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Privatisation and cross-border electricity trade: From internal market to European Supergrid?

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ABSTRACT

The perspective European Supergrid would consist of an integrated power system network, where electricity demands from one country could be met by generation from another country. This paper makes use of a bi-linear fixed-effects model to analyse the determinants for trading electricity across borders among 34 countries connected by the European Supergrid. The key question that this paper aims to address is the extent to which the privatisation of European electricity markets has brought about higher cross-border trade of electricity. The analysis makes use of distance, price ratios, gate closure times, size of peaks and aggregate demand as standard determinants. Controlling for other standard determinants, it is concluded that privatisation in most cases led to higher power exchange and that the benefits are more significant where privatisation measures have been in place for a longer period.

1. Introduction

For the greatest part of the last century European electricity markets have operated as separate national or regional networks. This is because of the historical role of national monopolistic energy utilities which developed grids under the assumption that each country could meet its energy demand through national supply and imports. Although full market liberalisation still presents heterogeneous features and arguably has not been completely achieved [20], the three European Union packages on the liberalisation of energy markets have marked the progress towards the highest level of integration of energy markets ever experienced in Europe. The slow, but inevitable liberalisation of European energy markets over the last ten years has been coupled with privatisation measures [31,33]. The European project for the liberalisation and integration of Member States' electricity markets has historically relied on privatisation as a mean to increase competition and reduce prices for consumers [23]. Historically trade across borders has favoured optimal balancing of demand and supply and increased the integration of European electricity markets.

The European Union move towards a low-carbon economy depends in part upon a transformed cross-border electricity system that can integrate renewables and smart meters alike, offering energy consumption savings at source and extended market potential for selling at remote end points. The increasing penetration of renewables and the introduction of smart metering devices are expected to increase the needs and opportunities for cross-trade electricity exchange. This has prompted policy-makers and scholars to go beyond the concept of smart grids and consider a so-called European Supergrid. This would consist of an integrated power system network, where electricity demands from one country could be met by generation from another country. It has been argued that besides increasing penetration of renewable energy sources and improving security of supply, a European Supergrid would potentially reduce congestion in the existing system [44,46].

No research thus far has directly addressed the question of which are the main determinants of power exchange in the European Supergrid. This paper investigates the extent to which the privatisation of European electricity markets affected cross-border trade. It analyzes what impacts distance, gate closure and ratio between prices have on power exchange among 34 countries. As a premise to this work, trade across border is examined here as direct evidence that the internal European market is successful and as indirect evidence, that privatisation is successful. A higher volume of electricity flows indicates a functioning European electricity trade market.

The paper commences by describing current cross-border electricity transmission across Europe and plans for the European Supergrid (Section 2); introduces a bi-linear fixed-effects methodology for modelling the impacts of privatisation on cross-border trade (Section 3); reports findings from the modelling and robustness tests (Section 4); and concludes by discussing findings and policy implications (Section 5).

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2. Cross-border electricity system

2.1. The European Supergrid

The EU (European Union) Governments' move towards a low-carbon economy depends in part upon a transformed cross-border electricity system that can integrate renewables, offer energy consumption savings at source and extended market potential for selling at remote end points. According to National Grid, an integrated European Supergrid for the UK's offshore wind delivery could provide a 25% discount for the UK consumer on the capital cost compared to connecting each offshore wind farm with a dedicated radial connection [29].

Congestion associated with peak demand is a problem for trading electricity across borders, when intermittent renewables in one member state are producing so much electricity that transmission capacity to other countries is exceeded. Congestion costs across the most busy interconnectors in Europe are currently estimated to be €1.3 bn each year [9]. Key policy documents by DECC (Department of Energy & Climate Change) and [35] highlight that peak congestion of the UK electricity grid may create significant impacts on system costs because of the need for higher marginal cost generation, lower capacity margins, higher cost system balancing and increasing grid reinforcement investment.

