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Shocked: Electricity Price Volatility Spillovers in Europe

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Shocked: Electricity Price Volatility Spillovers in Europe

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Abstract

European electricity markets are in the midst of unprecedented changes—caused by Russia's invasion of Ukraine and the rise of renewable sources of energy. Using high-frequency data, this paper investigates volatility spillovers across 24 countries in the European Union (EU) during the period 2014–2024 to provide a better understanding of the transmission of risks in an international context. We develop both a static and a dynamic assessment of spillover effects and directional decomposition between individual countries. Our main findings show that about 73 percent of the forecast error variation is explained by cross-variance shares, which means only 27 percent can be attributed to shocks within each country. In other words, cross-border volatility spillovers dominate the behavior in national electricity markets in Europe—and this effect has grown over time. We also implement an augmented gravity model of bilateral volatility spillovers across power markets in the EU. Altogether, these results provide important insights to policymakers and regulators with regards to greater integration of electricity markets and infrastructure improvements that would also help with the transition to low-carbon sources of power generation and strengthen energy security in Europe.

JEL Classification Numbers:	C22; C58; H23; L11; L94; Q41; Q42; Q48
Keywords:	Electricity prices; Volatility; Spillovers; Gravity model; Renewable energy; Electricity market reform; Europe
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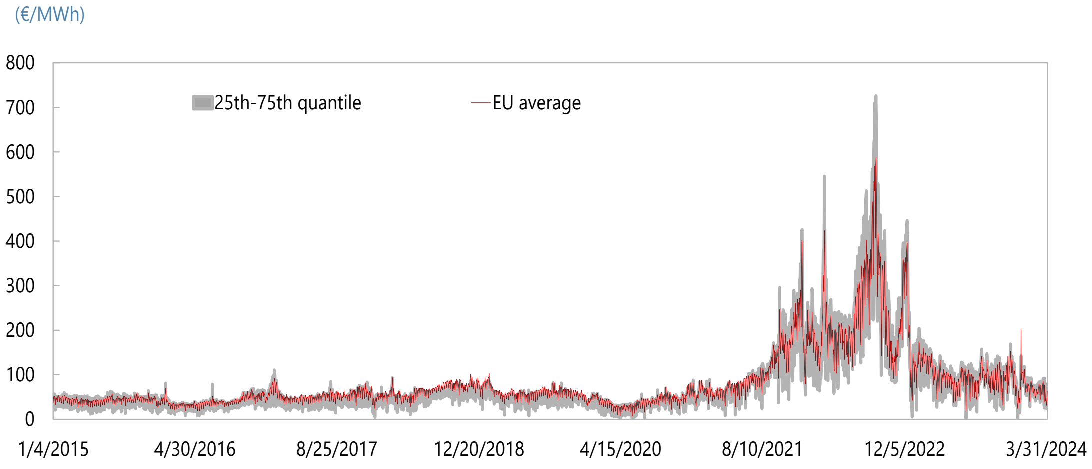
I. INTRODUCTION

European electricity markets are in the midst of unprecedented changes—caused by Russia's invasion of Ukraine and the rise of renewable sources of energy. Wholesale electricity prices in the European Union (EU) increased by more than 400 percent from an average of €35 per megawatt-hour (MWh) in 2020 to almost €250 per MWh in December 2021 even before the war in Ukraine, which triggered the worst global energy crisis since the oil embargo of the 1970s and pushed the average wholesale price of electricity above €500 per MWh in March 2022 (Figure 1). Electricity prices have come down from the peak but remain volatile and vulnerable to geopolitical and other shocks. Under the marginal pricing method, the most expensive technology needed to meet demand within a given period continues to determine wholesale electricity prices in Europe according to the cost of production, which in turn depends on energy sources used in electricity generation. Even as the levelized cost per unit of electricity from new utility-scale renewable power plants has dropped precipitously in recent years, the recent spike in wholesale electricity prices was broadly driven by the cost of production at natural-gas power plants (Zakeri *et al*., 2023). Understanding these complex interactions and spillovers across countries in the EU is therefore necessary for designing appropriate energy policies and reforms.

The continent's power grid—divided into several market areas—operates on a day-ahead auction price mechanism. The system is highly complex and involves large-scale mathematical programs with equilibrium constraints, indicating the technical challenges in market operation (Bask and Widerberg, 2009; Martin, Müller, and Pokutta, 2014). The European electricity market is characterized by its diverse structures and pricing mechanisms, but generally fall into two main pricing schemes: (i) marginal pricing (MP) and (ii) pay-as-bid (PAB), which have unique characteristics influencing market dynamics like frequency regulation and bidding. Some studies find extreme volatility spillovers across European electricity markets (Bunn and Gianfreda, 2010; Le Pen and Sevi, 2010; Castagneto-Gissey, Chavez, and De Vico Fallani, 2014; Ciarreta and

Figure 1. Wholesale Electricity Prices in Europe



Source: ENTSO-E; authors' calculations.

Zarraga, 2015; de Menezes and Houllier, 2016), but daily auction prices fail to explain persistent international differentials in wholesale electricity prices. This suggests deeper market forces at play that result in differences in the energy mix (i.e., the share of renewables), cause fragmentation, and limit competition and efficiency (Zachmann, 2008; Newbery *et al.*, 2018; Cevik and Ninomiya, 2023).

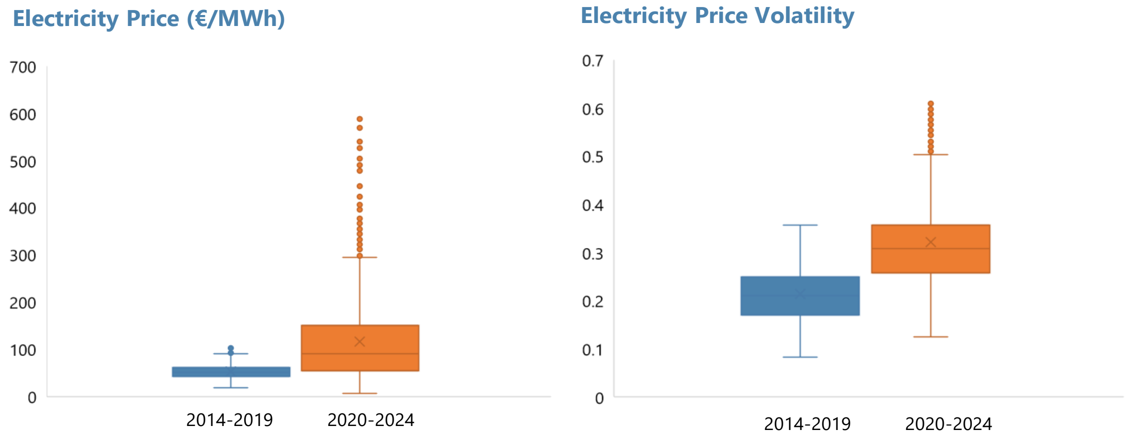
This study contributes to the literature by providing a dynamic assessment of volatility spillovers across power markets in Europe (Figure 2). We utilize the 15-minute frequency data for 24 European countries during the period from December 1, 2014 to April 30, 2024—obtained from the European Association for the Cooperation of Transmission System Operators (ENTSO-E)—to develop a granular analysis of wholesale electricity price volatility spillovers and directional decomposition between countries. We assess the degree of connectedness across power markets in the EU with the spillover index methodology developed by Diebold and Yilmaz (2009; 2012; 2014) to measure the varying extent to which volatility spills over from one country to another. This approach allows us to quantify the relative importance of domestic and other country shocks in electricity markets at different points in time and thereby provides a better understanding of the transmission of risks in an international context. A higher spillover value indicate a stronger influence of cross-country shocks on domestic wholesale electricity prices, pointing out extraneous events impacting the domestic electricity market. This methodology also show whether interaction between countries increase or decrease over time and how the direction of spillovers between countries change with particular events such as Russia's invasion of Ukraine. Furthermore, our analysis provides this information without having to pick out particular explanatory variables at the outset and without having to give a priori view on which are the most important electricity markets. Finally, the moving window application of the Diebold-Yilmaz technique presented in this paper also avoids having to pre-specify specific breakpoints as can be the case with other methodologies.

