Restructuring European electricity markets - a panel data analysis

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Abstract: This paper looks at the restructuring of European electricity markets that has been underway since the 1990s. The restructuring process, driven largely by EU legislation aiming to create a single market for electricity, has led to significant changes in how electricity markets in member states operate. This research estimates the impact of the restructuring process on electricity prices for industrial consumers. Much of the literature to date estimating the impacts of electricity market restructuring fails to take into account the possible endogeneity of the reform process. The possibility of endogenous reform is important to consider in this context; just as restructuring may affect prices, the decision to restructure may be influenced by prices. By using dynamic panel-data techniques, I aim to overcome this shortcoming. I find that once the endogeneity of reforms is accounted for, restructuring has, as of yet, had no statistically significant impact on electricity prices. This research highlights the importance of accounting for dynamics and possible endogeneity before drawing inferences about the results of EU electricity market reform.

1. Introduction

The restructuring of electricity markets has been underway around the world since the 1980s.[1] Restructuring (or "liberalisation") has generally involved separation (or unbundling) of vertically-integrated monopolies, privatisation of certain segments of the electricity market and incentive-based regulation for those parts of the industry not generally amenable to competition. As highlighted by Jamasb and Pollitt (2005), the restructuring of the electricity market in the European Union is the most significant cross-jurisdiction reform of the electricity-supply industry to date. While a number of member states were early adopters of electricity market reform, for many countries EU legislation was an important driver of the restructuring process. Legislative packages on electricity market restructuring were adopted in the EU in 1996, 2003, and 2009, and the impact of these packages are analysed here.

The liberalisation of electricity markets was undertaken for various reasons: political ideology, to improve government finances, and in many cases in the context of overall liberalisation of the services sector. Within the EU, expanding the internal market to network services was also a motivating factor, as noted by Florio (2013). In an overview of international restructuring processes, Joskow (2008) found that the motivation for reform was generally driven by factors such as construction-cost over-runs for new power plants, escalating operating costs, and high retail prices. He also notes that falling natural gas prices and new technologies (such as CCGT power plants) in some instances resulted in falling production costs. Policy makers sought to achieve overall cost reductions in the sector that would be passed on to consumers in the form of lower retail prices. Joskow (2008) presents a "standard liberalization prescription" for successfully reforming the electricity-supply industry. Some of the main steps he includes are the privatisation of formerly state-owned and vertically integrated monopolies to create incentives for performance improvements; and the vertical separation (or unbundling) of the sector to prevent cross-subsidisation among various industry segments and to ensure equal access to the networks for all competitors. He also recommends the horizontal restructuring of the generation segment to allow competition in power production, and the integration of transmission facilities with network operations to create an independent system operator.

While the overarching aim of electricity market reform was to improve efficiencies, which should (all else equal) result in lower prices, the EU energy market restructuring process may not have been accompanied by falling energy prices for numerous reasons. As stated previously, it was believed unbundling of the vertically integrated monopolies was necessary to foster competition in the industry.[2] Increased competition should increase operational efficiency and lower costs. However, it has been argued that unbundling is associated with increased operational costs and loss of scope or coordination economies. Thus, the potential impact of unbundling on the final price of electricity is ambiguous. Arguments for and against ownership unbundling of the transmission network are provided by Pollitt (2008).

[1] In 1982, Chile was the first country to begin the restructuring process, while other early reformers include Great Britain (with the introduction of The Electricity Act in 1989), and Norway (where the New Energy Act was introduced in 1990; see Bye and Hope, 2005).

[2] Indeed research by Davies and Waddams Price (2007) does find evidence that the market share of the incumbent electricity suppliers in various UK regions is lower when these companies have been unbundled.

Likewise, the expected effect of sector privatisation on electricity prices is unclear. A conceptual framework for assessing the impacts of reform is provided by Fiorio and Florio (2013). They note that, while private ownership may decrease inefficiencies and costs, this will not result in lower prices in the absence of effective regulation due to the inelastic nature of electricity demand. The importance of regulatory oversight in the context of restructuring energy markets is also highlighted by Florio (2014), who notes the continued importance of economic regulation to protect consumers. As the electricity sector becomes increasingly subject to both privatisation and market forces, there is a clear need for regulation to ensure that the benefits from restructuring are passed on to consumers and to protect more vulnerable consumer groups. This additional need for effective regulatory oversight may itself lead to higher costs, potentially offsetting other cost savings. The issue of ownership, and the various costs and benefits related to private versus public ownership, is discussed by Fiorio and Florio (2013), Haney and Pollitt (2013) and Del Bo (2013).

A significant change taking place in European energy markets concurrently with market restructuring is the increased focus on decarbonisation as a policy objective. As part of its 2020 Climate and Energy Package, the EU has adopted strict greenhouse gas abatement targets and minimum requirements on the proportion electricity generation coming from renewable sources. This has led to large-scale deployment of renewable generation technologies, particularly from wind and solar resources, across the EU. As noted by Moreno et al. (2012), the ultimate effect of increasingly "green" generation portfolios on electricity prices is ambiguous. While the increased use of zero-marginal-cost power sources may help lower electricity prices, the deployment of many of these intermittent technologies has been dependent on additional infrastructure investments as well as embedded subsidies that have raised electricity prices to retail customers. Increased levels of renewable generation on the system may also lead to additional network-related costs (as many sources of renewable generation are in locations far from demand centres and thus require investment in transmission and distribution networks to bring them on stream), and costs resulting from the need for back-up generation for intermittent generation sources.

