ESRI

Working Paper No. 504

June 2015

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 taking place since the 1990s. This liberalisation 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. In this paper I estimate 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 potential endogeneity of the reform process. By using dynamic panel-data techniques, I aim to overcome this shortcoming. I find that once the potential 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 endogeneity before drawing inferences about the results of EU electricity-market reform.

Keyword(s): Econometric modelling; EU; electric utilities; market design

JEL Code(s): D47, L94, Q4

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Acknowledgements: I gratefully acknowledge financial support from Science Foundation Ireland under grant number 09/SRC/E1780. Part of this work was completed while I was a Fulbright Scholar at the University of Maryland, and Fulbright funding is gratefully acknowledged. The opinions, findings and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of Science Foundation Ireland or of the Fulbright Commission. I wish to thank Seán Lyons, Laura Malaguzzi-Valeri, Valeria Di Cosmo and seminar participants at the ESRI, the ZEW 2014 Mannheim Energy Conference and at the UMD/FERC 2014 TransAtlantic Infraday for helpful comments and suggestions. All remaining errors are my own responsibility.

1 Introduction

The restructuring of electricity markets has been taking place around the world since the 1980s.[1] This has generally involved unbundling of vertically-integrated monopolies, privatisation of certain segments of the electricity market and incentive 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 it is the impact of these packages that I analyse in this paper.

The liberalisation of electricity markets was undertaken for various reasons - due to political ideology, to improve government finances, and in many cases in the context of overall liberalisation of the services sector. Joskow (2008) notes that a desire for reform was driven by factors such as high operating costs, construction cost over-runs for new power plants and high retail prices. He also notes that falling natural gas prices and new technologies, such as CCGT power plants, were, in some instances, resulting in falling production costs. There was a desire from policy makers to achieve an overall reduction in costs in the sector that would be passed onto 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 vertically-integrated monopolies to create incentives for performance improvements; the vertical separation (or unbundling) of the sector to prevent cross-subsidisation between 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 generation, and the integration of transmission facilities with network operations to create an independent system operator.

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 regulation due to the inelastic nature of electricity demand. They also highlight that unbundling of the industry will lead to increased administration and transaction costs. They discuss how, under full competition, as the number of competitors increase, mark-ups and prices will fall, but that increased costs due to unbundling may drive prices in the opposite direction. Thus, while the main motivation behind electricity market reform is to increase efficiency which, all other things equal, should result in lower electricity prices, different reform steps may have opposite effects on prices. Indeed research by Apt (2005) and Erdogdu (2011), amongst 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 generation costs; I hypothesise that the reform measures adopted may also influence price - whether their effects will be positive or negative is ambiguous. In addition to the reform measures adopted, factors such

[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)).

as the generation mix, electricity trade, and other policies affecting the electricity supply industry may also influence the final price of electricity. Thus, any analysis of the effects of electricity market restructuring on consumers will need to control for these factors. While a number of different 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,[2] is missing data for a number of EU countries. Therefore, for my analysis, data were compiled from a number of different sources (further details 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 will be important in considering electricity market reform in other countries. As such, research analysing the effects of reform on prices will be of interest to policymakers both in Europe, and elsewhere. I contribute to the research on the effects of electricity market restructuring in a number of ways. Firstly, I consider a wider range of EU countries than previous analyses of EU electricity market reform. Secondly, I collect detailed data measuring reform steps, e.g., whether, and to what extent, unbundling of the system operators has taken place. Finally, in accordance with best-practice established by more recent studies of restructuring, I account 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. Section 5 discusses the results. Finally, section 6 presents some concluding remarks.

2 Related literature

Numerous papers have been written that 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 is provided by Pollitt (2009) who highlights outstanding concerns relating to levels of competition in the market. 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, supports schemes for renewable energies.

There is also a growing literature of empirical analyses of the effects of electricity market reform on a range of outcome variables. One of the earliest papers to empirically test the impact of electricity market reform is Steiner (2000). She finds 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, and with some changes made to how the reform variables are defined. They find that this significantly impacts the results - their results show that unbundling of generation and the introduction competition in wholesale markets did not lead to lower prices, and may in fact have resulted in higher prices.

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

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. He concludes that reforms have heterogenous impacts across countries.