In this paper, we examine wholesale electricity price volatility and its spillover effects across 24 countries in Europe. Our main findings show that about 73 percent of the forecast error variation is explained by cross-variance shares, which means only 27 percent can be attributed to shocks within each country. In other words, cross-border volatility spillovers dominate the behavior in national electricity markets in Europe—and this effect has grown over time, especially after Russia's invasion of Ukraine. Nevertheless, we observe significant heterogeneity in the extent of volatility spillovers across countries: Ireland stands out as the country with the lowest spillover from others, while Hungary is subject to the highest level of spillover effects. There are also considerable differences in the strength of bilateral interaction in wholesale electricity markets. The strongest bilateral interaction in wholesale electricity markets is between Portugal and Spain with Spain explaining 32.4 percent of Portugal's forecast error variance and Portugal accounting for 31.4 percent of Spain's forecast error variance. Another strong interaction is between Latvia and Lithuania with Lithuania explaining 22.1 percent of Latvia's forecast error variance and Latvia accounting for 18.6 percent of Lithuania's forecast error variance. In contrast, volatility spillovers are significantly lower between geographically distant and unconnected markets, such as Austria and Ireland, which account for 0.5 percent and 0.3 percent of each other's forecast error variance, respectively. Hence, as expected, the extent of spillover effects is greater between adjoining electricity markets that are physically connected.

To further explore bilateral volatility spillovers across electricity markets in Europe, we implement an augmented gravity model and use the 15-minute frequency dataset with more than 876,582 observations on 576 pairs of countries over the period 2014–2024. These results shed additional light on the relationship between electricity price volatility spillovers and geography and the growing share of renewables in electricity generation. The main finding of this exercise is that the increased share of intermittent renewable sources of energy (such as solar and wind) is associated with greater volatility spillover effects in electricity markets between the countries.

As experienced during the war in Ukraine, energy markets in Europe—and beyond—are highly vulnerable to systemic shocks. Although data constraints do not allow the identification of specific policy measures at high frequency, the empirical analysis presented in this paper suggests that infrastructure modernization and regulatory reforms can help minimize the volatility in wholesale electricity prices, especially during the transition to renewables. This would be consistent with the EU's pursuit for a single market in electricity and closer integration of electricity grids throughout Europe. Furthermore, moving from the current zonal system with cost-based redispatch to a nodal pricing system would improve the efficient distribution of electricity and dampen excessive price fluctuations, considering the growing share of renewable energy sources with greater intermittency and close to zero marginal costs of generation, as shown by the results.[2] Altogether, these steps would also help with the transition to low-carbon sources of power generation, which is necessary for integrating electricity markets and

Figure 2. Distribution of Wholesale Electricity Prices and Volatility



Source: ENTSO-E; authors' calculations.

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[2] The share of renewables increased from an average of 16 percent of gross electricity consumption in 2005 to 44.7 percent in 2023, and it is projected to reach over 70 percent by 2030 (Busch *et al.*, 2023).

strengthening energy security in Europe (Newbery, Strbac, and Viehoff, 2016; Newbery *et al.*, 2018; Pollitt, 2019; Cevik, 2024a; Cevik and Jalles, 2024; Jamash, Nepal, and Davi-Arderius, 2024).

The remainder of this paper is organized as follows. Section II provides an overview of the relevant literature. Section III presents the data used in the analysis and stylized facts on electricity markets in Europe. Section IV presents the empirical methodology and results. Finally, Section VI offers concluding remarks with policy recommendations.

II. DATA OVERVIEW

We use a balanced panel dataset of high-frequency observations covering 24 countries in Europe during the period 2014–2024. Wholesale electricity prices for the period from December 1, 2014 to April 30, 2014 are obtained from the ENTSO-E in €/MWh at 15-minute frequency for 24 European countries. Our variable of interest is the volatility of wholesale electricity prices on a 15-minute basis for each country in the sample. We take the natural logarithm of price returns between each 15-minute period and calculate the standard deviation of log-returns.[3]

Table 1 provides the descriptive statistics for wholesale electricity price volatility, showing substantial variation across countries and over time. The average volatility of wholesale electricity prices is 0.262 over the sample period from 2015 to 2024, with a minimum mean value of 0.128 in Greece and a maximum mean value of 0.414 in Finland. The highest standard deviation in the dataset is also in Finland with 0.308, and the lowest standard deviation is in Italy with 0.043. This confirms that the volatility distribution of wholesale electricity prices in Europe has significant heterogeneity. There is a similar pattern of positive skewness across countries that implies a greater probability of large increases in volatility than large declines. The sample kurtosis is also markedly higher than 3 for the volatility of wholesale electricity prices in some countries, exhibiting fat-tail distributions. Finally, unit root tests reject the null hypothesis at the 1 percent level for all countries, thereby indicating that all volatility series are stationary.

Standard gravity variables—geographic distance and geographical contiguity—are drawn from the Centre d'Etudes Prospectives et d'Informations Internationales (CEPII) gravity database, as presented in Mayer and Zignago (2011) and Conte, Cotteriaz, and Mayer (2022). Geographic distance is measured as the great-circle distance in kilometers between the capital cities of each country pair; and a binary variable for geographical contiguity is assigned a value of 1 if a country pair shares an adjacent border and a value of 0 otherwise. We also include real GDP per capita and population in origin and destination countries to better encapsulate the role of size among country pairs. Finally, we augment the gravity model by introducing the 15-minute frequency data on the share of renewables in electricity generation in origin and destination countries, which is obtained from the ENTSO-E database. Descriptive statistics for these variables are presented in Table 2, indicating a significant degree of dispersion across countries in terms of

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[3] We present wholesale electricity prices and volatility series for each country in Appendix Figure A1 and Appendix Figure A2, respectively.

Table 1. Descriptive Statistics: Wholesale Electricity Price Volatility

Country	Mean	Std.Dev.	Minimum	Maximum	Skewness	Kurtosis	ADF
AT	0.292	0.181	0.098	1.827	4.571	31.984	-7.436***
BE	0.305	0.202	0.090	1.437	2.765	9.594	-8.075***
CH	0.232	0.161	0.056	1.305	3.184	15.318	-7.743***
CZ	0.310	0.150	0.098	1.054	1.797	4.532	-8.442***
DE	0.394	0.210	0.096	1.549	2.140	6.994	-7.931***
DK	0.369	0.217	0.062	1.635	1.772	5.333	-5.798***
EE	0.286	0.144	0.050	0.830	0.844	0.497	-5.294***
ES	0.227	0.193	0.033	1.298	2.273	6.246	-5.042***
FI	0.414	0.308	0.047	1.697	1.475	2.215	-4.822***
FR	0.277	0.156	0.095	1.141	2.451	8.044	-7.232***
GR	0.128	0.058	0.034	0.386	0.829	0.929	-5.043***
HU	0.243	0.113	0.090	0.892	2.977	12.853	-7.184***
IE	0.193	0.110	0.000	0.669	1.282	2.594	-5.209***
IT	0.131	0.043	0.053	0.346	1.433	3.332	-5.662***
LT	0.267	0.141	0.059	0.830	1.083	1.072	-5.468***
LV	0.263	0.142	0.059	0.830	1.083	1.055	-5.26***
NL	0.215	0.137	0.064	0.793	1.956	3.865	-5.185***
NO	0.157	0.166	0.023	1.271	3.900	19.343	-5.612***
PL	0.193	0.094	0.073	0.880	3.691	21.797	-7.649***
PT	0.217	0.195	0.032	1.269	2.372	6.421	-5.063***
RO	0.281	0.112	0.111	0.793	1.381	2.146	-7.037***
SE	0.325	0.250	0.038	1.405	1.237	1.237	-4.235***
SI	0.255	0.113	0.086	0.743	1.625	3.299	-6.905***
SK	0.318	0.150	0.097	0.915	1.419	1.875	-7.853***

Notes: AT, BE, CH, CZ, EE, ES, FI, FR, GR, HU, LT, LV, NL, PL, PT, RO, SI, SK, DE, DK, IE, IT, NO, and SE denote Austria, Belgium, Switzerland, the Czech Republic, Estonia, Spain, Finland, France, Greece, Hungary, Lithuania, Latvia, the Netherlands, Poland, Portugal, Romania, Slovenia, Slovakia, Germany, Denmark, Ireland, Italy, Norway, and Sweden, respectively. ADF refers to the augmented Dickey-Fuller stationarity test, with *** marking significance at the 1 percent level.

