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Zentrum für Europäische
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ELECTRICITY MARKET INTEGRATION AND THE IMPACT OF UNILATERAL POLICY REFORMS[*]

Luigi Grossi[†], Sven Heim[‡], Kai Hüschelrath[§], and Michael Waterson[¶]

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Abstract

The harmonization and integration of separate national energy markets to an interconnected internal European market is a top priority of the European Commission. However, as energy policy largely remains subject to national sovereignty, a higher degree of integration can cause unilateral national policies to harm interconnected markets. We investigate the impact of two distinct national reforms in Germany – the phase-out of nuclear power plants after the Fukushima incident and the expansion of renewables promoted by fixed feed-in tariffs and unlimited priority feed-in – on neighbouring countries. We find that the phase-out triggered price increases of up to 19 percent in neighbouring countries whilst the renewable energy support schemes caused a price decrease of up to 0.17 percent for each percent of additional generation from German renewables. We also apply a novel approach to estimate the degree of market integration and find large differences between neighbouring countries in a range from 14 percent to 99 percent. Our findings point up the need for increased efforts to harmonize national energy policies, but also the need to consider the impact of unilateral environmental measures on other countries' supplies in the context of a partially integrated and partly unilateral system.

Keywords Energy; Electricity; Market Integration; Nuclear Phase-Out; Renewables

JEL Class L51; L94; Q41; Q48; Q54

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[†] University of Verona, Via dell'Artigliere 19, Verona, Italy, E-mail: luigi.grossi@univr.it.

[‡] ZEW Centre for European Economic Research and MaCCI Mannheim Centre for Competition and Innovation, E-mail: heim@zew.de.

[§] ZEW Centre for European Economic Research and MaCCI Mannheim Centre for Competition and Innovation; University of Mannheim; E-mail: hueschelrath@zew.de.

[¶] University of Warwick, Coventry CV4 7AL, United Kingdom and ZEW Centre for European Economic Research, E-mail: michael.waterson@warwick.ac.uk.

“Our vision is of an integrated continent-wide energy system where energy flows freely across borders, based on competition and the best possible use of resources, and with effective regulation of energy markets at EU level where necessary.”

European Commission (2015), A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy, Brussels.[1]

1 Introduction

The harmonization and integration of separate national markets to internal markets has been at the heart of the idea of Europe since the very early days of the integration process. What began with first steps to an integrated market for coal and steel in the early 1950s – the European Coal and Steel Community (ECSC) agreed to by Belgium, France, West Germany, Italy, the Netherlands and Luxembourg in Paris in 1951 – was subsequently enlarged especially in two dimensions: the number of policy areas for which an harmonization and integration is targeted and the number of countries that decided to join the subsequent agreements leading to the current state of the European Union.

European energy markets in general and European electricity markets in particular are – without doubt – of strategic importance for the European Union. It is therefore not surprising that already in the original ECSC, some legislative power in energy policy was taken over by the Community. However, it took until October 2005 before the introduction of a mandatory, comprehensive European energy policy was approved by the European Council. Although the EU Treaty of Lisbon of 2007 as well as more recently the creation of the Energy Union[2] (which both define the progress towards a fully integrated internal electricity market as a key target of the European Commission) included significant further changes towards a common EU energy policy, in practice, many competencies in relation to energy remain with the respective national governments. This generates a potential conflict between the creation of an

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[1] Communication from the European Commission to the European Parliament, the Council, the European Economic and Social Committee, the Committee of Regions and the European Investment Bank. A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy. COM(2015) 80 final, February 2015, p. 2.

[2] See http://ec.europa.eu/priorities/energy-union/index_en.htm (last accessed on 11 July 2015).

internal market for electricity on the one hand and (unilateral) policy reforms of single member countries on the other.