Thus, while the main motivation behind electricity market reform is to increase efficiency and lower electricity prices, different reform steps may have opposing effects on prices. Furthermore, the fact that reform has taken place in the context of changes in the generation mix, with increasing levels of renewable and distributed generation, might also impact price. Indeed research by Apt (2005) (who analyses reform in the US) and Erdogdu (2011) (who considers a large number of developed and developing countries), among others, has not found a clear effect of reform on prices. Jamasb et al. (2005) have highlighted the need for more empirical studies on the effect of electricity market restructuring.

This paper seeks to contribute to the empirical evidence on the effects of restructuring in the EU. The main drivers of electricity price are likely to be electricity demand, and supply and generation costs.[3] This research hypothesises that the restructuring reforms might also influence price, but whether these effects will be positive or negative is ambiguous. In addition, factors such as the generation mix, electricity trade, and other policies affecting the electricity supply industry will also influence the final price of electricity. Thus, any analysis of the effects of market restructuring on the prices consumers pay for electricity should control for these factors. While a number of different

[3] As noted by Florio (2007).

data sets on electricity market liberalisation exist, there are none that contain sufficient detail to estimate the effects of detailed reform steps while controlling for potential confounding factors. Furthermore, the most comprehensive data set available, the OECD's ETCR database,[4] is missing data for a number of EU countries. Therefore, the data used in this analysis were compiled from a number of different sources (further details are provided in Section 3).

The restructuring that has taken place in Europe is the most internationally comprehensive to date; therefore, understanding the experience of the EU is relevant to electricity market reform in other countries. In particular, research analysing the effects of reform on electricity prices will be of interest to policymakers both in Europe and elsewhere. This study contributes to the research on the effects of electricity market restructuring in several ways. Firstly, the analysis considers a wider range of EU countries than previous analyses of EU electricity market reform. Secondly, the analysis includes detailed data on reform steps, including whether, and to what extent, system operators have been unbundled. Finally, in accordance with more recent and rigorous studies of restructuring, this analysis accounts for the dynamic nature of electricity prices, and for the potential endogeneity of the restructuring process. The paper proceeds as follows: section 2 contains a review of the relevant literature on this topic; section 3 presents the data used in my analysis; section 4 outlines the methodology; and section 5 discusses the results. Finally, section 6 presents some concluding remarks.

2. Related literature

Numerous papers provide conceptual discussions of electricity market restructuring and prescribe the appropriate steps to be taken in implementing reform. For example, Jamasb and Pollitt (2005) discuss the progress of electricity market reform in the EU. The authors note that individual member states have made significant progress towards liberalisation, but that the existence of a single market for electricity is far from being realised. An update by Pollitt (2009), highlights persistent concerns relating to levels of competition in the market. Pollitt (2012) provides an overview of the lessons learned from the liberalisation era based on an extensive literature review. More recently, Glachant and Ruester (2014) note that progress made towards an internal EU energy market may face setbacks in the coming years due to fragmented national policies regarding, for example, financial support schemes for renewable energies. On the other hand market coupling across the EU is decreasing market fragmentation;[5] evidence of increased market integration, at least for some European countries, is provided by Böckers and Heimeshoff (2014).

There is a growing literature of empirical analyses of the effects of electricity market reform considering a range of outcome variables. In one of the earliest papers to empirically test the impact of electricity market reform, Steiner (2000) found that restructuring is associated with lower electricity prices and higher capacity-utilisation rates. However, these results are questioned by Hattori and Tsutsui (2004), who replicate Steiner's analysis using an expanded data set. They also find that how the reform variables are defined significantly impacts the results. Their results show that generation unbundling and competition in wholesale markets did not lead to lower prices, and may in fact have resulted in higher prices.

[4] http://stats.oecd.org/Index.aspx?DataSetCode=ETCR

[5] I am grateful to an anonymous referee for highlighting this.

Further empirical evidence on the effects of restructuring electricity markets is provided by Nagayama (2007). He finds no evidence that individual reform measures have led to lower prices in developing countries. However, he does find that, in the presence of an independent regulator, unbundling is associated with lower prices, and that other reforms, such as privatisation, reduce prices in some regions but not others. Using a panel of 63 developed and developing countries, Erdogdu (2011) finds no consistent effects of restructuring on electricity price-cost margins and concludes that reforms have heterogeneous impacts across countries.

Moreno et al. (2012) examine the impact of increased renewable deployment and changing market concentration levels on electricity prices for European households. They find that increased penetration of renewable energy is associated with higher prices. Furthermore, they find that the lower concentration of European wholesale electricity markets (i.e., more participants on the supply side) is also associated with higher prices; although not addressed in the paper, this latter result could be indicative of reverse causality.

In summary, the earlier research on the impact of electricity market restructuring has yielded no consistent findings. This is unsurprising given the different countries, time periods, and reform measures analysed. A significant shortcoming of the earlier papers is a failure to take into account the path dependency of electricity prices and the possibility that restructuring may be endogenous; while prices and investment in the industry may be affected by reform, these variables may likewise influence the decision to restructure the industry.[6] More recently, a number of authors have used improved econometric techniques to account for this potential endogeneity. Indeed, evidence of endogenous reform was found by Nagayama (2009), who concludes that while high prices drive market liberalisation, market liberalisation does not necessarily lead to a reduction in electricity prices.

Accounting for the potential endogeneity of the reform process, Swadley and Yücel (2011) examine the impact of unbundling on prices and efficiency in electricity markets in 16 US states and Washington DC. The authors find that, if markets are designed correctly, retail consumers benefit from lower prices. Of the different market designs they examine, none lead to lower prices in the very short run. They also highlight that in order to see lower retail prices, consumers must actively participate in the market.