Table 2. Descriptive Statistics: Gravity Variables

Variable	Number of observations	Mean	Standard deviation	Minimum	Maximum
Bilateral Electricity Price Volatility Spillovers	876,852	0.004	0.189	-3.277	2.855
Distance (in kilometers)	803,781	1,291	670	55	3,290
Contiguity	803,781	0.1	0.3	0.0	1.0
Real GDP (in billions)					
Origin	876,852	3,253	9,435	25	43,604
Destination	876,852	3,196	7,648	25	43,604
Population (in millions)					
Origin	876,852	17.02	19.71	1.37	84.54
Destination	876,852	20.32	24.47	1.37	84.54
Share of Renewables (in percent)					
Origin	875,870	37.5	24.7	0.0	100.0
Destination	872,544	47.8	29.7	0.0	100.0

Source: CEPII; ENTSO-E; IMF; authors' calculations.

bilateral wholesale electricity price volatility spillovers and considerable heterogeneity in the level of income, population, geographic distance, geographical contiguity, and the share of renewables in electricity generation.

III. EMPIRICAL METHODOLOGY AND RESULTS

A. Estimating Electricity Price Volatility and Its Spillovers

There are common price trends and patterns of co-movement across countries, with Russia's war in Ukraine causing an unprecedented surge. We use the spillover index method introduced by Diebold and Yilmaz (2009; 2012; 2014) to measure the volatility connectedness of electricity markets across Europe. This approach—widely used in the financial literature—allows us to estimate the contribution of domestic shocks and other country shocks in electricity markets at different points in time. A higher spillover value indicates a stronger influence of cross-country shocks on domestic wholesale electricity prices, pointing out extraneous events impacting the domestic electricity market. This methodology also shows whether interaction between countries increase or decrease over time and how the direction of spillovers between countries changes with particular events such as Russia's invasion of Ukraine. Similarly, the moving window application of the Diebold-Yilmaz technique also avoids having to pre-specify specific breakpoints as can be the case with other methodologies. In summary, the spillover index methodology produces gross spillover values, which refer to the spillover from one country to another, and net spillover values, which refer to the difference in the gross spillovers between any two countries. Accordingly, an appealing feature of the methodology is that we can also calculate the gross spillover from all countries to a single country and likewise, the net spillover value between those countries and that specific country.

We explore volatility spillovers with an econometric framework that captures a broad spectrum of interdependencies under diverse market conditions. Given the nature and complexity of interactions in wholesale electricity markets, it is preferable to compute spillovers using a method which is invariant to variable ordering. Koop, Pesaran, and Potter (1996) and Pesaran and Shin (1998) develop the generalized vector autoregression (VAR) framework, which produces variance decompositions that are invariant to the ordering of the variables in the VAR. Under this approach, when one variable is shocked, the effect of shocks to other variables is integrated out using the historically observed distribution of the errors. The result is a set of decompositions that are invariant to variable ordering. This flexibility helps avoid the problem of having specify in advance what one believes ae the principal variables determining electricity price relationships and thus allows the data reveal the strength and direction of those relationships as they evolve over time.

The Diebold-Yilmaz methodology utilizes the generalized VAR framework and organizes the variance decomposition output to produce the spillover index, which provides a measure of the relative importance of the cross-variance shares (or spillovers) and thus indicates the degree of interaction between the variables. The generalized VAR framework used in this paper is structured as follows:

$$x_t = \sum_{i=1}^{p} \Phi_i x_{t-i} + \varepsilon_t \quad (1)$$

where x_t denotes the vector of the volatility of wholesale electricity prices , Φ_i is the autoregressive matrices, and ε_t is a vector of shocks. Using the volatility contributions from the generalized VAR variance decomposition, we can construct the total volatility spillover index:

$$S(H) = \frac{\sum_{i,j=1;i\neq j}^{N} \tilde{\theta}_{ij}^{g}(H)}{\sum_{i,j=1}^{N} \tilde{\theta}_{ij}^{g}(H)} \times 100 \quad (2)$$

This is the generalized VAR analog of the Cholesky factor-based measure used by Diebold and Yilmaz (2012). The total spillover index measures the contribution of spillovers of volatility shocks across markets to the total forecast error variance. Although it is sufficient to study the total volatility spillover index to understand how much of the shocks to volatility spill over across markets, the generalized VAR approach enables us to learn about the direction of volatility spillovers across markets. As the generalized impulse responses and variance decompositions are invariant to the ordering of variables, we calculate the directional spillovers using the normalized elements of the generalized variance decomposition matrix. We measure the directional volatility spillovers received by market i from all other markets *j* as:

$$S_{i\leftarrow j}(H) = \frac{\sum_{i,j=1}^{N} \tilde{\theta}_{ij}^{g}(H)}{\sum_{j=1;j\neq i}^{N} \tilde{\theta}_{ij}^{g}(H)} \times 100 \quad (3)$$

In a similar fashion, we measure the directional volatility spillovers transmitted by market *i* to all other markets *j* as:

$$S_{i\rightarrow j}(H) = \frac{\sum_{j=1;j\neq i}^{N} \tilde{\theta}_{ji}^{g}(H)}{\sum_{i,j=1}^{N} \tilde{\theta}_{ij}^{g}(H)} \times 100 \quad (4)$$

One can think of the set of directional spillovers as providing a decomposition of the total spillovers to those coming from (or to) a particular source. We obtain the net volatility spillover from market *i* to all other markets *j* as:

$$S_i^{net}(H) = S_{i\rightarrow j}(H) - S_{i\leftarrow j}(H) \quad (5)$$

The net volatility spillover is simply the difference between the gross volatility shocks transmitted to and those received from all other markets. The net volatility spillover provides summary information about how much each market contributes to the volatility in other markets, in net terms. It is also of interest to examine the net pairwise volatility spillovers, which we define as:

$$S_{ij}^{net}(H) = \tilde{\theta}_{ij}^{g}(H) - \tilde{\theta}_{ji}^{g}(H) \quad (6)$$

The net pairwise volatility spillover between markets *i* and *j* is simply the difference between the gross volatility shocks transmitted from market *i* to market *j* and those transmitted from *j* to *i*. Accordingly, this methodology provides a measure of interdependence across electricity markets by calculating the contribution of domestic shocks and cross-country shocks for each country.

In Table 3, we present the total spillover index and its components for each country in percentage form, with each row adding up to 100. The sum total of the off-diagonal entries (cross-variance shares) in each row gives a measure of the gross spillover from other countries to the country in question as shown in the "Contribution from Others" column of Table 3. The total spillover index is equal to the average of country entries in the "Contribution from Others" column, measuring what proportion of the forecast error variance in the system is attributable to cross-variance shares. These off-diagonal components for each country add up to its gross spillover to countries as shown in the "Contribution to Others" row at the bottom of Table 3. The difference between each country's entry in the "Contribution to Others" row and entry in the "Contribution from Others" column provides a measure of net spillover between this country and others as shown in the "Net Contribution" column of Table 2. This indicates whether a country is a net recipient or transmitter of spillovers in wholesale electricity markets.

We can make a number of observations on Table 3. First, the total spillover index has a value of 72.8 percent, which corresponds to the average value of cross-border volatility spillovers presented in the "Contribution from Others" column. This implies that about 73 percent of the forecast error variation is explained by cross-variance shares and accordingly means that only the remaining 27 percent can be attributed to shocks within each country. As a result, we can conclude that cross-border volatility spillovers dominate the behavior in national electricity markets in Europe. Second, as presented in the "Contribution from Others" column, the extent of spillovers from other countries shows significant variation across countries. Ireland with a value of 31.5 percent stands out as the country with the lowest spillover from others, while Hungary with a value of 82.7 percent is subject to the highest level of spillovers. Third, the strongest bilateral interaction in wholesale electricity markets is between Portugal and Spain with Spain explaining 32.4 percent of Portugal's forecast error variance and Portugal accounting for 31.4 percent of Spain's forecast error variance. Another strong interaction is between Latvia and Lithuania with Lithuania explaining 22.1 percent of Latvia's forecast error variance and Latvia accounting for 18.6 percent of Lithuania's forecast error variance. In contrast, volatility spillovers are significantly lower between geographically distant and unconnected markets, such as Austria and Ireland, which account for 0.5 percent and 0.3 percent of each other's forecast error variance, respectively. Therefore, as expected, the extent of spillover effects is greater between adjoining electricity markets that are physically connected.