In summary, the earlier research on the impact of electricity market restructuring has yielded no consistent results. This is unsurprising given the different countries, time periods, and measures of reform 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.[3] 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 finds 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 do benefit from lower prices. They note that, of the different market designs they examine, none lead to lower prices in the very short run. They also highlight that in order to lower retail prices, consumers need to 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 Growitsch and Stronzik (2014). Gugler et al. (2013) look at the impact of market reform on investment in 16 EU countries from 1990 to 2010. They find that different reform steps have opposite 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 from 1978 and investigate how they have been affected by energy-market liberalisation generally and ownership structure specifically. They find that the impact of liberalisation on prices is small and uncertain but that private ownership is significantly associated with *higher* prices.

Finally, a recent paper published by Growitsch and Stronzik (2014) looks at the impact of ownership unbundling of gas transmission networks in Europe. Using dynamic panel-data techniques, the authors find that ownership unbundling has no significant impact on the price of gas; however, they do find evidence that legal unbundling is associated with lower gas prices.

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

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 data on Norway although it is not an EU member state.[4] 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, and required 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 functioning of electricity markets in Europe. While the data covers 28 countries and 11 years, the panel is unbalanced as information on certain variables is 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 consumer band "Ic" thereafter. I take the average of the biannual prices to form an annual price series.

For the analysis, I collect data on the following market restructuring variables - these are the explanatory variables of most interest in my analysis:

- 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 the systems operators from other segments of the market to ensure equal access to the grid for all participants, particularly for new competitors in the market.[5] 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

[4] 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.

[5] However, as Growitsch and Stronzik (2014) note, the economic evidence on the effects of TSO unbundling remains ambiguous.

out in the Third Package (Directive 2009/72/EC).[6] The intermediate steps are separation of management; separate accounting; and legal unbundling. The data on TSO unbundling are from two sources; the main source are the EC's Benchmarking reports on the opening of electricity and gas markets.[7] 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).[8]

- 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 that indicates 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, I check for more recent developments in countries which did not have a wholesale market in place by 2009 using individual country profiles prepared by the European Commission[9] 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 - whether it is a formal market, i.e., 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.

- Market opening: Using data from the EC's Benchmarking reports and from the CEER's country-level reports, I gather information on the degree of retail market opening. 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.

While the variables discussed above are those that are the most interesting for the purpose of this analysis, they will not 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 - this is a variable commonly included in reduced-form models examining the determinants of electricity prices. Real per capita income may also capture information about the structure of the economy and the overall level of economic

[6]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.

[7]http://ec.europa.eu/energy/gas_electricity/legislation/benchmarking_reports_en.htm

[8]http://www.ceer.eu/portal/page/portal/EER_HOME/EER_PUBLICATIONS

[9]http://ec.europa.eu/energy/gas_electricity/internal_market_en.htm

development.[10] Data on real per capita GDP, expressed in 2005 dollar terms, are available from the World Bank. Also included in the model is 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. Furthermore, 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.[11]

To account for the costs 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 coefficient between the IEA industrial gas prices and the price of gas used in power generation, for those countries and years where it is available, and find that it is 0.96.[12] 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. Therefore, in the estimation, I control for the proportion of electricity generated from nuclear and hydro power. These data are available from the World Bank.

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 are likely to have impacted the electricity price and thus I attempt to control for such measures. I use data from the IEA/IRENA Joint Policy and Measures Database,[13] 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.[14]

3.2 Descriptive statistics

Table 1 presents descriptive statistics for some of the main variables in the sample. It shows a significant variation in industrial electricity prices. It also shows that there is significant variation

[10]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.

[11]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.

[12]I would like to 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 (correlation coefficient = 0.78).

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

[14]Other measures included in the IEA/IRENA database, such as policy supports, are not included as a wide definition of policy supports is used, which may in fact incorporate the presence of economic instruments.

across the sample in the market-structure variables particularly in terms of TSO unbundling and market opening. Table 1 also shows 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 renewable sources.

Table 1: Descriptive statistics

	Mean	Std. dev.	Min	Median	Max	N	Data source
Industrial electricity price (€/kWh)	0.077	0.025	0.0306	0.0737	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 market (0/1)	0.682	0.467	0	1	1	308	EC/CEER
Wholesale market concentration (0/1)	58.568	27.857	15.3	52.4	100	264	EC/CEER
Retail market opening (%)	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	2.760	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 and for a number of countries that were earlier adopters of reform (UK and Norway) and those that restructured their electricity supply industries later (Malta and the Czech Republic). It shows large differences between European countries in terms of their electricity price levels and trends.