Congestion has been addresses in European electricity markets discussions through implicit auctions [11,19,25]. In 2006, Germany, France and Belgium inaugurated the of their electricity markets in a trilateral market when limited to these three countries, which brought about a higher convergence of prices and stimulated other market coupling projects connecting in 2009 Denmark and Germany, in 2010 Germany and Nordic regions, in 2011 Italy and Slovenia as well as Netherlands and Norway [36,37]. The literature in the area of market coupling is vast and rapidly increasing, mainly focussing on issues of whether price convergence between couples of electricity prices really occurred [5,21,24]. At the time of writing this paper there are several proposals and projects to develop further market coupling, including across Iberian and Scandinavian countries.

2.2. Cross-border transmission capacity in Europe

Since the year 2000 in Europe there has not been any significant increase in cross-border transmission capacity, but cross-border trade has increased significantly (Fig. 1).

One possible explanation for this increase can be in part a rise in consumption. In principle, according to economic theory privatisation can play a role in enhancing cross-border trade [47,48]. These dynamics have already been explored empirically for other sectors, including transport [16], banking [27], telecommunications [22] and financial markets [14] In practice, the high complexity of electricity markets in terms of governance, processes and operations [7,49] means that a set of contextual issues need to be taken into account. The substantial increase in cross-border trade in electricity has not brought about higher investments in interconnecting capacity. Until recently, Transmission System Operators did not need to invest in cross-border interconnectors to balance electricity demand and supply. However, recently concerns have been raised over the need for higher cross-border trade. In the UK, these policy issues are in connection with the unprecedented need for about £200 billion investment in capacity; the closing of power stations which could cause mid-decade energy shortfall; the challenge to raise finance needed to meet low carbon targets; and the current trading arrangements which need to be improved to provide security of supply and efficient energy prices. Indeed, the capacity assessment by Ref. [35] points to a 4% capacity margin for the years 2015 and 2016. This can be interpreted as a 1 in 12 year chance of a 2.75 GW loss. In Italy, the motivation for the financing cross-border investments include the desire to address combination of problems with financing generating capacity; the absence of storage and efficient Demand Side Management programmes; the failure to coordinate investments in generation and transmission following the removal of a central entity; and the penetration of renewable sources of energy which increase price volatility, reduce market price levels and worsen the commercial attractiveness of conventional capacity. In France, the main reasons for considering cross-border electricity trade arrangements are the high imbalance settlement prices for capacity owners and suppliers along with critical reports by the French Electricity Transmission Network on the balance between electricity supply and demand. For these reasons, any analysis on the effects of privatisation on electricity flows needs to take into account the duration of the privatisation, the volume of the market object of the cross-border trade, the peak purchasing power of the net importer, the geographical ease or difficulty to trade electricity, the ratio of prices between net importer and net exporter and the presence of the same gate closure time.

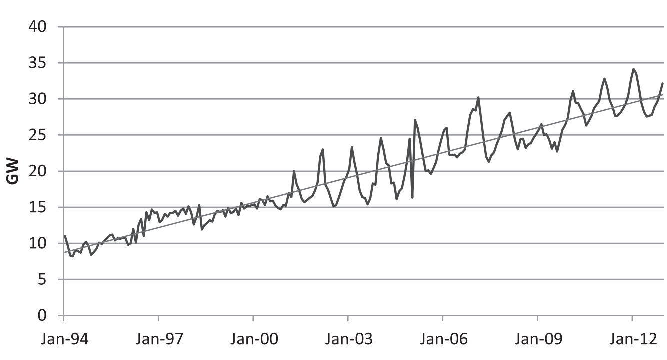

Fig. 1. Total cross-border trade (data source: [10]).

2.3. Privatisation of electricity markets

In Europe, the gradual privatisation of electricity markets has introduced competition in different parts of the industry. The increasing level of competition is expected to lead to higher efficiency in investment decisions, including for cross border trade [31,33]. Despite the introduction of privatisation in the area of generation in the early 1990s, vertically integrated utilities persisted in holding the majority of interconnector capacity, hence preventing competition from other markets [45].

In principle, trade across country borders allows to achieve higher efficiency gains thanks to market division of capital assets. In practice, in European electricity markets this was implemented through measures which set out to restructure the sector by unbundling vertically integrated utilities [26,43]. The aim of vertical unbundling is to separate potentially competitive generation and supply from the natural monopoly activities of transmission and distribution networks [13,38].