The "Net Contribution" column of Table 3 provides a measure of net volatility spillovers for each European country (estimated as the contribution to others *minus* the contribution from others). When there are bidirectional spillover effects between countries, the net spillover score shows in which direction the greater strength of influence occurs and the extent of that influence. For

Table 3. Total Spillover Index and Components

(In percent)

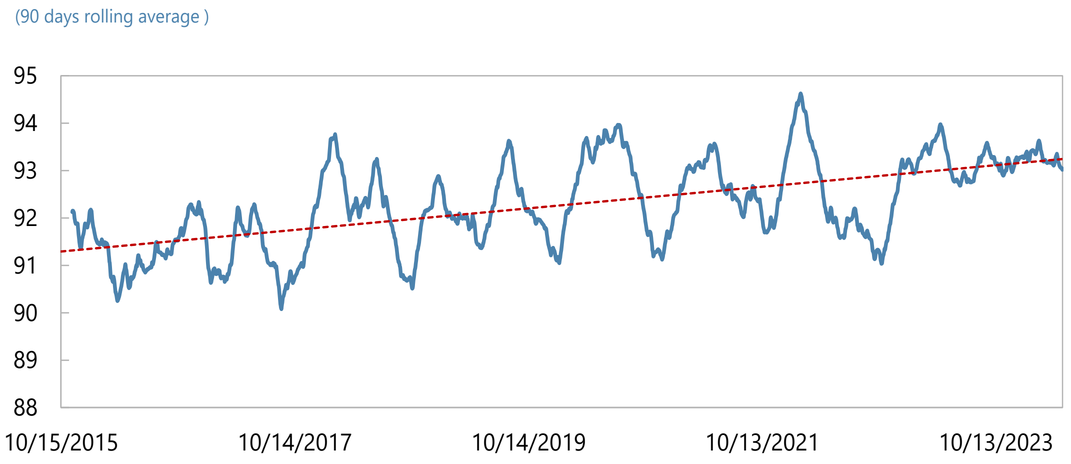
	AT	BE	CH	CZ	EE	ES	FI	FR	GR	HU	LT	LV	NL	PL	PT	RO	SI	SK	DE	DK	IE	IT	NO	SE	Contribution From Others	Net Contribution
AT	**27.5**	4.6	6.1	5.2	2.0	2.7	0.4	8.0	0.4	5.9	2.2	2.5	3.3	1.7	1.3	5.7	7.2	4.4	4.0	1.2	0.5	1.7	1.0	0.6	72.5	-41.8
BE	1.4	**25.6**	10.9	3.3	3.0	1.5	1.0	13.3	0.6	6.5	3.0	3.7	8.7	1.8	1.2	2.1	3.3	2.5	2.3	1.1	0.6	0.5	1.2	1.0	74.4	-10.4
CH	2.2	8.3	**22.0**	3.7	2.9	2.8	0.8	11.6	1.5	10.2	3.6	3.9	4.5	1.3	2.2	3.6	5.9	2.6	2.3	0.4	0.8	1.4	0.8	0.8	78.0	11.6
CZ	3.9	2.1	6.3	**22.7**	1.4	1.3	0.2	8.6	0.8	4.5	2.0	2.0	4.2	2.5	1.0	4.1	5.9	15.5	4.8	2.8	0.4	1.4	1.0	0.7	77.3	22.6
EE	0.4	2.5	2.0	2.8	**21.3**	0.2	6.3	1.9	0.7	2.9	18.9	19.8	1.1	1.2	0.1	1.6	1.2	1.3	0.8	3.7	0.1	0.7	2.2	6.4	78.7	34.3
ES	0.5	0.9	1.0	0.6	2.4	**31.1**	2.8	1.0	0.3	3.4	2.1	1.8	0.7	0.6	32.4	0.8	2.2	0.7	0.7	2.6	1.8	0.7	5.0	3.9	69.0	6.7
FI	0.2	0.7	0.2	1.5	11.7	0.3	**24.6**	0.2	2.6	0.4	12.5	14.0	0.2	0.3	0.3	0.6	0.2	0.8	0.4	2.9	0.2	0.6	3.7	21.0	75.4	1.5
FR	1.3	8.8	10.8	6.7	2.9	2.8	1.1	**17.3**	0.5	8.4	3.1	3.7	7.1	2.1	2.2	4.2	6.0	3.4	1.8	1.0	1.6	0.7	1.4	1.3	82.7	20.0
GR	0.8	0.8	1.1	1.3	5.0	5.2	6.5	0.8	**22.3**	2.1	5.5	6.8	1.7	0.8	5.5	2.6	0.9	1.4	1.0	6.0	0.3	3.9	8.6	9.4	77.7	-51.8
HU	2.1	3.4	10.6	7.2	2.5	2.6	0.9	8.9	1.5	**17.2**	3.2	3.5	3.3	3.9	1.9	8.7	7.2	4.6	1.5	0.8	0.2	1.6	1.5	1.3	82.8	19.7
LT	0.4	2.9	2.3	2.5	16.4	0.4	5.1	1.9	0.7	3.3	**20.5**	22.1	0.9	1.8	0.3	1.6	1.0	1.3	1.0	3.9	0.4	0.4	2.8	6.2	79.5	48.0
LV	0.5	3.1	2.5	2.6	16.3	0.6	5.2	2.1	0.7	3.4	18.6	**22.2**	0.9	2.0	0.4	1.6	1.1	1.3	1.1	3.3	0.5	0.4	3.1	6.8	77.8	63.1
NL	0.9	8.1	5.4	5.0	5.5	2.2	4.8	7.2	1.6	4.2	6.5	7.5	**18.5**	1.1	2.1	2.4	3.4	2.1	2.2	1.0	0.2	1.9	2.6	3.7	81.5	-21.4
PL	0.4	0.8	1.6	7.6	4.5	1.1	3.6	5.7	0.5	6.1	6.9	6.8	3.5	**30.2**	1.1	2.5	2.5	2.4	0.7	1.7	0.3	0.7	2.9	6.2	69.8	-33.7
PT	0.6	0.9	0.6	0.4	2.6	31.4	2.8	0.7	0.3	2.6	2.2	1.9	0.7	0.5	**34.5**	0.6	1.4	0.5	0.6	2.7	2.3	0.8	4.6	3.9	65.5	6.4
RO	2.2	2.0	4.6	7.0	1.2	3.2	0.2	5.0	2.3	10.6	1.4	1.5	3.6	3.9	3.2	**26.9**	8.5	5.2	2.0	1.1	0.2	2.5	1.6	0.3	73.1	-2.1
SI	1.8	1.8	5.4	9.3	1.2	3.4	0.2	7.2	0.7	9.3	1.5	1.7	4.9	2.3	3.2	7.5	**22.0**	5.9	4.6	1.6	0.4	2.9	1.2	0.2	78.1	-0.7
SK	3.6	2.2	5.2	18.2	1.3	1.3	0.2	7.3	0.6	6.3	1.7	1.7	2.6	3.6	1.0	5.0	5.7	**22.0**	4.6	3.1	0.4	1.2	0.6	0.5	78.0	-8.7
DE	3.6	4.0	3.5	8.5	1.3	0.9	0.3	5.7	0.6	3.0	1.9	1.9	3.5	1.8	0.7	3.9	6.2	6.9	**31.8**	5.3	1.8	1.7	0.8	0.4	68.2	-23.0
DK	1.1	2.3	0.8	2.0	7.2	1.7	7.7	1.5	1.2	1.3	7.3	8.4	1.4	0.9	2.3	0.6	1.4	2.4	2.1	**26.5**	1.4	1.1	7.4	10.1	73.6	-10.7
IE	0.3	0.3	2.0	0.1	1.2	1.1	0.5	1.4	0.1	0.8	0.8	1.2	1.3	1.4	0.8	6.4	4.1	0.5	0.2	1.4	**68.6**	3.3	0.5	1.6	31.5	-14.3
IT	1.9	0.9	0.7	2.8	0.5	8.3	0.2	0.8	3.0	1.0	1.3	1.4	1.3	0.2	7.7	3.1	1.4	2.5	5.8	7.6	2.1	**43.8**	1.1	0.6	56.2	-24.7
NO	0.6	1.9	5.7	0.6	8.1	0.3	11.6	1.7	2.4	5.7	8.9	9.8	0.5	0.4	0.5	1.7	0.4	0.5	0.3	4.0	0.4	0.7	**22.4**	10.7	77.6	-18.7
SE	0.2	0.9	0.4	1.2	11.8	0.5	14.6	0.3	2.5	0.6	12.3	13.6	0.3	0.3	0.5	0.3	0.1	0.6	0.3	4.0	0.2	0.5	3.7	**30.5**	69.5	28.0
Contribution to others	30.7	64.1	89.6	99.9	113.0	75.7	76.9	102.7	26.0	102.5	127.5	140.9	60.1	36.2	71.9	71.0	77.3	69.3	45.1	62.9	17.2	31.5	59.0	97.5		1748.4
Contribution including own	58.2	89.6	111.6	122.5	134.3	106.7	101.5	120.0	48.2	119.7	148.0	163.1	78.6	66.3	106.4	97.9	99.3	91.3	77.0	89.3	85.8	75.3	81.3	128.0		
																								Total Spillover Index	**72.8**	

