \text{EEX}\}$, $\{\text{EPEX}, \text{APX}\}$, $\{\text{EPEX}, \text{EEX}\}$ and $\{\text{APX}, \text{EEX}\}$.

Figure 9 shows the pairwise volatility spillover, i.e. the difference between the volatility transmitted by market i to market j and the volatility transmitted back to market i from market j. When the pariwise voaltility spillover exceeds zero we have a case where market i transmits more volatility than what it receives from market j. With four electricity markets we obtain six different pairwise volatility spillover plots. Specifically we get $\{\text{BPX}, \text{EPEX}\}$, $\{\text{BPX}, \text{APX}\}$, $\{\text{BPX}, \text{EEX}\}$, $\{\text{EPEX}, \text{APX}\}$, $\{\text{EPEX}, \text{EEX}\}$ and $\{\text{APX}, \text{EEX}\}$.

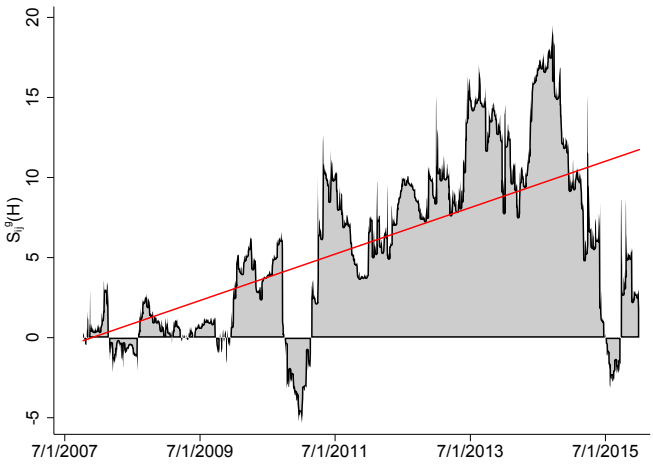
For BPX and EPEX we observe that the pairwise volatility is predominantly less than zero, which implies that BPX gives more than it receives to EPEX. However, from regressing the pairwise spillover between BPX and EPEX on time we obtain a positive and significant coefficient, thus implying that that the relation between these two markets might experience a reversal if the trend persist. On the other hand, BPX has been increasingly transmitting volatility to APX. As France is more dominant in exports to Germany, EPEX as well transmits volatility to EEX. the Netherlands on the other hand receive spillover from EEX, in the meantime relying on imports from Germany. Interestingly, there are present spillover relation between markets $\{\text{BPX}, \text{EEX}\}$ and $\{\text{EPEX}, \text{APX}\}$ which are not physically connected by power lines show no trend in the regression.