Other papers that assess the impact of restructuring, while controlling for potential endogeneity, include Gugler et al. (2013), Fiorio and Florio (2013), and Pompei (2013). Gugler et al. (2013) look at the impact of market reform on investment in 16 EU countries from 1990 to 2010 and find that different reform steps have opposing effects on investment in the industry. They conclude that, broadly speaking, restructuring measures that directly affect the market (such as the introduction of a wholesale-power pool) increase investment, while measures that affect the incumbent directly (such as ownership unbundling) decrease investment.

Fiorio and Florio (2013) also look at restructuring for a subset of European countries (the EU-15). Using a longer time series, they look at the evolution of electricity prices for the period 1978 to 2006 and investigate how they have been affected by energy-market liberalisation generally and

[6] This issue is discussed in greater detail by Jamasb et al. (2005).

ownership structure specifically. They find that the impact of liberalisation on prices is mixed but that private ownership is significantly associated with higher prices.

Pompei (2013) looks at the effect of regulatory reform in the OECD on total factor productivity (TFP) growth in the electricity sector. He finds that reforms to promote competitiveness lead to some general benefits, but with some negative impacts on efficiency. Breaking TFP growth into technological change, pure efficiency gains, and scale efficiency improvements, he finds that less strict entry regulation is associated with increased technological change and that vertical integration has a negative impact on pure efficiency. He also finds that higher levels of public ownership (that is lower levels of privatisation) are positively related to improvements in scale efficiency. The author stresses the importance of looking at the subcomponents of liberalisation when assessing its effects.

Finally, evidence from a number of studies examining the effect of energy market restructuring on households is summarised by Florio (2014). He highlights the lack of conclusive evidence that reforms have benefitted consumers. He notes that privatisation is not a pre-requisite for reform, that network unbundling does not benefit consumers unless it is accompanied by competition, and that the evidence that increased market openness has reduced prices is limited. His conclusions highlight the importance of the regulatory environment in safeguarding consumers, and the need for improved data to properly track the progress and effects of restructuring.

3. Data

No single data source on European electricity market restructuring exists at the level of detail needed to carry out the analysis for this paper. Therefore, data were collected from a number of sources, and compiled into a single data file. I focus on 27 EU member states (i.e., all EU countries prior to the recent joining of Croatia) and also include Norway, even though it is not a EU member state.[7] The inclusion of newer EU member states in the data (which were excluded by some previous studies of EU electricity market reform) provides additional variation in the reform and control variables included in the analysis.

The EU's first electricity restructuring package (Directive 96/92/EC) was adopted in 1996, with a requirement that it be transposed into national law by 1998. The second legislative package (Directive 2003/54/EC) was adopted in 2003, to be transposed into national law by 2004. The third and most recent energy package (Directive 2009/72/EC) was adopted in 2009, and member states had until 2011 to transpose the Directive into national law. Thus, by focusing on the period from 2001 to 2011, I am capturing a period during which significant changes were taking place to the design and function of electricity markets in Europe. While the data covers 28 countries and 11 years, the panel is unbalanced as data are incomplete for some countries and years.

3.1 Variables and sources

The dependent variable in the analysis is the log of electricity price to industrial users. These data are available from Eurostat; I use the price for medium-sized industrial users exclusive of taxes and levies; this corresponds to consumer band "Ie" up to 2007 (i.e.: Eurostat's old methodology) and

[7] While it would have been informative to widen the coverage of the data beyond these countries, collecting data on the market structure of non-EU countries would not have been possible at the level of detail used in this analysis.

consumer band “Ic” thereafter. I take the average of the biannual prices to form an annual price series.

For the analysis, data were collected on the following market restructuring variables as the explanatory variables of most interest:

- Transmission System Operator (TSO) unbundling. This variable refers to the extent to which the TSO’s activities have been separated from companies with stakes in the generation or supply of electricity. According to the European Commission (2007), as conflicts of interest may arise when there is vertical integration in the electricity market, it is necessary to vertically separate system operators from other segments of the market to ensure equal access to the grid for all participants, particularly for new competitors in the market.[8] The EC also expressed a concern that vertical integration would lead to under-investment in grid infrastructure and, thus, insufficient network capacity. This variable ranges from zero to four; with zero referring to a situation where no unbundling of the TSO has taken place and four referring to a situation where the TSO has undergone full ownership unbundling as set out in the Third Package (Directive 2009/72/EC).[9] The intermediate steps are separation of management, separate accounting, and legal unbundling. The data on TSO unbundling are derived mainly from the EC’s Benchmarking reports on the openness of electricity and gas markets.[10] Where data at a sufficient level of detail are not available in these reports, and for more recent years, these data are supplemented with information from annual, country-level reports from the Council of European Energy Regulators (CEER).[11]
- Distribution System Operator (DSO) unbundling. The source of this data series is the same as described above for TSO unbundling, and the variable is constructed in the same manner. Full ownership unbundling of the DSO was not required by the EU restructuring packages, therefore, for most countries, legal separation is the deepest level of DSO unbundling.
- Existence of a wholesale market. One of the steps many countries took in restructuring their electricity markets was the establishment of a wholesale market for electricity. This variable comes from the data set used by Erdogdu (2011), and is a 0/1 dummy variable indicating whether or not there was a wholesale market for electricity in place in a given country, in a given year. As the data used by Erdogdu (2011) end in 2009, data on more recent developments in countries which did not have a wholesale market in place by 2009 come from individual country profiles prepared by the European Commission[12] and from the CEER country-level reports. While this variable indicates whether or not there was a market in place for trading wholesale electricity, it does not differentiate between the types of markets, that is, whether it is a formal market (such as a power exchange), or an over-the-counter market comprising bilateral contracts between parties. Furthermore, it does not contain information about the volume of electricity traded.