example, Latvia with 63.1 percent exerts the largest net spillover to other countries, followed by Lithuania with 48 percent, and Estonia with 34.3 percent. In our view, this largely reflects the integration of electric systems in the Baltics with the Russia-controlled power grid during the period before Russia's invasion of Ukraine, although these countries have cut down energy imports from Russia following the war in Ukraine and are set to desynchronize completely from the Soviet-era electricity network in 2025. In contrast, Greece and Austria are net recipients of spillovers, with -51.8 percent and -41.8 percent, respectively. Overall, net volatility spillovers manifest a range of factors including electricity production mix, electricity trade (exports and imports), price formation, and infrastructure quality.

The full-sample estimation of the total spillover index and its components presented in Table 2 provides an interesting and granular assessment, but the methodology used in this paper becomes even more informative when the total spillover index is estimated on a moving window basis. This approach allows us to evaluate how the pattern of volatility spillovers evolve over time across Europe. Accordingly, we estimate the spillover index on a 90-day rolling window basis and present the resulting plot in Figure 2. There is a clear upward trend in dynamic volatility spillovers, increasing from an average of 89.9 in 2015 to 91.7 during the period 2019–2021 and 91.9 after 2022 with Russia's invasion of Ukraine. The patter of volatility spillovers with peaks and throughs highlights various developments including the oil price plunge of 2014-2016 and the COVID-19 pandemic in 2020. The unabating rise in renewables may also be a weighty factor contributing to the volatility of wholesale electricity prices and consequently increasing spillovers across electricity markets, as shown by Cevik and Ninomiya (2023).

The upward trend demonstrated in Figure 3 also suggests a surge in the transmission of cross-border spillovers across electricity markets in Europe after Russia's invasion of Ukraine. This is why we estimate the total spillover index for the period from January 1, 2022 to April 30, 2024.

Figure 3. Dynamics of the Total Spillover Index



Source: ENTSO-E; authors' calculations.

These results, presented in Appendix Table A1, show that the total spillover index increases to the peak of 96.3 percent and average of 83.4 percent, from 72.8 percent for the entire sample period, due to geopolitical developments and disruptions in energy supply chains across Europe following the outbreak of the war.

B. Developing a Gravity Model of Volatility Spillovers

To further explore bilateral volatility spillovers across electricity markets in Europe, we develop an augmented gravity model and use the 15-minute frequency dataset with more than 876,582 observations on 576 pairs of countries over the period 2014–2024. We include the standard gravity variables (income, population, geographic distance and geographical contiguity) along with the share of renewables in electricity generation in each country.

The gravity framework is the workhorse model in the literature to analyze the patterns of international trade as well as cross-border capital, migration and tourism flows (Tinbergen, 1962; Anderson, 1979; Bergstrand, 1985; Helpman and Krugman, 1985; Deardorff, 1998; Eaton and Kortum, 2002; Glick and Rose, 2002; Anderson and van Wincoop, 2003; Portes and Rey, 2005; Bergstrand and Egger, 2007; Gil-Pareja, Llorca-Vivero, and Martínez-Serrano, 2007; Chaney, 2008; Head and Ries, 2008; Santana-Gallego, Ledesma-Rodríguez, and Pérez-Rodríguez, 2010; Zhou, 2010; Okawa and van Wincoop, 2012; Yotov *et al.*, 2017; Cevik, 2022; Cevik 2023; Cevik 2024b). In the gravity model, bilateral flows between two countries are modeled as a proportionate function of economic size as measured by GDP and inversely proportionate to geographic distance between the countries.

In this paper, we augment the parsimonious gravity model with additional control variables and investigate the impact of several factors including geographical proximity and the share of renewables on bilateral electricity price volatility spillovers in a panel data context:

$$s_{ijt} = \alpha + \beta_1 gravity_{ijt} + \beta_2\, renewable_{it} + \beta_3\, renewable_{jt} + \eta_{ij} + \varphi_{it} + \mu_{jt} + \varepsilon_{ijt} \qquad (2)$$

in which s_{ijt} denotes bilateral wholesale electricity price volatility spillovers between a pair of countries (origin and destination) at time t; $gravity_{ijt}$ is a vector of standard gravity variables, including the level of income and population in origin and destination countries, geographic distance and geographical contiguity; $renewable_{it}$ and $renewable_{jt}$ are the share of renewables in electricity generation in origin and destination countries.

The η_{ij}, φ_{it} and μ_{jt} coefficients designate the country-pair fixed effects capturing time-invariant factors in origin and destination country and the origin and destination time fixed effects controlling for common shocks, respectively.[4] ε_{ijt} is the error term. To account for possible heteroskedasticity, all standard errors are clustered at the country-pair level.

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[4] The country-pair fixed effects cannot be included when geographic distance and geographical continuity between a pair of countries are already in the model. We also estimate the gravity model with country-pair fixed effects instead of gravity and low-frequency variables and obtain broadly similar results as shown in column [3].

Table 4. Gravity Model of Bilateral Electricity Price Volatility Spillovers

Variable	Coefficient [1]	[2]	[3]
Distance	0.000***	0.000***	
	[0.000]	[0.000]	
Contiguity	-0.098***	-0.103***	
	[0.005]	[0.005]	
Real GDP			
Origin	0.000***	-0.000***	
	[0.000]	[0.000]	
Destination	0.000*	0.000**	
	[0.000]	[0.000]	
Population			
Origin	0.001***	0.001***	
	[0.000]	[0.000]	
Destination	0.001***	0.001***	
	[0.000]	[0.000]	
Share of Renewables			
Origin		0.066***	0.095***
		[0.006]	[0.011]
Destination		0.140***	0.058***
		[0.004]	[0.010]
Number of observations	803,781	798,724	871,565
Number of countries	24	24	24
R^2	0.117	0.119	0.135
Country-pair FE	No	No	Yes
Country-time FE	Yes	Yes	Yes

Note: The dependent variable is bilateral electricity price volatility. Robust standard errors are reported in brackets. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Source: Authors' estimations.

Most gravity models are estimated with cross-sectional data, which may lead to biased results due to potential correlation between explanatory variables and unobservable country characteristics as it does not control for heterogeneity. Panel data estimations help address such econometric concerns by controlling for country and time fixed effects (Egger, 2000). Therefore, in this paper, we estimate the augmented gravity model with the Poisson Pseudo Maximum Likelihood (PPML) regression recommended by Santos Silva and Tenreyro (2006), which controls for heteroskedasticity and also tolerates correlated errors across countries and over time.