Privatisation is supposed to facilitate cross-border in three ways. First, privatisation and induce the necessary competition so that cross-border electricity trade can enable countries to balance historically grown generation with current demand [1]. Second, in combination with the presence of international interconnectors, annual demand variations can be better balanced by using prices which are closer to the real cost of generating electricity [18]. Third, privatisation enables countries to use more efficiently complementary resources. For instance, flexible hydroelectric generation can be used to export peak power and import thermal power during off peak hours [30].

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The privatisation of electricity markets does not automatically coincide with an integrated European electricity market where cross-border trade occurs. The supply and demand of electricity depends on resources, geography and economic growth [28]. These factors are reflected in differences in electricity prices across countries. For this reason, other determinants of cross-border trade, like distance, price ratios, overall size of the electricity market (in terms of aggregated demand and peak demand) and gate closure times will be used as standard determinants in our analysis as explained in the next section.

In this paper the complex concept of privatisation is operationalised with reference to the extent to which countries present public, mostly public, mixed, mostly private and private ownership of electricity assets. Inherently, privatisation is defined here in cases where there is a significant move away from full public ownership towards more private involvement, taking into account the extent to which electricity assets are privately owned.

3. A dyadic fixed-effects gravity model

3.1. Model

The model analyses a set of determinants, with a view to understand what influence these may have on cross-border electricity trade in the European Supergrid. The dependent variables on trade between countries A and B is determined as:

$$F_{A,B} = F_{A\rightarrow B} + F_{B\rightarrow A}$$

A bi-linear fixed-effects model which automatically controls for all factors that a country pair has in common and that are time-invariant, such as geographical similar geomorphology of the territory [12] was applied.

The approach is in line with other dummy-intensive generalised gravity models [3]. The model makes use of bilateral pair dummies (*Privatisation and gate dummy*) to consider partner fixed effects which substitute for time-invariant dyadic effects (e.g. common borders, language similarity) that are normally used in conventional gravity equations. The use of country-pair fixed effects allows controlling for unobservable heterogeneity among country pairs that is constant over time than using grid structure, contiguity, and other dyadic-specific variables. The bi-linear fixed-effects model considers countries in pairs to appraise the gross trade among these two countries.

In terms of robustness tests, the MRM (moment restriction method) by Ref. [4] is performed. The robustness of results is validated by increasing and consequently decreasing the lag length. The manual addition of fixed effects is supposed to better represent the fixed effects. This was possible through compression of data capacity before Stata processing. Dyadic fixed effects gravity models are generally used in the international trade and economics literature in relation to exports, Foreign Direct Investment, inward and outward investment stocks [6,8]. In energy research to date dyadic models have been used for electricity demand to investigate interactions between household members [42] and the travelling wave of high voltage transmission lines [50], but not for understanding market dynamics.

3.2. Data sample

The model sets out to test the hypothesis that the privatisation of electricity markets along with infrastructural features like distance, price ratios, volumes of aggregate and peak demand can foster power trade across borders.

This paper applies a bi-linear fixed-effects methodology, which is exclusively based on the within-variation in the data, measuring electricity trade in flows. The choice of using absolute electricity trade flows rather than electricity trade flows as a share of a country's overall net electricity demand is due to the fact that the latter measure would capture the relative importance of electricity trade to the country installing the interconnector, but not electricity trade flows directly. Given that the model focuses on the within-variation in the data, considering electricity trade in flows suits the research objectives of this work. The electricity traded each year is a flow to which each year's flow was added. The sample covers 34 European Supergrid countries. The model required three steps to achieve a sample of bi-linear electricity trade.

First, the model makes use of electricity trade flow data (in GWh) from Ref. [10] Exchange Data. A list of countries is presented in Appendix I. At this stage the analysis focused on the bilateral inward gross trade of electricity. Other sources consist of data from Eurostat and the International Energy Agency on energy flows.