Figure 9: **Net pairwise spillover:**

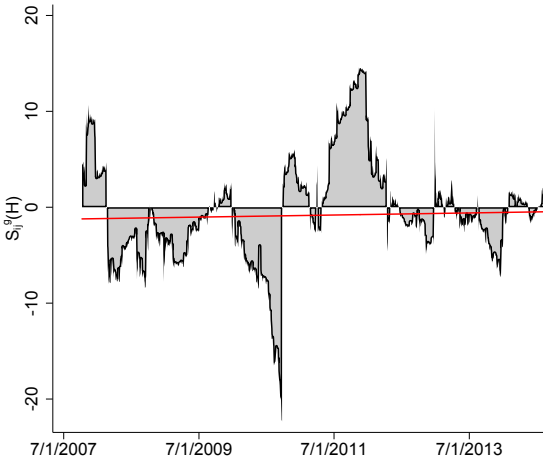
(a) **(BPX,EPEX)**



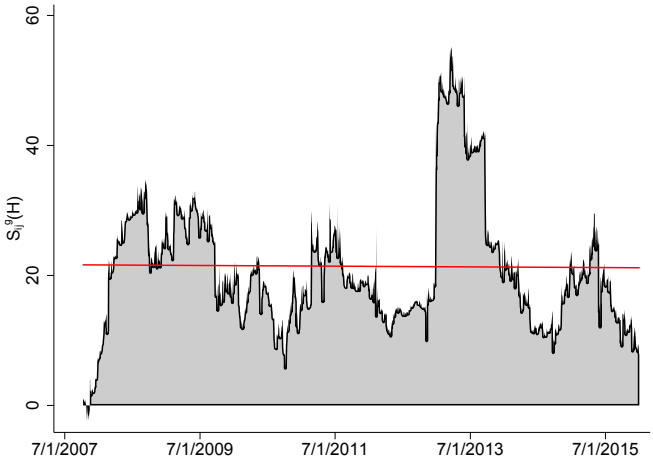
(b) **(BPX,APX)**



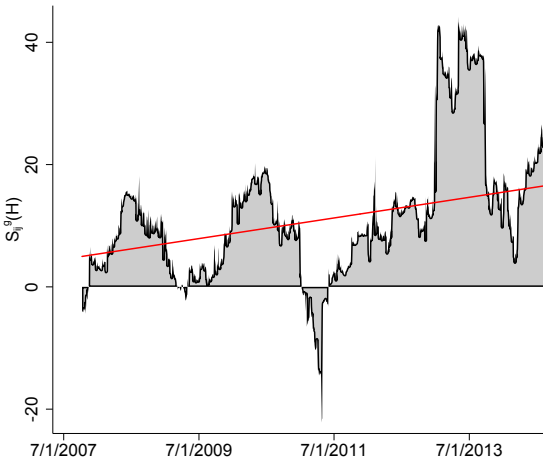
(c) **(BPX,EEX)**



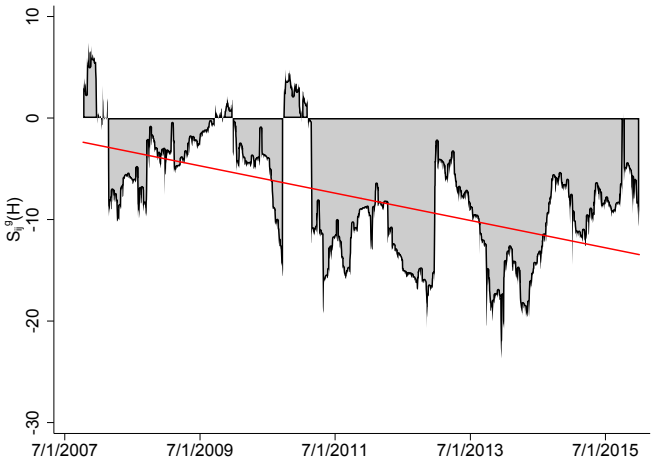
(d) **(EPEX,APX)**



(e) **(EPEX,EEX)**



(f) **(APX,EEX)**



In addition, we would like to remark that we tested the possibility that levels of spillovers were affected by the pairwise country net exchange of power. We collected monthly pairwise net exchange of power and regressed it against monthly spillovers, which we averaged by the daily price return data. We found no significant connection between them with the exception of BPX, APX. We found no significant connection between pairwise volatility and net exchange of power with the exception of BPX, APX, which is significant at 5% level. This can be expected as they are two smaller market and the exchange of power is high between the two.

5 Conclusion

In this study we applied the model by (Diebold and Yilmaz (2012)) to investigate spillover of power price volatility in the CWE region. We observe the spillover is present and the total volatility spillover is measured at 36.3% in the time period 2007-2015. We calculated the total and gross directional volatility spillovers. There we notice that the smaller markets, BPX and the APX are responsible for approximately half of its volatility. While the larger exchanges EEX and EPEX are considerably higher. As suspected, this indicates that the smaller markets are more susceptible to receive volatility from its larger neighbours.

With EPEX as the largest contributor of volatility in the regions its is the only exchange that gives more spillover than it receives, both in net directional spillover and pairwise spillover.France is the largest exporter in the CWE region and the EPEX least affected by external spillovers, moreover the only exchange that gives more than it receives of volatility. We observe that Belgium is the increasingly import dependent, but at the same time BPX is receiving less spillover. BPX receives most of its volatility from EPEX in France. The Netherlands is the most import dependent country in the region. Of all the exchanges APX receives most net directional volatility from its neighbor exchanges.

Although there is no direct interconnection between France and the Netherlands and Germany and Belgium, spillover is still present, but trend stationary. Consequently, our analysis lead us to suggest that there are inherent volatility spillovers in the region related to common supply and demand characteristics.

5.1 Further work

As there is not much literature on the volatility spillover between electricity markets there is work to be done. In our attempt to investigate relationship between volatility spillovers and interconnected physical transmission of power, we find evidence that there is a significant relationship between APX and BPX. But not between other exchanges. To get a better picture of this relationship we would have to acquire and test daily power transmission data, which would be interesting for further work.

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