These results, presented in Table 4, provide interesting insights into the relationship between bilateral wholesale electricity price volatility spillovers and geography and the reliance on renewables in electricity production. First, distance between the countries is positively associated with electricity price volatility spillovers, but the geographical contiguity variable appears to have a negative coefficient, which indicates a dampening effect on volatility spillovers.[5] Second, the level of income in origin and destination countries have opposite effects on bilateral electricity price volatility spillovers: the estimated coefficient on GDP in origin country is negative and statistically significant, while the estimated coefficient on GDP in destination country is positive and statistically insignificant. On the other hand, population in both origin and destination countries are found to have a statistically significant positive effect on volatility spillovers, possibly capturing the impact of electricity demand. We should note that even though the absolute magnitude of estimated coefficients on gravity variables is small, their impact could still be very large given the mean value of these variables in the sample. Finally, with regards to the share of renewables in electricity production, we find positive and statistically highly significant coefficients in both origin and destination countries. In other words, the increased share of intermittent renewable sources of energy—such as solar and wind—is associated with greater volatility spillover effects in wholesale electricity markets between the countries in Europe, which is consistent with the findings of Cevik and Ninomiya (2023) and other studies.

IV. CONCLUSION

Europe's electricity markets are going through unprecedented changes driven by the energy transition and geopolitical tensions. The energy sector has long been in the midst of a structural shift away from fossil fuels in an effort to mitigate climate change, but geopolitical shock waves triggered by the war in Ukraine have coalesced into the worst global energy crisis since the oil embargo of the 1970s. Wholesale electricity prices in Europe increased from an average of €35 per MWh in 2020 to above €500 per MWh in March 2022, causing economic and political repercussions throughout the continent. Although electricity prices have come down from the peak, markets remain volatile and vulnerable to shocks. In this study, we provide a dynamic and high-frequency analysis of volatility spillovers across wholesale electricity markets in 24 European countries during the period from December 1, 2014 to April 30, 2024.

Our main findings show that about 73 percent of the forecast error variation is explained by cross-variance shares, which means only 27 percent can be attributed to shocks within each country. In other words, cross-border volatility spillovers dominate the behavior in national electricity markets in Europe—and this effect has grown over time, especially after Russia's invasion of Ukraine. Nevertheless, we observe significant heterogeneity in the extent of volatility spillovers across countries: Ireland stands out as the country with the lowest spillover from others, while Hungary is subject to the highest level of spillover effects. There are also considerable differences in the strength of bilateral interaction in wholesale electricity markets. The greatest bilateral interaction in wholesale electricity markets is between Portugal and Spain

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[5] It should be noted that the different frequency of electricity and gravity variables—daily *versus* annual—contributes to differences in variation and hence in the magnitude of the estimated coefficients.

with Spain explaining 32.4 percent of Portugal's forecast error variance and Portugal accounting for 31.4 percent of Spain's forecast error variance. Another strong interaction is between Latvia and Lithuania with Lithuania explaining 22.1 percent of Latvia's forecast error variance and Latvia accounting for 18.6 percent of Lithuania's forecast error variance. In contrast, volatility spillovers are significantly lower between geographically distant and unconnected markets, such as Austria and Ireland, which account for 0.5 percent and 0.3 percent of each other's forecast error variance, respectively. Thus, as expected, the extent of spillover effects is greater between adjoining electricity markets that are physically connected.

To further explore bilateral volatility spillovers across wholesale electricity markets in Europe, we develop an augmented gravity model and use the 15-minute frequency dataset with more than 876,582 observations on 576 pairs of countries over the period 2014–2024. These results shed additional light on the relationship between electricity price volatility spillovers and geography and the growing share of renewables in electricity generation. The main finding of this exercise is that the increased share of intermittent renewable sources of energy (such as such as solar and wind) is associated with greater volatility spillover effects in electricity markets between the countries.

As experienced with multiple geopolitical shocks including Russia's invasion of Ukraine, energy markets in Europe—and elsewhere—remain susceptible to systemic shocks. Even though data constraints do not allow us to identify the impact of specific policy measures, the empirical analysis presented in this paper indicate that infrastructure modernization and regulatory reforms can help minimize the volatility in wholesale electricity prices, especially during the transition to renewables. At the same time, moving from the current zonal system with cost-based redispatch to a nodal pricing system would improve the efficient distribution of electricity and dampen excessive price fluctuations, considering the growing share of renewable energy sources with greater intermittency and close to zero marginal costs of generation, as shown by the results. Altogether, these steps would also help with the transition to low-carbon sources of power generation, which is necessary for integrating electricity markets and strengthening energy security in Europe.

REFERENCES

Anderson, J. (1979). “A Theoretical Foundation for the Gravity Equation,” *American Economic Review*, Vol. 69, pp. 106-116.

Anderson, J., and E. van Wincoop (2003). “Gravity with Gravitas: A Solution to the Border Puzzle,” *American Economic Review*, Vol. 93, pp. 170–192.

Bask, M., and A. Widerberg (2009). “Market Structure and the Stability and Volatility of Electricity Prices,” *Energy Economics*, Vol. 31, pp. 278–288.

Bergstrand, J. (1985). “The Gravity Equation in International Trade: Some Microeconomic Foundations and Empirical Evidence,” *Review of Economics and Statistics*, Vol. 67, pp. 474–481.

Bergstrand, J., and P. Egger (2007). “A Knowledge-and-Physical-Capital Model of International Trade, Foreign Direct Investment, and Foreign Affiliates Sales: Developed Countries,” *Journal of International Economics*, Vol. 73, pp. 278–308.

Bunn, D., and A. Gianfreda (2010). “Integration and Shock Transmissions across European Electricity Forward Markets,” *Energy Economics*, Vol. 32, pp. 278–291.

Busch, S., R. Kasdorp, D. Koolen, A. Mercier, and M. Spooner (2023). “The Development of Renewable Energy in the Electricity Markets,” European Economy Discussion Paper No. 187 (Brussels: European Commission).

Castagneto-Gissey, G., M. Chavez, and F. De Vico Fallani (2014). “Dynamic Granger-Causality Networks of Electricity Spot Prices: A Novel Approach to Market Integration,” *Energy Economics*, Vol. 44, pp. 422–432.

Cevik, S. (2022). “Going Viral: A Gravity Model of Infectious Diseases and Tourism Flows,” *Open Economies Review*, Vol. 33, pp. 141–156.

Cevik, S. (2023). “Long Live Globalization: Geopolitical Shocks and International Trade,” IMF Working Paper No. 23/225 (Washington, DC: International Monetary Fund).

Cevik, S. (2024a). “Climate Change and Energy Security: The Dilemma or Opportunity of the Century?” *Environmental Economics and Policy Studies*, Vol. 26, pp. 653–672.

Cevik, S. (2024b). “Geopolitics and International Trade: The Democracy Advantage,” IMF Working Paper No. 24/21 (Washington, DC: International Monetary Fund).

Cevik, S., and K. Ninomiya (2023). “Chasing the Sun and Catching the Wind: Energy Transition and Electricity Prices in Europe,” *Journal of Economics and Finance*, Vol. 47, pp. 912–935.

Cevik, S., and J. Jalles (2024). “Restructuring Reforms for Green Growth,” *Scottish Journal of Political Economy*, Vol. 71, pp. 515–541.

Ciarreta, A., and A. Zarraga (2015). "Analysis of Mean and Volatility Price Transmissions in the MIBEL and EPEX Electricity Spot Markets," Energy Journal, vol. 36, pp. 41–60.

Chaney, T. (2008). “Distorted Gravity: The Intensive and Extensive Margins of International Trade,” *American Economic Review*, Vol. 98, pp. 1707-1721.

Conte, M., P. Cotteriaz, and T. Mayer (2022). “The CEPII Gravity Database,” CEPII Working Paper No. 2022-05 (Paris: Centre d’Etudes Prospectives et d’Informations Internationales).

de Menezes, L., and M. Houllier (2016). “Reassessing the Integration of European Electricity Markets: A Fractional Cointegration Analysis,” *Energy Economics*, Vol. 53, pp. 132–150.