Second, Exchange volumes are used as a sign of the amount of successful cross-border trade. For the minority of cases where no inward net imports data, but only outward trade data are reported, these were reversed to fill in missing inward net imports data. Denmark and Norway frequently exchange power, given their different mix of power stations, despite the fact that there is little net trade over the year as a whole. There is also a minority of instances in which no inward net imports data are registered (e.g. into Denmark), but only outward trade data are reported (e.g. out of Norway). Where these overlap, inward and reversed outward gross trade data are very highly correlated (at $r = 0.73$), the combined gross trade data from ENTSO-E (European Network of Transmission System Operators for Electricity), Eurostat, and the International Energy Agency were then combined with publicly available data from OECD (Organisation for Economic Co-operation and Development) for the relatively small share of cases for which ENTSO-E does not report data [2].

Third, the [34] Product Market Regulation Database provided data on the progress with privatisation of electricity markets and market opening to competition in EU countries. The database classifies countries in terms of public, mostly public, mixed, mostly private and private ownership of electricity assets. It also identifies the timeline of changes in privatisation. In essence, it highlights the strong move away from full public ownership towards more private involvement, but also how few countries in Europe have full private ownership of electricity assets [39]. The coding of the privatisation variable is based on year-to-year first difference taking value 1 if either country improves on the privatisation scale for years when the privatisation assessment was conducted by the OECD (i.e. 1994. 1998, 2003, 2008 and 2011). For countries in which the timeline does not specify changes relevant to this coding system, interpolation is used. This is for years where no assessment is available as it is assumed that economic signals of privatisation condition the market (e.g. if there is a legislative proposal heading to further move away from publicly owned assets). For the seven remaining non-EU countries, data on privatisation were based on ENTSO-E individual countries packages.

Notably, for around half of the cases there are no reported gross trade data at any point of time. Gross trade are set to zero for these cases if there are no reported gross trade flow data at any point of time for these country pairs either. The reason is that in these cases one can be fairly confident that there are no bilateral exchanges existent. The use of the natural log of gross trade allows an unproblematic interpretation of estimated coefficients as elasticities whilst reducing skewness of the dependent variable. Year-specific time dummy variables in all estimations are used to account for any trends in total gross trade that affect all cases equally. The analysis covers the years from 1994 to 2012.

3.3. Variables

It is expected that cross-border trade increases with raising differences between electricity demand and supply. The

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privatisation of electricity markets facilitates cross-border trade as it reduces the costs. The privatisation variable is labelled *Privatisation* and takes ascending values based on public, mostly public, mixed, mostly private and private ownership of electricity assets based on OECD (2009) and ENTSO-E individual countries packages.

The following five determinants of gross trade are included as control variables. First, the log of total host annual electricity demand (*ln Demand*), to control for market size, which is expected to have a positive influence on gross trade. Second, the log of host electricity demand at peak time per capita (*ln Peak Demand*), to control for the peak purchasing power. Third, the log of the distances in percent, taking the highest distance between capitals as 100 and expressing all other distances between pairs of capitals proportionally (*ln distance*), as a proxy for geographical difficulty to trade electricity, suggesting a negative impact on gross trade. Fourth, the ratio of prices between net importer and net exporter (*price ratio*) to control for ratio of price (data from Eurostat). Fifth, a dummy is included taking the value of one, if the net importer and net exporter countries have the same gate closure time (*gate dummy*), hence establishing which countries are able to trade electricity or inform TSOs of their final position before the real-time dispatching of electricity occurs.

The basic statistical features of the abovementioned variables are summarised in Table 1. The lagged DV of gross trade is not large because a considerable number of observations with 0 gross trade was attributed a value of 0.1 before taking the log.

4. Findings

With the exception of gate dummy, which features a positive coefficient sign, but is not statistically significant at standard levels, all variables involve statistically significant coefficients. Countries with larger demand, lower distance from other countries, combined with higher peak demand tend to import more electricity. The variable of main interest, i.e. *Privatisation*, features a statistically significant positive coefficient. In order to interpret its significance, necessary correction needs to be considered for the estimated variance for dummy variable coefficients in semi logarithmic equations. The average benefit of privatisation corresponds to an increase in cross-border trading by around 0.85%. An alternative to estimating the model in logs would have consisted of using levels with a Poisson estimator. However, logs are chosen here because to include dyad-specific fixed effects. For the static model, estimating the model in levels with xtnbreg leads to an estimated coefficient that is also statistically significant at the 0.01 level. Table 2 presents the main modelling findings.