[8] However, as Growitsch and Stronzik (2014) note, the economic evidence on the effects of TSO unbundling remains ambiguous.
[9] Note that the Third Package gave countries the option to have an independent systems operator in place in cases where countries did not wish to undertake full ownership unbundling of the transmission assets.
[10] http://ec.europa.eu/energy/gas electricity/legislation/benchmarking reports en.htm
[11] http://www.ceer.eu/portal/page/portal/EER HOME/EER PUBLICATIONS
[12] http://ec.europa.eu/energy/gas_electricity/internal_market_en.htm

- Market openness. Using data from the EC's Benchmarking reports and from the CEER's country-level reports, information was gathered on the degree of retail market openness. This variable represents the proportion of the total market (both residential and industrial) that is open to competition (i.e., the proportion of customers that are free to choose their electricity supplier). This variable ranges from zero to 100 percent, and is calculated on a consumption-volume basis.
- Wholesale market concentration. This is the market share of the largest generator in the electricity market. These data are available from Eurostat.
- Electricity imports. EU policies also aimed to increase electricity trade between member states. The model also includes information on the level of electricity imports relative to total electricity consumption in each country. I expect imports to be negatively associated with prices. As noted by the UK's Department of Energy and Climate Change (DECC, 2013), the possibility of importing electricity increases competition and thus should result in lower electricity bills. Independent of issues relating to market power, imported electricity should be cheaper and thus should result in lower prices to retail customers. However, this assumes that interconnection will be used efficiently which, as McInerney and Bunn (2013) show, is not always the case.[13]

While the variables discussed above are those that are the most interesting for the purpose of this analysis, they are not expected to be the main drivers of electricity prices. The variables that will be more important determinants of electricity price are demand and the costs of supplying electricity. To control for demand, I include real per-capita GDP which is a variable commonly included in reduced-form models examining the determinants of electricity prices. Real per-capita GDP may also capture information about the structure of the economy and the overall level of economic development.[14] Data on real per-capita GDP, expressed in 2005 dollar terms, are available from the World Bank.

To account for the cost of electricity generation, I include the price of natural gas in the model. A consistent data source for the price of gas used in electricity generation was not available; therefore, I use Eurostat data on the price of gas to industrial users as a proxy for the gas price paid by electricity generators. To check that this is a reasonable proxy, I examine the correlation between the IEA industrial gas prices and the price of gas used in power generation, for those countries and years where it is available, finding a coefficient of 0.96.[15] A country's generation mix is also likely to have an important impact on electricity prices. Prices are generally lower in countries that generate a significant proportion of electricity from hydro and nuclear sources; I control for the proportion of electricity generated from these sources in the estimation.[16] These data are available from the World Bank. The share of (non-hydro) renewables in power

[13] A European Commission "non-paper" on the Internal Energy Market (European Commission, 2011) notes that a lack of harmonised market rules between countries can actually result in electricity being exported from more expensive to less expensive markets, when trade should flow in the opposite direction.
[14] Indeed if GDP was only affecting electricity price through electricity demand, I could simply include industrial electricity consumption in the model. However, I find that electricity consumption is not significant in the model, indicating the GDP may be capturing more than demand effects.
[15] Ideally, the model should control for coal input prices also, as coal is the other main fossil fuel used, but a complete data series was not available. For those values of coal and gas prices that I do have, I find that the two prices are highly correlated, with a coefficient of 0.78.
[16] That is, the sum of hydro-plus-nuclear generation.

generation is not included in the model; on average this proportion is low, as shown in Table 1, and does not have a significant effect on price once other controls are included.

Over the time period analysed, significant efforts have been made by EU countries to increase the penetration of renewable energy sources used in power generation, through various economic and regulatory instruments. These policies are likely to have impacted the final price of electricity; for example, guaranteed price supports for renewables are generally funded via an increase in the final price of electricity. Furthermore, any increase in production costs associated with these policies are likely to be passed on to end-use electricity consumers. Due to these potential impacts on the electricity price, I attempt to control for such measures. I use data from the IEA/IRENA Joint Policy and Measures Database,[17] which gives information by country on past and present measures in place to support renewable energies. I use information on those supports classified as "Economic instruments". These measures include direct investments, fiscal or financial incentives, and market-based instruments. A feed-in tariff is a common example. I control for this by including a 0/1 dummy variable in the model, indicating whether or not an economic instrument is in place in a given country and year.[18]

3.2 Descriptive statistics

Table 1 presents descriptive statistics for some of the primary variables in the sample. It shows significant variation in industrial electricity prices. It also shows that there is significant variation across the sample in the market-structure, variables particularly in terms of TSO unbundling and market openness. Table 1 illustrates the high concentration of wholesale electricity markets in Europe. Furthermore, it shows that there is a large variation between countries in terms of the shares of electricity generated from nuclear, hydro, and other energy sources.

[17] www.iea.org/policiesandmeasures/renewableenergy/index.php

[18] There are also indicators of other policies in place to support renewables in the IEA/IRENA database, one such example is the presence of "policy supports". I do not control for this separately as a wide definition of policy supports is used by IEA/IRENA, which frequently includes the presence of economic instruments. Therefore including it may lead to double-counting of renewable-support policies.