Turning next to some structural indicators, Figure 2 shows that, on average over the period analysed, retail market opening has been increasing, as expected. I also find that the wholesale market concentration has, on average across the EU, declined since the early 2000s.

The average level of retail market opening masks the large variation in the degree of market opening across the EU over the period analysed, illustrated by Figures 3 and 4. While in 2001, many of the countries which I classify as “early reformers” had fully opened their retail electricity markets to competition, in other countries - the “late reformers”, levels of market opening in 2001 were low. Figure 4 shows that in Latvia and Estonia in 2001 just over 10 percent of the market has been opened to retail competition, while in Malta the market had still not been opened to any form of retail competition by 2010.

4 Methodology

When looking at the impact of market restructuring there are numerous potential outcome variables that one may examine. The final price of electricity is an obvious variable to examine - a major motive for market reform at an 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.

Figure 1: Evolution of industrial electricity prices

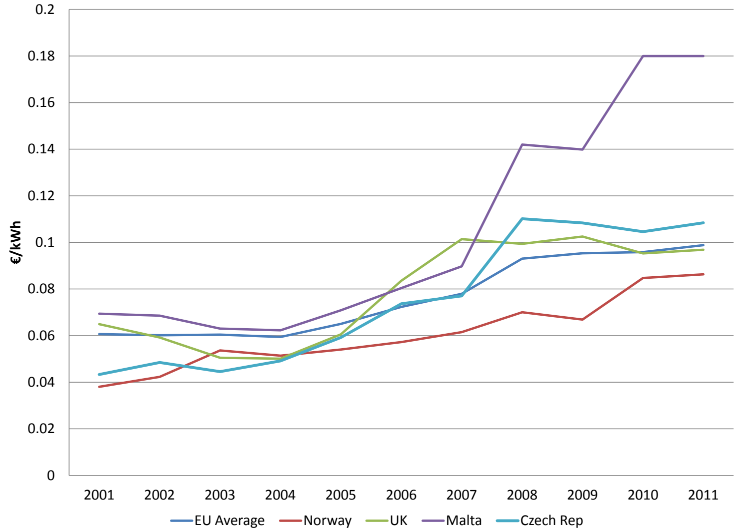


Figure 2: Average levels of EU market concentration and market opening

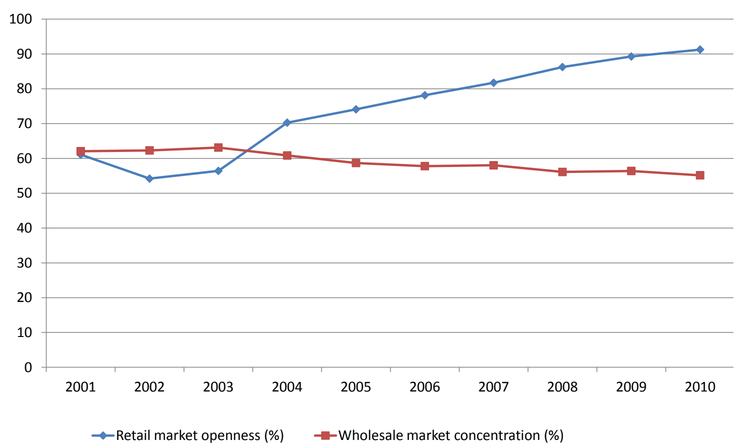


Figure 3: Degree of market opening 2001 and 2010 - "early reformers"