In the second column the lagged dependent variable is included. The coefficient of the *Privatisation* variable cannot be directly compared to the one from the non-lagged model (in the first column) because in the lagged model it merely represents the short-run effect, which is estimated at around 0.81%. The long-run effect needs to take into account the coefficient of the lagged dependent variable and is estimated at around 0.85%. As a result, the lagged long-run benefit of privatisation does not differ significantly from the non-lagged benefit, and is in fact slightly higher. Because within the time frame of this analysis (1993–2012), changes in privatisation status of sample countries occur in rather restricted time periods -also in response to the European Commission's privatisation packages-to avoid model skewing, the MRM by Ref. [4] is performed. Applying MRM has the advantage that the endogeneity of variables can be explicitly taken into account. The estimated effect of the *Privatisation* may possibly suffer from reverse causality bias. One of the shortcomings of the MRM is that it removes any correlation between the explanatory variables and fixed effects by first differencing the variables. Because the dummy variable, whose value is zero at first and consequently always one beyond the year that privatisation is implemented, this creates the problem that the first-differenced variable is zero at first. Subsequently it is one only in the year the privatisation is implemented, and zero again in all subsequent years. This means that, by first differencing the *Privatisation* variable, the MRM can only estimate an effect of changes to the privatisation status in the first year they become operational. For the purpose of this paper it would be more relevant to understand the effect that the privatisation exerts over its entire lifetime. To overcome this problem, the *Privatisation* is substituted with a variable that measures the years passed since becoming effective, with the year of conclusion set to one (*Privatisation age*). In first differences, this new variable is zero for all years prior to privatisation becoming operational and then one for all years from becoming operational onwards.

The column on the right presents the MRM findings, which are not comparable with the non-lagged model (first column) or lagged fixed-effects results (second column) because the relevant variable is no longer the implementation of a privatisation policy, but the number of years since privatisation has been in place. Findings demonstrate that the age of privatisation has a positive impact on cross-border trade.

In terms of robustness of these findings, the estimated coefficients of the *Privatisation* variable for all three model specifications are illustrated Table 3. It results that overall privatisation has a positive effect on cross-border trading. To a great extent, robustness testing has been implicit in the core results reported to this point, as two alternative models and independent variables were tested. Additional robustness tests focus on the questions of lag length and outliers.

The analysis subsequently tested multiple alternative lag lengths using both econometric models in order to verify the robustness of our results. In relation to the possibility of outliers influencing the results, robustness tests were carried out by excluding any observations that appeared to be major outliers in

Table 1
Statistical features of main variables.

Variable	Min	Max	Mean	Deviation
Privatisation	0	1	0.23	0.12
Privatisation age	0	12	4.12	1.56
ln gross trade	−1.13	3.01	0.28	0.87
ln demand	19.27	28.41	25.24	2.53
ln peak demand	8.25	17.24	14.25	1.87
ln distance	−1.52	2.01	0.05	0.61
Price ratio	6.52	8.16	7.34	0.24
Gate dummy	0	1	0.09	0.21

Table 2
Modelling findings.

	Non-lagged model	Lagged model	MRM
Privatisation	0.0085 (2.16)***	0.0081 (2.07)**	
Privatisation age			0.0069 (6.28)***
ln gross trade		0.0459 (3.43)***	0.0222 (2.96)***
Gate dummy	0.001 (1.32)	0.0021 (1.81)*	
Observations	21,318	20196	18,212
Bi-linear matches	1122	1122	1122
R-squared	0.15	0.39	
p-value			0.67 (0.52)
Country-pairs fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes

*; **; and ***indicate statistical significance at 0.1; 0.05; and 0.01 levels respectively.

the data, most notably Latvia and Bosnia. In all cases the results remained broadly similar when exceptional cases were excluded, with significance levels and magnitudes changing in degree rather than in kind.