Table 1: Descriptive statistics

	Mean	Std.dev.	Min	Median	Max	N	Source
Ind. electricity price (€/kWh)	0.077	0.025	0.031	0.074	0.182	289	Eurostat
TSO unbundling (0-4)	3.093	0.924	0	3	4	279	EC/CEER
DSO unbundling (0-4)	2.547	0.705	0	3	4	243	EC/CEER
Liberalised wholesale mkt. (0/1)	0.682	0.467	0	1	1	308	EC/CEER
Wholesale mkt. conc. (%)	58.568	27.857	15.3	52.4	100	264	Eurostat
Retail market openness (%)	77.652	32.076	0	100	100	282	EC/CEER
GDP/capita ($2005)	27,179	18,540	2,873	23,958	87,717	308	World Bank
Gas price (€/Gj)	7.189	2.093	2.428	7.242	12.704	287	Eurostat
Imports (GWh)	8,892	10,771	0	5,679	56,861	301	Eurostat
Share of hydro (%)	15.681	23.114	0	5.017	99.334	308	World Bank
Share of nuclear (%)	19.764	23.978	0	4.115	82.239	308	World Bank
Share of renew. (excl. hydro) (%)	4.938	6.092	0	2.76	40.223	308	World Bank
Renew. supports - econ. instrument (0/1)	0.383	0.487	0	0	1	308	IEA/IRENA

TSO and DSO unbundling are measured on a scale from 0 to 4: 0 = no unbundling; 1 = management unbundling; 2 = accounting unbundling; 3 = legal unbundling; 4 = ownership unbundling

Figure 1 illustrates average annual industrial electricity prices (in nominal terms, excluding taxes) across countries in the sample (EU-27 plus Norway) and for Finland and Malta.[19] The data indicate large differences in terms of electricity price levels and trends.

[INSERT FIGURE 1 HERE]

Over the period analysed, as expected retail markets gradually expanded. However, large variations in the degree of market openness across the EU over the period analysed are shown in Table 2.[20] While in 2001, many of the countries that I classify as "early reformers" had fully opened their retail electricity markets to competition; in countries that I classified as "late reformers," experience with market openness in 2001/2002 was low. Table 2 shows that in Latvia and Estonia for 2002, just over 10 percent of the market was open to retail competition, while in Malta the market had still not been opened to any form of retail competition as of 2011.

[19] These countries are chosen for illustration purposes as they represent countries that reformed early (Finland) and much later (Malta).

[20] According to EU legislation not all countries were required to restructure at the same pace. Some countries, particularly smaller countries, were granted derogations allowing them to implement reforms at a slower pace.

Table 2: Degree of market openness and wholesale market concentration 2001 and 2011 – "early" and "late" reformers

	Retail market openness		**Wholesale market concentration**	
	2001	**2011**	**2001**	**2011**
Early reformers:				
Austria	100	100	34.4	55.3
Belgium	35	100	92.6	70.7
Denmark	90	100	36	42
Finland	100	100	23	25.6
Germany	100	100	29	28.4****
Ireland	30	100	96.6	38
Italy	45	100	45	27
Luxembourg	57*	100	55.8**	82
Netherlands	33	100	n/a	n/a
Norway	100	100	30.7	33.6
Poland	51	100	19.8	17.8
Slovenia	64	100	.	52.4
Spain	54	100	43.8	23.5
Sweden	100	100	48.5	41
UK	100	100	22.9	45.6
Late reformers:				
Bulgaria	15*	100	n/a	n/a
Cyprus	0	66.7	99.6	100
Czech Rep	30*	100	69.9	69.4
Estonia	10*	33.2	90	87
France	30	100	90	86
Greece	30	100	98	85.1****
Hungary	30*	62.9	39.5	44.1
Latvia	11*	100	95	86
Lithuania	21*	100	77.1	24.9
Malta	0	0	100	100
Portugal	30	100	61.5	44.9
Romania	33*	100	20.5***	26
Slovakia	41*	100	84.5	77.7

Note that data were missing for some countries in some years: *, **, ***, **** Indicate that data refer to 2002, 2003, 2004 and 2010 respectively.

4. Methodology

When looking at the impact of market restructuring, numerous potential outcome variables may be examined. The final price of electricity is an obvious variable, as a major motive for market reform at the EU level was the desire to lower costs and improve the competitiveness of European industry vis-à-vis US and Japanese competitors. Therefore, I focus on the impact of restructuring on industrial electricity prices.

In order to identify the effects of reform on prices, I exploit the variability in the degree and speed at which various European countries reformed their electricity markets. Using fixed-effects estimation, I estimate the effect of market restructuring on market outcomes, controlling for any unobserved country-specific variables that are constant over time. The model can be expressed as:

$$P_{it} = R_{it}\beta + X_{it}\gamma + \delta_t + \zeta_i + u_{it}$$

$$i = 1, \ldots, I; t = 1, \ldots, T \qquad (1)$$

P_{it} represents the price of electricity to industrial users in country i at time t. R_{it} is a matrix of electricity market reform variables and X_{it} refers to the control variables.[21] I include, where appropriate, time fixed effects, δ_t, to capture common trends across the EU and common cyclical movements in macroeconomic variables. Country fixed effects, ζ_i, are included to control for country-specific characteristics that do not vary over time. The term u_{it} is the error term.

As mentioned previously, a major shortcoming of much of the analyses of the impact of market restructuring to date is a failure to account for the potential endogeneity of the reform process (for a detailed discussion, see Jamasb et al., 2005). It may be that restructuring leads to higher prices, at least initially (see Swadley and Yücel, 2011), or it may be that countries in which electricity prices are higher are more likely to reform their electricity markets.