Diebold, F., and K. Yilmaz (2009). “Measuring Financial Asset Return and Volatility Spillovers, with Application to Global Equity Markets,” *Economic Journal*, Vol. 119, pp. 158–171.

Diebold, F., and K. Yilmaz (2012). “Better to Give Than to Receive: Predictive Directional Measurement of Volatility Spillovers,” *International Journal of Forecasting*, Vol. 28, pp. 57–66.

Diebold, F., and K. Yilmaz (2014). “On the Network Topology of Variance Decompositions: Measuring the Connectedness of Financial Firms,” *Journal of Econometrics*, Vol. 182, pp. 119–134.

Deardorff, A. (1198). “Determinants of Bilateral Trade: Does Gravity Work in a Neoclassical World?” in *The Regionalization of the World Economy,* edited by J. Frankel (Chicago: University of Chicago Press).

Eaton, J., and S. Kortum (2002). “Technology, Geography and Trade,” *Econometrica*, Vol. 70, pp. 1741-1779.

Egger, P. (2000). “A Note on the Proper Econometric Specification of the Gravity Equation,” *Economic Letters*, Vol. 66, pp. 25–31.

Gil-Pareja, S., R. Llorca-Vivero, and J. Martínez-Serrano (2007). “The Effect of EMU on Tourism,” *Review of International Economics*, Vol. 15, pp. 302–312.

Glick, R., and A. Rose (2002). “Does a Currency Union Affect Trade? The Time-Series Evidence,” *European Economic Review*, Vol. 46, pp. 1125–1151.

Head, K., and J. Ries (2008). “FDI as an Outcome of the Market for Corporate Control: Theory and Evidence,” *Journal of International Economics*, Vol. 74, pp. 2–20.

Helpman, E., and P. Krugman (1985). *Market Structure and Foreign Trade: Increasing Returns, Imperfect Competition, and the International Economy* (Cambridge, MA: MIT Press).

Jamash, T., R. Nepal, and D. Davi-Arderius (2024). “Electricity Markets ion Transition and Crisis: Balancing Efficiency, Equity, and Security,” *Economics of Energy & Environmental Policy*, Vol. 13, pp. 5–21.

Koop, G., M. Pesaran, and S. Potter (1996). “Impulse Response Analysis in Nonlinear Multivariate Models," *Journal of Econometrics*, vol. 74, pp. 119–147.

Le Pen, Y., and B. Sevi (2010). “Volatility Transmission and Volatility Impulse Response Functions in European Electricity Forward Markets,” *Energy Economics*, Vol. 32, pp. 758–770.

Martin, A., J. Müller, and S. Pokutta, (2014). “Strict Linear Prices in Non-Convex European Day-Ahead Electricity Markets,” *Optimization Methods and Software*, Vol. 29, pp. 189–221.

Mayer, T., and S. Zignago (2011). "Notes on CEPII's Distance Measures: The GeoDist Database," CEPII Working Paper No. 2011-25 (Paris: Centre d'Etudes Prospectives et d'Informations Internationales).

Newbery, D., G. Strbac, and I. Viehoff (2016). "The Benefits of Integrating European Electricity Markets," *Energy Policy*, Vol. 94, pp. 253–263.

Newbery, D., M. Pollitt, R. Ritz, and W. Strielkowski (2018). "Market Design for a High-Renewables European Electricity System," *Renewable and Sustainable Energy Reviews*, Vol. 91, pp. 695–707.

Okawa, Y., and E. van Wincoop (2012). "Gravity in International Finance," *Journal of International Economics*, Vol. 87, pp. 205–215.

Pesaran, H., and Y. Shin (1998). "Generalized Impulse Response Analysis in Linear Multivariate Models," *Economic Letters*, Vol. 58, pp. 17–29.

Portes, R., and H. Rey (2005). "The Determinants of Cross-Border Equity Flows," *Journal of International Economics*, Vol. 65, pp. 269–296.

Pollitt, M. (2019). "The European Single Market in Electricity: An Economic Assessment," *Review of Industrial Organization*, Vol. 55, pp. 63–87.

Santana-Gallego, M., F. Ledesma-Rodríguez, and J. Pérez-Rodríguez (2010). "Exchange Rate Regimes and Tourism," *Tourism Economics*, Vol. 16, pp. 25–43.

Santos Silva, J., and S. Tenreyro (2006). "The Log of Gravity," *Review of Economics and Statistics*, Vol. 88, pp. 641–658.

Yotov, Y., R. Piermartini, J.-A. Monteiro, and M. Larch (2017). *An Advanced Guide to Trade Policy Analysis: The Structural Gravity Model* (New York: United Nations and World Trade Organization).

Zachmann, G. (2008). "Electricity Wholesale Market Prices in Europe: Convergence?" *Energy Economics*, Vol. 30, pp. 1659–1671.

Zakeri, B., I. Staffell, P. Dodds, M. Grubb, P. Ekins, J. Jaaskelainen, S. Cross, K. Helin, and G. Gissey (2023). "The Role of Natural Gas in Setting Electricity Prices in Europe," *Energy Reports*, Vol. 10, pp. 2778–2792.

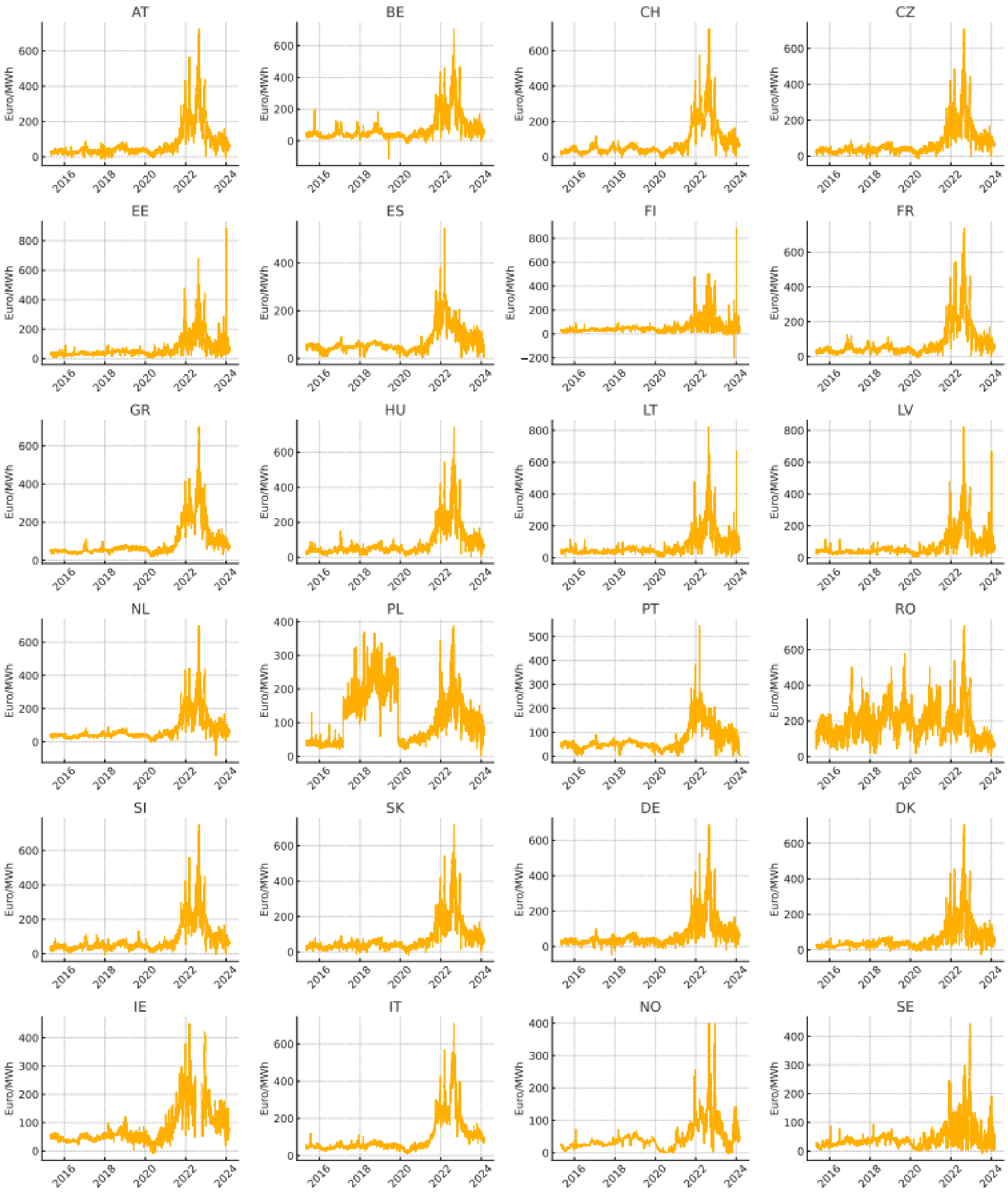
Zhou, M. (2010). "Multidimensionality and Gravity in Global Trade, 1950–2000," *Social Forces*, Vol. 88, pp. 1619–1673.