In order to further validate the model with different country performances, three tests are carried out. First, the sample is restricted to EU member states only. With the exception of the lagged estimation, the interconnectors continue to exert a positive effect on cross-border trade. Second, the sample is constrained to non-EU countries. Third, the restriction is on the 5 lower aggregate electricity demand countries. Privatisation status seems to have a positive effect in both subsamples, even if for low demand countries the coefficient of *Privatisation* is marginally insignificant in the lagged model. The sizes of the respective coefficients are relatively similar across the subsamples. Excluding these groups of countries does not change dramatically the estimated coefficients of *Privatisation* and *Privatisation age*, respectively. They remain positive and statistically significant.

The results are validated by different restrictions applied to the model, counting the MRM test. The coefficients for the privatisation variable are statistically significant.

5. Conclusions

In this paper it is shown that privatisation has the potential to facilitate higher cross-border trade in countries which belong to the hypothetical European Supergrid. It is also shown that the age of privatisation has a positive impact on cross-border exchange. This has important implications not only in terms of price of imports and exports of electricity, but also with regards to demand and supply balancing. The combination of privatisation and cross-border trade can bring about sharing of reserve capacity thereby reducing costs for extra power stations and limiting inefficient dispatch of power stations required for provision of reserves.

Initiatives to harmonise different electricity market designs can in theory improve cross-border trade and market balancing. However there are limits to the extent to which higher harmonisation can push market integration close to real time without negatively affecting the reliability of the electricity system [17].

This study takes a different approach from existing econometric studies on cross-border trading, which focused mainly on the effects of cross-border trade, rather than the determinants. Such studies based on earlier sample periods highlight the weak impact of cross-border trade on wholesale and final prices and costs [40] and their consequences in terms of productivity improvements [15].

The outcome of this paper does not allow for very specific policy recommendations, but provides some indications for the design of the European Supergrid. Alongside the favourable impact of cross-border trade, their potential negative effects also have to be considered. As it was pointed out in Section 2, implementing privatisation for cross-border trade purposes only could absorb valuable resources for inner grid development. These are particularly valuable in light of the highly electrified low carbon future prescribed in most EU Member States' energy policies. The main limitation of this paper −similar to other cross-country analyses-is that its dyadic fixed-effects methodology precludes understanding individual countries' motivations for cross-border trade and for joining the European Supergrid. The case for privatised cross-border trading depends on the extent to which the benefits from privatisation exceed the costs of arm's length transaction among separated markets. The size of the country, which in this paper was measured in terms of overall demand and peak demand, counts to the point that a small power sector needs to run with a proportionally high level of reserve and has few options for adjusting output to demand, so it can gain a lot from getting some of the flexibility it needs from trade with a larger system [41]. Conversely, managing complex trading mechanisms might become too expensive for smaller markets [32]. Following the same logic, the case for privatised cross-border trading is more solid for countries with large power systems, which are more comfortable absorbing some of the costs associated with power exchange with other countries.

The success or failure of the European Supergrid initiative is likely to depend on privatisation factors as well as grid and political development factors, like the amount of spending on interconnectors, which country took the lead in running the interconnector, political commitment and adequate allocation of institutional responsibilities. These and other factors influencing cross-border trade might depend on contextual issues which are not captured in this paper.

Table 3
Model validation after sampling restrictions.

	Non-lagged dummy	Lagged dummy	MRM age of privatisation status
EU-28 member states	0.03836 (4.328)***	0.01023 (2.813)***	0.00411 (3.956)***
Non-EU countries	0.06193 (4.152)***	0.00943 (2.431)**	0.00187 (2.346)**
5 lower aggregate electricity demand countries	0.01345 (1.464)*	0.00432 (1.351)	0.00752 (3.963)***
Country-pairs fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes

Appendix I. Countries

Austria
Bosnia and Herzegovina
Belgium
Bulgaria
Croatia
Czech Republic
Denmark
Estonia
Estonia
Finland
France
Germany
Great Britain
Greece
Hungary
Ireland
Italy
Latvia
Lithuania
Luxembourg
Montenegro
Macedonia
Netherlands
Norway
Poland
Portugal
Romania
Serbia
Slovakia
Slovenia
Spain
Sweden
Switzerland
Ukraine

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