It is clear that endogeneity of the reform process is likely to be an important issue in the estimation. While EU legislation was an important driver of reform in many countries, other countries embraced liberalisation and restructuring at a pace much faster than mandated by EU policy. This implies that, in the basic panel regression, causality may run in both directions (prices may be affected by the restructuring process, but likewise they may be an important driver of the decision to restructure), and thus the regressors may be correlated with the error term.

I also investigate the autoregressive properties of the dependent variable by including a lagged dependent variable in the model. In an analysis of market restructuring in the telecommunications sector, Gutierrez (2003) shows empirically that a failure to take account of path-dependency leads to an overestimation of the effects of reform. Unsurprisingly, I find that the lagged dependent variable is significant and I thus analyse the effects of reform using a dynamic panel-data model, where among the regressors I also include a lagged dependent variable to explain the persistence of the price series:

$$P_{it} = \alpha P_{i,t-1} + R_{it}\beta + X_{it}\gamma + \delta_t + \zeta_i + u_{it} \qquad (2)$$

$$i = 1, \ldots, I; t = 1, \ldots, T.$$

As discussed by Baum (2006), a problem arises in the estimation of the above equation as, in a fixed-effects model, the lagged dependent variable will be correlated with the error term. This will bias the coefficient on the lagged dependent variable, and also on any explanatory variables that are correlated with the lagged dependent variable. It has been shown (see Nickell, 1981) that this problem is particularly severe when the time dimension of the panel is short. To circumvent this problem, I use a dynamic GMM estimator, which uses first-differences to sweep out the individual fixed effects and then uses an instrumental-variables estimator which constructs instruments for the

[21] As discussed in Section 3.1, these are: per capita GDP, the price of gas, generation from nuclear-plus-hydro, imports, renewable support schemes and the cost of carbon.

lagged dependent variable using the second and deeper lags of Y; longer lags of Y will be orthogonal to the error term. Lags two and deeper of any endogenous regressors can also be used as instruments. The model described by Equation 2 is estimated using the Blundell-Bond system GMM estimator, and I present the results first by assuming electricity restructuring is exogenous and subsequently accounting for the potential endogeneity of the restructuring process.

This model can be estimated using difference or system GMM, I choose to use system GMM as it is more efficient.[22] The model is estimated using a two-step procedure that is robust with regard to autocorrelation and heteroscedasticity in panel data. However, because the use of the two-step estimator can, in small samples, cause severe downward bias in the standard errors (as discussed by Windmeijer, 2005, and Roodman, 2009a), I use the Windmeijer (2005) finite-sample correction of the variance for more accurate inference.

5. Results

5.1 Static panel analysis

I first estimate the effects of variables that are likely to be the largest determinants of electricity prices; these are fuel costs, demand (as measured by real GDP), and the level of imports relative to total electricity consumption. I subsequently add variables describing the market structure. Column (1) of Table 3 presents the results of a regression of the log of the industrial electricity price on what are likely to be its most important determinants, and includes time and country fixed effects. Column (1) reveals that real per-capita GDP and the price of gas are strongly related to the electricity price. As these variables are expressed as logs, the coefficients can be interpreted as elasticities; a one percent increase in real per-capita GDP is associated with a 0.44 percent increase in the price of electricity to industrial users. A positive association between GDP and household electricity price is estimated by Fiorio and Florio (2013), while Nagayama (2009) estimates a positive relationship between per capita GDP and industrial electricity prices. I control for the price of gas as a proxy for generation costs; in their study of electricity markets in the US, Swadley and Yücel (2011) find that the price of coal and gas have a significant impact on electricity prices. Column (1) shows that the price of electricity to industrial users is positively and significantly related to the natural gas price; a one percent increase in the gas price is associated with a 0.48 percent increase in the industrial end-user electricity price.

Table 3 shows that the proportion of electricity that comes from nuclear-plus-hydro sources is associated with lower electricity prices, although the relationship is not statistically significant in this specification. I find that electricity prices decrease with the proportion of electricity imports; a one percent increase in electricity imports (relative to total consumption) appears to reduce the price of

[22] Difference GMM transforms the equation (Equation 2 in this case) into first differences to remove the fixed effect, and then uses lagged levels as instruments for the first-differenced variables. System GMM adds a second equation in levels that increases efficiency in cases when lagged levels are poor instruments for first-differenced variables.

electricity by approximately 0.07 percent.[23] This result supports the view expressed by DECC (2013) that imports should result in lower electricity bills.[24]

The model presented in Column (2) includes a suite of market structure and reform variables, and controls for the presence of renewable supports and for the average cost of carbon under the EU's Emission Trading Scheme (ETS). However, as the data on some of the market reform variables are incomplete, adding all of them decreases the number of observations. Therefore, in Column (3), I exclude those reform variables that are never statistically significant, that are shown in Column (2) to be of little economic importance, and/or for which data are missing; these are the degree of unbundling of the DSO, the degree of retail market openness, and wholesale market concentration.

The coefficients on real GDP, gas price, and imports do not change notably after I include the market-reform variables. The coefficient for nuclear-plus-hydro generation becomes higher and significantly associated with lower prices, as expected. Column (3) of Table 3 shows that, relative to the reference case of legal unbundling of the TSO, countries that have undergone only the minimal possible separation, that is separate management of the TSO from other segments of the market, have an industrial electricity price that is 9.4 percent higher. This effect is implausibly large and signals the problem with assessing the impacts of reform using a static framework. None of the other modes of unbundling are significantly associated with the electricity price. Column (3) also shows that the presence of a liberalised wholesale-electricity market is associated with a price that is 5.8 percent lower.