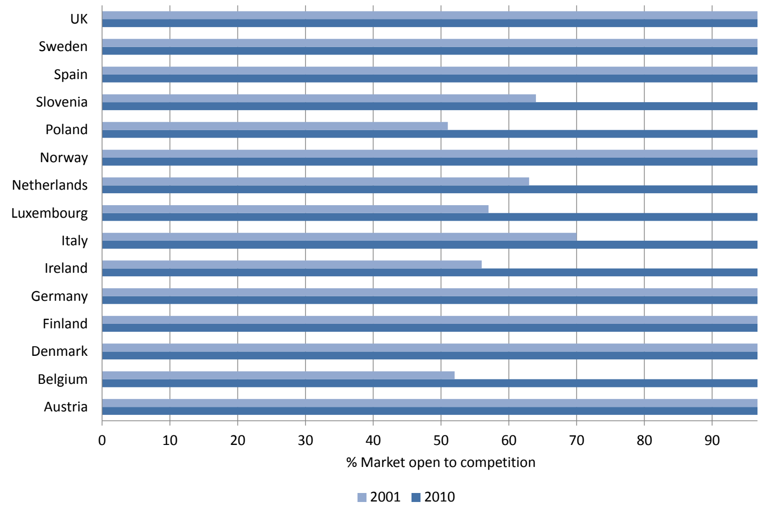
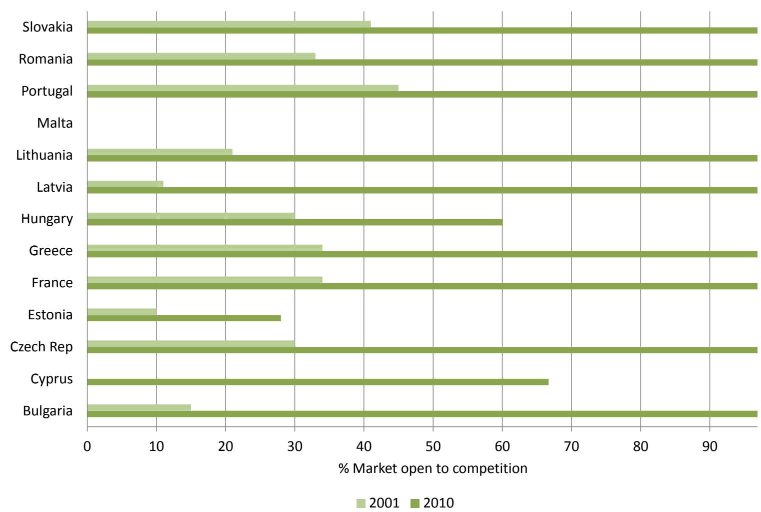


Figure 4: Degree of market opening 2001 and 2010 - "late reformers"



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:

$$\begin{aligned} &P_{it} = R_{it}\beta + X_{it}\gamma + \delta_t + \zeta_i + u_{it} \\ &i = 1, ..., I; t = 1, ..., T \end{aligned} \tag{1}$$

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. I include, where appropriate, year 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. u_{it} is the error term.

As mentioned previously, a major shortcoming of much of the literature to date analysing the impact of market restructuring is a failure to account for the potential endogeneity of the reform process (for a detailed discussion of this refer to 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 have 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, Gutiérrez (2003) shows empirically that a failure to take account of dynamics leads to an overestimation of the effects of reform. Unsurprisingly, I find that the lagged dependent variable is significant and thus I 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:

$$\begin{aligned} &P_{it} = \alpha P_{i,t-1} + R_{it}\beta + X_{it}\gamma + \delta_t + \zeta_i + u_{it} \\ &i = 1, ..., I; t = 1, ..., T. \end{aligned} \tag{2}$$

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 get around 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 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 firstly assuming electricity restructuring is exogenous, and then 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.[15] The model is estimated using a two-step procedure which is robust to autocorrelation and heteroscedasticity in panel data. However, the use of the two-step estimator can, in small samples, cause severe downward bias in the standard errors (this issue is discussed by Windmeijer (2005) and Roodman (2009a)), therefore I use the Windmeijer finite-sample correction of the variance - shown, by Windmeijer (2005), to lead to more accurate inference.

5 Results

5.1 Static panel analysis

I first estimate the effect of the those 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; and I subsequently add variables describing the market structure. Column (1) of Table 2 presents the results of a regression of the likely most important determinants on the log of the industrial electricity price, and includes year 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 increases the price of electricity to industrial users by 0.44 percent. 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 increases the end-user electricity price by 0.48 percent.

Table 2 shows that the proportion of electricity that comes from nuclear and hydro sources is associated with a lower electricity price, although the relationship is not statistically significant in this specification. I find that electricity prices are decreasing in the proportion of electricity imports; a one percent increase in electricity imports (relative to total consumption) reduces the price of electricity by approximately 0.07 percent.[16] This result supports the view expressed by DECC (2013) that imports should result in lower electricity bills.[17]

[15] 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 - an equation in levels, to the estimation which increases efficiency in cases when lagged levels are poor instruments for first-differenced variables.

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

[17] 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

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 opening and of 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 on nuclear-plus-hydro generation becomes larger and is now significantly associated with lower prices, as expected. Column (3) of Table 2 shows that, relative to the reference case of legal unbundling of the TSO, countries that have only undergone the minimal possible separation, that is separate management of the TSO from other segments of the market, have an industrial electricity price that is 11.6 percent higher. None of the other categories 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 5.9 percent lower.