Appendix Table A1. Total Spillover Index and Components (2022-2024)

(In percent)

	AT	BE	CH	CZ	EE	ES	FI	FR	GR	HU	LT	LV	NL	PL	PT	RO	SI	SK	DE	DK	IE	IT	NO	SE	Contribution From Others	Net Contribution
AT	**13.0**	7.0	10.4	4.8	3.5	2.6	0.4	9.6	0.9	6.4	5.1	5.3	3.0	3.1	2.1	4.5	4.6	3.5	2.6	0.5	2.4	1.2	2.4	1.1	87.0	22.8
BE	9.5	**12.4**	12.8	4.7	3.3	0.9	0.5	13.5	0.6	7.4	5.4	5.5	2.9	3.4	0.8	2.9	2.4	2.2	2.3	0.6	1.6	0.7	2.7	1.1	87.6	8.1
CH	11.3	9.0	**17.7**	2.6	3.8	0.9	0.4	11.9	0.5	10.4	5.5	5.6	0.9	3.2	0.5	4.0	2.2	2.0	0.8	0.4	1.7	1.8	1.9	1.2	82.3	38.9
CZ	3.5	2.6	6.2	**27.0**	1.2	1.2	0.1	16.6	1.0	2.0	2.8	2.8	9.9	1.3	1.3	4.7	4.9	3.7	2.8	0.5	1.3	0.6	1.9	0.2	73.0	91.8
EE	7.2	4.7	4.6	2.2	**12.2**	3.3	1.7	5.0	2.7	3.1	12.1	12.5	1.3	2.1	3.6	3.3	2.2	2.6	1.5	4.2	2.0	1.8	1.3	2.5	87.8	-17.7
ES	1.3	0.8	1.2	2.7	2.1	**20.4**	2.9	1.1	13.1	1.1	1.3	1.5	1.1	1.4	20.7	6.7	1.8	1.7	2.0	1.0	8.5	4.5	1.0	0.1	79.6	24.3
FI	0.6	1.0	1.1	1.1	1.3	8.6	**28.0**	1.1	13.2	0.8	1.8	1.9	0.3	1.7	7.8	3.3	0.9	0.6	1.3	1.4	5.3	2.7	1.7	12.5	72.0	-21.1
FR	6.3	6.4	11.2	12.0	2.3	1.8	0.9	**20.1**	0.9	5.1	4.2	4.4	4.2	2.4	1.4	3.5	3.1	2.2	1.9	0.2	2.2	0.4	2.4	0.5	79.9	101.0
GR	2.3	3.4	1.5	1.9	3.7	7.4	4.9	3.3	**22.3**	0.9	3.3	3.9	2.2	0.1	7.1	4.3	3.1	0.9	2.1	3.2	0.5	9.6	5.7	2.5	77.7	15.2
HU	7.8	7.0	13.9	10.2	2.7	0.9	0.3	16.4	0.5	**8.9**	4.3	4.4	2.5	2.5	0.5	5.2	3.0	3.0	1.5	0.4	1.0	0.7	1.4	1.0	91.1	-18.2
LT	8.0	5.7	5.1	1.7	10.1	1.4	1.6	5.0	0.8	3.9	**13.9**	14.3	1.1	2.5	1.5	3.0	2.1	3.0	2.2	5.9	1.8	1.0	1.9	2.8	86.1	12.2
LV	8.0	5.8	5.2	1.6	10.0	1.4	1.6	5.0	0.9	3.9	13.7	**14.2**	1.1	2.5	1.5	2.9	2.1	2.9	2.1	5.8	1.8	1.0	2.0	2.8	85.8	16.4
NL	4.2	4.0	4.9	15.0	1.5	2.9	1.7	10.1	0.5	2.6	4.1	4.4	**18.4**	1.0	3.0	5.1	5.3	3.3	2.9	0.5	0.5	1.2	2.4	0.5	81.7	-3.4
PL	1.7	1.3	3.5	24.4	2.1	4.2	0.8	15.9	2.0	1.2	4.2	4.3	8.0	**5.9**	4.9	2.3	2.5	1.6	1.0	1.1	1.3	1.8	1.6	2.6	94.1	-52.0
PT	1.3	0.8	1.2	2.8	2.0	19.7	2.8	1.0	13.5	1.1	1.2	1.3	1.1	1.3	**20.3**	7.2	1.9	1.8	2.1	1.0	8.8	4.7	0.8	0.2	79.7	24.0
RO	5.5	3.1	7.1	16.2	1.8	3.5	0.4	13.5	2.9	3.9	3.6	3.8	5.8	1.4	3.1	**8.7**	5.1	4.1	2.3	0.2	1.2	1.7	0.8	0.4	91.3	8.5
SI	4.5	3.3	5.0	18.3	1.6	3.6	0.4	13.9	2.0	2.1	2.9	3.0	9.0	1.2	3.6	5.7	**7.4**	4.5	3.0	0.2	1.8	1.2	1.6	0.1	92.6	-23.8
SK	4.9	3.4	7.1	21.1	1.4	1.6	0.2	15.7	1.2	3.5	3.0	3.0	7.5	1.9	1.5	5.5	5.5	**5.1**	2.8	0.3	1.5	0.7	1.4	0.3	94.9	-38.2
DE	6.2	6.3	3.7	9.3	2.5	1.3	1.2	9.4	1.8	2.5	4.7	4.8	6.6	3.4	1.4	3.8	5.1	4.8	**10.2**	3.8	2.8	0.9	2.8	1.0	89.8	-41.4
DK	3.2	6.9	2.4	1.2	4.0	3.7	6.0	2.7	2.8	1.6	5.4	5.5	1.8	1.2	4.0	1.1	1.4	1.5	3.4	**22.4**	2.3	1.5	8.6	5.4	77.6	-35.0
IE	4.2	2.0	2.7	5.2	1.0	5.7	3.6	3.0	10.0	2.0	1.0	1.1	3.5	0.4	5.4	12.4	6.4	3.8	3.5	0.6	**18.9**	3.0	0.7	0.3	81.1	-23.2
IT	1.0	1.8	1.3	3.8	1.0	14.3	2.4	1.5	10.8	1.1	0.2	0.3	2.2	1.6	14.6	5.3	1.7	1.7	2.7	0.1	3.0	**26.4**	0.6	0.6	73.6	-27.8
NO	5.5	8.5	8.6	0.9	3.8	2.7	4.1	5.0	4.0	5.6	4.4	4.4	1.6	0.8	3.4	2.5	1.0	0.9	1.1	5.6	3.2	2.4	**16.4**	3.8	83.6	-32.9
SE	1.8	0.9	0.6	1.3	3.5	10.3	12.4	0.9	6.0	0.7	4.2	4.3	0.6	1.6	9.9	0.7	0.5	0.5	0.7	5.2	1.4	1.0	3.2	**28.2**	71.8	-28.3
Contribution to others	109.7	95.8	121.2	164.7	70.1	103.9	50.9	180.9	92.9	72.8	98.4	102.2	78.2	42.0	103.6	99.8	68.8	56.7	48.5	42.6	57.9	45.8	50.7	43.5		2001.5
																								Total Spillover Index	**83.4**	

Appendix Figure A1. Wholesale Electricity Prices by Country (Euro/MWh)



Appendix Figure A2. Wholesale Electricity Price Volatility by Country