Finally, column (3) shows that the presence of economic instruments supporting renewables are associated with an industrial electricity price that is 7.1 percent higher, and prices are also increasing in the cost of carbon.[25]

5.2 Dynamic panel model

The results discussed above are based on a static model; however, the price of electricity is likely to exhibit a certain degree of path-dependency, implying that the dynamic nature of this variable should be accounted for in the model. Thus, I re-estimate the model in a dynamic-panel framework that includes a lagged-dependent variable as a control. As discussed in Section 4, including a lagged-dependent variable in a fixed-effects model may lead to biased coefficients, and thus system GMM is used to estimate the dynamic model. As a robustness check I also run a dynamic model using the bias-corrected least-squares dummy variable (LSDVC) estimator (for an explanation of this estimator refer to Bruno, 2005).

Initially I model the effect of unbundling and liberalised wholesale markets on electricity prices assuming these reform variables are exogenous, and later relax this assumption. Column (1) of Table 4 presents the results when I assume that the significant reforms from the static, fixed-effects model

[23] Fiorio and Florio (2013) generally find that electricity prices have a significant negative relationship with electricity imports.

[24] The effect of imports on the final price of electricity could also be capturing the degree of market isolation as market power, and thus the price of electricity, is likely to be higher in a more isolated market (as indicated by lower imports). However, when I check the effect of overall electricity trade (imports plus exports relative to electricity consumption), this variable is not statistically significant, suggesting that imports are capturing more than market isolation.

[25] As the ETS came into effect in 2005, the carbon price is zero prior to this year.

are exogenously determined. In this model, I find that the presence of a liberalised wholesale market is associated with prices that are 6.1 percent lower. The results from this model show that the categorical variable representing TSO unbundling no longer indicates that minimal unbundling increases prices; once a lagged dependent variable is included in the model, none of the categories of TSO unbundling are significantly associated with electricity prices. Table 4 also shows that the relationship between real GDP and electricity prices is no longer significant once the path dependency of electricity prices is taken into account. The coefficient on the gas price remains positive and significant in the dynamic model, although the coefficient is slightly lower. The results from Column (1) confirm that renewable support schemes are associated with higher electricity prices. However, the coefficients for the share of electricity generated by nuclear-plus-hydro sources, the ETS price, and the share of imports in electricity consumption are no longer statistically significant.[26]

As mentioned previously, the results presented in the first column of Table 4 are based on the assumption that the unbundling of the TSO and the introduction of liberalised wholesale markets are exogenously determined. However, it may be that countries decided to take these steps as a result of having higher electricity prices. Column (2) presents the results of a model in which I assume the reform variables are endogenously determined. When I assume electricity reform is endogenous, the coefficients on TSO unbundling remain insignificant. Furthermore, in this model, the coefficient for the liberalised wholesale market variable is no longer significant. Thus, assuming that electricity market reform is endogenous, I cannot conclude that it has had any significant effect on electricity prices for industrial customers.

Table 4 presents some of the diagnostics from the dynamic GMM regressions, reporting the results of a test for second-order autocorrelation and a Sargan test of over-identifying restrictions. The Arellano-Bond tests indicate that second-order autocorrelation is not a problem, while the Sargan tests indicate that the instruments used in the models are appropriate. Note that I restrict the number of lags in the models to avoid the potential pitfall of instrument proliferation in system GMM estimation (as discussed by Roodman, 2009b).[27]

Finally, it has been noted by Growitsch and Stronzik (2014), for example, that when the number of countries in the sample is relatively small, the dynamic GMM estimator may lead to small-sample bias. Therefore, I follow the authors and check whether the results are significantly different based on the bias-corrected least-squares dummy variable (LSDVC) estimator. Column (3) of Table 4 confirms that they are not; in this model only the lagged dependent variable, the price of gas and the proportion of electricity generated from nuclear-plus-hydro sources are significant.

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[26] Fiorio and Florio (2013) also found that imports, while significant in a static model, were not significant in a dynamic model.

[27] In the endogenous model, as I have included a number of covariates in the equation and as there are only a limited number of countries in the data set, I constrain the model such that only the second lags of the endogenous variables are being used as instruments. The first lag is not available as an instrument as it will be correlated with the error term, and while deeper lags of the endogenous variables are valid instruments, using deeper lags will reduce the sample size. In the exogenous model, lags two to five are used. In both models I also collapse the instrument matrix, a technique discussed by Roodman (2009a) and Roodman (2009b), to further restrict the number of instruments. Some robustness checks that were carried out on the number of instruments are discussed in the Appendix to this article available online.