Finally, column (3) shows that the presence of economic instruments supporting renewables are associated with an industrial electricity price that is 7.2 percent higher, and prices are also increasing in the cost of carbon.[18]

5.2 Dynamic panel analysis

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 I should account for the dynamic nature of this variable in the model. Thus, I re-estimate the model in a dynamic-panel framework which 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 I estimate the dynamic model using system GMM. 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 3 presents the results when I assume that the significant reforms from the static, fixed-effects model are exogenously determined. In this model I find that the presence of a liberalised wholesale market is associated with prices that are 6.6 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 3 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

consumption), this variable is not statistically significant, suggesting that imports are capturing more than market isolation.

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

Table 2: 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***	0.438**	0.488***
	(0.139)	(0.177)	(0.151)
Log(Gas price)	0.478***	0.429***	0.423***
	(0.0543)	(0.0702)	(0.0628)
Log(Sh. of hydro+nucl in power gen)	-0.0411	-0.112***	-0.0703**
	(0.0285)	(0.0352)	(0.0311)
Log(Electricity imports%)	-0.0660***	-0.0850***	-0.0529**
	(0.0189)	(0.0258)	(0.0204)
TSO Unbundling:			
None			0.106
			(0.118)
Management		0.202***	0.116**
		(0.0716)	(0.0468)
Accounting		0.0797	0.0316
		(0.0503)	(0.0395)
Legal		*Reference*	*Reference*
Ownership		0.0188	-0.00497
		(0.0287)	(0.0239)
DSO Unbundling:			
None		0.0286	
		(0.115)	
Management		-0.0120	
		(0.0516)	
Accounting		0.00874	
		(0.0302)	
Legal		*Reference*	
Wholesale market (0/1)		-0.0812*	-0.0592**
		(0.0447)	(0.0296)
Retail market opening (0-100%)		0.000120	
		(0.000754)	
Wholesale market concentration (0-100%)		0.000588	
		(0.00132)	
Renew. supports - econ instruments		0.0706***	0.0720***
		(0.0250)	(0.0228)
Avg annual ETS price (€/tCO_2)		0.0029	0.00657***
		(0.0023)	(0.00226)
Year dummies	Yes	Yes	Yes
Constant	-8.531***	-8.463***	-8.800***
	(1.369)	(1.763)	(1.529)
Observations	255	179	237
R-squared	0.823	0.855	0.836
Number of country_id	26	23	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 positive and significant in the dynamic model, although the coefficient falls slightly. The results from Column (1) confirm that renewable support schemes are associated with higher electricity prices. However, the coefficients on the share of electricity generated by nuclear and hydro sources, on the ETS price and on the share of imports in electricity consumption are no longer statistically significant.[19]

Column (1) of Table 3 assumes 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, the coefficient on the liberalised wholesale market variable is no longer significant in this model. Thus, assuming that electricity market reform is endogenous, I cannot conclude that it has had any significant effect on electricity prices.

To highlight some of the diagnostics from the dynamic GMM regressions, Table 3 reports 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)).[20] Some robustness checks that were carried out on the number of instruments are discussed in the Appendix.

Finally, it has been noted by, for example, Growitsch and Stronzik (2014), 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 3 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 and hydro sources are significant.

6 Conclusions

This research studies the restructuring of European electricity markets that has been taking place 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 Systems Operator is associated with higher electricity prices. This research also shows that the presence of a liberalised wholesale market for electricity is associated with lower prices. However, the results show that industrial electricity prices in Europe exhibit a strong degree of path dependency, which highlights that an analysis of

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

[20]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.