Table 3: Fixed-effects estimation

Y variable: Log(Ind. Electricity price)	(1) Basic model	(2) Incl. mkt structure	(3) Only signif mkt structure
Log(Real GDP/capita)	0.436***	0.459**	0.489***
	(0.139)	(0.181)	(0.155)
Log(Gas price)	0.478***	0.436***	0.430***
	(0.0543)	(0.0702)	(0.0629)
Log(Sh. of hydro+nucl in power gen)	-0.0411	-0.111***	-0.0711**
	(0.0285)	(0.0355)	(0.0313)
Log(Electricity imports%)	-0.0660***	-0.0925***	-0.0535***
	(0.0189)	(0.026)	(0.0204)
TSO Unbundling:			
None			0.106
			(0.119)
Management		0.150**	0.0936**
		(0.0616)	(0.0441)
Accounting		0.0354	0.0165
		(0.0551)	(0.045)
Legal		Reference	Reference
Ownership		0.0174	-0.00197
		(0.0292)	(0.0239)
DSO Unbundling:			
None		0.0468	
		(0.117)	
Management		0.0117	
		(0.047)	
Accounting		0.0161	
		(0.0307)	
Legal		Reference	Reference
Wholesale market (0/1)		-0.0721	-0.0581*
		(0.0442)	(0.0298)
Retail market openness (0-100%)		0.00004	
		(0.000759)	
Wholesale market concentration (0-100%)		0.000533	
		(0.00135)	
Renew. supports - econ instruments		0.0691***	0.0711***
		(0.0251)	(0.0229)
Avg annual ETS price (€/tCO2)		0.00296	0.00636***
		(0.00231)	(0.00227)
Year dummies	Yes	Yes	Yes
Constant	-8.531***	-8.752***	-8.817***
	(1.369)	(1.8)	(1.561)
Observations	255	181	238
R-squared	0.823	0.85	0.834
Number of country id	26	24	26

Standard errors are in parentheses. ***p<0.01, **p<0.05, * p< 0.1. The coefficient on “no unbundling” of the TSO is omitted in Column (2) due to collinearity.

Table 4: Dynamic-panel estimation

Y variable: Log(Ind. Electricity price)	(1) Reforms - exogenous	(2) Reforms - endogenous	(3) LSDVC estimator
Log(Ind. Electricity price)(t-1)	0.411***	0.773***	0.629***
	(0.107)	(0.0822)	(0.0626)
Log(Real GDP/capita)	-0.0155	-0.0145	0.214
	(0.0256)	(0.0288)	(0.162)
Log(Gas price)	0.389***	0.232***	0.326***
	(0.0712)	(0.0573)	(0.065)
Log(Sh. of hydro+nucl in power gen)	-0.012	-0.00427	-0.0549**
	(0.00816)	(0.0051)	(0.026)
Log(Electricity imports%)	-0.00387	-0.0152	-0.0325
	(0.0162)	(0.0159)	(0.0229)
TSO Unbundling:			
Management	0.0114	-0.0072	0.0308
	(0.0412)	(0.0454)	(0.0531)
Accounting	-0.0162	-0.121	0.00971
	(0.0201)	(0.194)	(0.0422)
Legal	Reference	Reference	Reference
Ownership	0.0387	-0.114	0.0194
	(0.0271)	(0.076)	(0.0238)
Liberalised wholesale market (0/1)	-0.0610**	-0.00942	-0.0353
	(0.0275)	(0.0414)	(0.0324)
Renew. supports - econ instruments	0.0605**	0.027	0.0198
	(0.0305)	(0.0201)	(0.0236)
Avg annual ETS price (€/tCO2)	0.000695	0.00101	-0.00179
	(0.00095)	(0.00105)	(0.00221)
Year dummies	Yes	Yes‡	Yes
Constant	-2.113***	-0.941*	
	(0.536)	(0.509)	
Observations	217	217	217
Number of country id	26	26	26
Arellano-Bond AR(2) test (Pr > z)	0.254	0.741	n/a
Sargan test (Prob > chi2)	0.193	0.974	n/a

For GMM estimates, Windmeijer-corrected standard errors are in parentheses. ***p<0.01, **p<0.05, * p< 0.1
‡ Except those years that are jointly insignificant.

6. Conclusions

This paper analyses the restructuring of European electricity markets as set out in the European Energy Packages. Analysing electricity market reform in a static model, I find that less complete unbundling of the Transmission System Operator is associated with higher electricity prices for industrial customers. The results from the static model also show that the presence of a liberalised wholesale market for electricity is associated with lower prices. However, I find that industrial electricity prices in Europe exhibit a strong degree of path dependency, which highlights that an analysis of prices should not be conducted using a static framework. When electricity market restructuring is analysed in a dynamic framework, TSO unbundling does not appear to play a significant role; regardless of whether electricity market reform is modelled as an exogenous or an endogenous process, I do not find any evidence that unbundling affects the industrial electricity price. Furthermore, if it is assumed that electricity market reform was exogenously driven by EU policy, the presence of a liberalised wholesale market appears to drive down the industrial electricity price. However, once the potential endogeneity of reform is accounted for, this effect disappears.

Possible endogenous effects are important to consider in this context; just as restructuring may affect prices (as noted previously, the effect could be positive or negative), the decision to restructure may be influenced by prices. This research illustrates that the results of reduced-form models, assessing the impact of market conditions on price, are highly sensitive to the estimation strategy. Based on the findings presented, taking endogeneity into account, no firm conclusions can be drawn about whether or how electricity market restructuring has affected the industrial electricity price. These findings do not suggest that European countries should not have engaged in the reform process. For many countries, energy market restructuring has taken place in the context of a broader liberalisation process; to not have engaged in electricity market reform may have harmed the credibility of that process, with potentially negative economic consequences.[28]

As noted by Nagayama (2009), accurate estimation of the long-term effects of reform will need further analysis over longer time periods, as the restructuring process may not yet have had sufficient time to influence end-user electricity prices. Until the restructuring process is more mature, and additional data become available, the results of this analysis should encourage caution among policy makers in terms of drawing inferences about the impact of EU electricity market reform. Moreover, this analysis emphasises the importance of taking account of path dependency in electricity prices. Any analysis that ignores dynamics and possible endogeneity is likely to miscalculate the effects of restructuring.

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[28] I am grateful to an anonymous referee for highlighting this fact.

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