Table 3: Dynamic-panel estimation

Y variable: Log(Ind. Electricity price)	(1) Reforms - exogenous	(2) Reforms - endogenous	(3) LSDVC estimator
Log(Ind. Electricity price)(t-1)	0.418***	0.768***	0.632***
	(0.105)	(0.0887)	(0.0741)
Log(Real GDP/capita)	-0.0100	-0.0223	0.219
	(0.0254)	(0.0215)	(0.202)
Log(Gas price)	0.396***	0.233***	0.326***
	(0.0701)	(0.0629)	(0.0599)
Log(Sh. of hydro+nucl in power gen)	-0.0121	-0.00816	-0.0534**
	(0.00817)	(0.00527)	(0.0263)
Log(Electricity imports%)	-0.00221	0.00401	-0.0302
	(0.0166)	(0.00919)	(0.0233)
TSO Unbundling:			
Management	0.0257	0.0906	0.0448
	(0.0456)	(0.0580)	(0.0588)
Accounting	0.00631	0.0255	0.0268
	(0.0262)	(0.0311)	(0.0359)
Legal	*Reference*	*Reference*	*Reference*
Ownership	0.0380	-0.0301	0.0198
	(0.0285)	(0.0581)	(0.0265)
Liberalised wholesale market (0/1)	-0.0659**	-0.00164	-0.0342
	(0.0276)	(0.0398)	(0.0277)
Renew. supports - econ instruments	0.0593**	0.0161	0.0192
	(0.0287)	(0.0196)	(0.0234)
Avg annual ETS price (€/tCO_2)	0.000786	0.00113	-0.000299
	(0.000927)	(0.00102)	(0.00194)
Year dummies	No	Yes†	Yes
Constant	-2.148***	-0.741**	
	(0.525)	(0.347)	
Observations	216	216	216
Number of country_id	25	25	25
Arellano-Bond AR(2) test (Pr > z)	0.183	0.746	n/a
Sargan test (Prob > chi2)	0.236	0.923	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 prices should not be conducted using a static framework. When electricity market restructuring is analysed in a dynamic framework, the results regarding TSO unbundling do not hold; regardless of whether electricity market reform is modelled as an exogenous or an endogenous process, the results do not provide any evidence that unbundling affects the industrial electricity price. Regarding the effect of a liberalised wholesale market on price, I find that, based on the assumption that electricity market reform was exogenously driven by EU policy, the presence of a liberalised wholesale market drives down the industrial electricity price. However, once the potential endogeneity of reform is accounted for, this effect disappears. Thus, this research illustrates that assessing the effect of electricity market restructuring is highly sensitive to the estimation strategy. Furthermore, no firm conclusions can be drawn on whether or not electricity market restructuring has affected the industrial electricity price.

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 transfer through to end-user electricity prices. Until the restructuring process is more mature, and additional data become available, the results of this paper should encourage caution amongst policy makers drawing inferences on the impact of EU electricity market reform. This research shows that the results of reduced-form models that assess the impact of market conditions on price are highly sensitive to the estimation strategy. Additionally, it illustrates the importance of taking account of the path dependency of electricity prices. Any analysis that reaches conclusions about the effects of restructuring, without accounting for dynamics or for potential endogeneity, is likely to miscalculate its effects.

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A Appendix

A.1 Robustness checks

Numerous authors have highlighted the limitations of the dynamic GMM model. For example, Roodman (2009b) discusses the sensitivity of results of difference and, in particular, system GMM to the number of instruments included in the model. He notes that the high number of internal instruments available in the model can lead to instrument proliferation. Including too many instruments in the model can, Roodman (2009b) notes, lead to over-fitting of the endogenous variables and can also weaken specification tests, such that results that are invalid may appear valid.

Roodman (2009b) suggests that researchers should apply more conservative levels of statistical significance before failing to reject the null of the Sargan and Hansen tests of instrument validity. While the p-values, reported in Table 3, are well above standard levels of statistical significance, instrument proliferation can weaken these specification tests. Therefore, I reduce the number of lags in the models and verify that the results of Sargan and Hansen tests (and indeed the difference-in-Hansen and difference-in-Sargan test) hold: Checking first the model in which I assume reform is exogenous, I reduce the number of lags used to construct the instrument matrix from two through five, to two through four, and then through three. I find that this does not change the interpretation of the Hansen and Sargan tests, whose p-values remain well above conventional significance levels. In terms of the coefficients of interest (i.e.: those on the restructuring variables - TSO unbundling and the wholesale-market dummy), the coefficients on TSO unbundling remain insignificant. The coefficient on the liberalised wholesale market dummy is not affected and the result remains significant.

In terms of the endogenous-reform model, I cannot reduce the number of lags being used by the model, as the model is already being restricted such that only the second lag is used to construct instruments for the endogenous variables. Thus, in order to test the sensitivity of the results to reductions in the number of instruments, I exclude exogenous covariates (as these also enter as instruments - instrumenting for themselves) that were not statistically significant. This reduces the number of instruments from 22 to 17. As in the exogenous model, this does not change the interpretation of the results from the Hansen and Sargan tests, and the coefficients on the restructuring variables remain insignificant. Thus, I conclude that the results presented in Table 3 are not being driven by instrument proliferation.

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