Against this background, we empirically investigate the impact of two distinct unilateral policy reforms in Germany on its neighbouring countries. First, the sudden and substantial phase-out of nuclear power plants after the Fukushima incident and second the promotion of renewables by the Renewable Energy Act ('Erneuerbare-Energien-Gesetz', EEG) which – due to fixed feed-in tariffs and unlimited priority feed-in for renewables – results in exogenous generation from intermittent renewables wind and solar. We find that both unilateral reforms had substantial – albeit opposite – impacts on market prices in neighbouring countries. While the phase-out triggered price increases of up to 17 percent, the price reductions caused by Germany's renewable energy support schemes were of a similar size for each megawatt of additional generation from German renewables. By subsequently capturing the impact of cross-border congestion we construct a counterfactual which enables causal inference of the degree of market integration in which Germany's neighbouring countries show large differences in a range from 14 percent to 99 percent. Our empirical findings point up the need for increased efforts to harmonize national energy policies with relevance beyond the European Union. In fact, a comparable market integration strategy was recently chosen by the US government through the Clean Power Plan, which defines clear federal targets for the replacement of conventional carbon intensive technologies but leaves the individual implementation strategies to be decided on the state level.

The remainder of the article is structured as follows. The second section provides an overview of the milestones of the European Union towards an internal market for electricity. In addition to the key motivations and policy actions, the section also provides a review of existing evidence on both the general benefits and the current degree of electricity market integration in Europe. The third section characterizes the interplay between market integration processes and unilateral policy reforms. In addition to an initial general assessment, this section characterizes two unilateral policy decisions of Germany in greater detail: the nuclear phase-out after the Fukushima incident and promotion of renewable energy production through support schemes. The fourth section provides our empirical assessment of, first, the impact of these two unilateral policy decisions of Germany on its neighbouring countries and, second, the identification of the degree of market integration. Section 4.1 describes the construction of the data set and presents the descriptive statistics; Section 4.2 describes our modelling approach. After presenting our estimation results in Section 4.3, Section 4.4 provides a detailed discussion of implications of our empirical results for the future integration of internal markets in general and internal electricity markets in particular. Section 5 concludes the paper with a summary of its main insights.

2 The Internal Market for Electricity

Before investigating the impact of unilateral policy reforms and the degree of market integration we describe the key motivations and policy actions behind it in Section 2.1, followed by an overview of existing evidence on the degree of market integration in Section 2.2.

2.1 Key motivations and policy actions

European energy policy is undergoing a rather long (and still ongoing) integration process. Initially, national electricity markets were heavily regulated, state-supported monopolies which needed to be liberalized and harmonized first[3] before a serious integration process was able to commence (see generally Serralles, 2006).

In striving for an internal market for electricity, the European Union is guided by the expectation of clearly positive welfare effects associated with the initiation and completion of the respective market integration processes. Main expectations include (1) an increase in competition and therefore efficiency in the production, transmission and distribution of electricity, (2) an increased security of supply, (3) an increased environmental protection and, last but not least, (4) an increased overall competitiveness of the EU (see, e.g., Domanico, 2007 or Serralles, 2006).

Generally, the integration of separate national markets is believed to lead to an increase in competition thereby pushing the respective providers towards cost reductions and/or productivity increases through innovation. These processes promise a more efficient use of existing generation and network capacities and thereby lower electricity prices for customers. Further efficiency potentials can be realized by a reduction of spare capacities necessary to guarantee an envisaged security of supply – basically because an interconnected internal market makes it easier to balance fluctuations in demand in a particular country compared to a national solution. This balancing effect is becoming more and more important with the increasing desire for

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[3] Referring to the detailed discussion in Serrralles (2006, pp. 2545), the success of the (gradual) transition from highly regulated, state-supported monopolies to an (competitive) internal market for electricity crucially depends on the presence of especially three market conditions: consumer choice, third-party access and unbundling of key assets.

environmental protection and the corresponding expansion of the intermittent renewable energy sources wind and solar. These (interrelated) beneficial effects of an internal market for electricity contribute to the overarching goal of increasing the overall competitiveness of the European Union with affordable, secure and sustainable energy supply being one important driver.

Aiming at realizing the mentioned benefits of market integration, the European Commission has been very active in initiating and implementing various policy actions at least since the mid-1990s with its 'First Electricity Directive': Directive 96/92/EC Concerning Common Rules for the Internal Market in Electricity. A detailed review of the various policy actions presented in Pellini (2014) underlines the importance of measures increasing either the use of existing interconnector capacities or the construction of new interconnectors. In a recent report on the progress towards completing the internal energy market, the European Commission (2014) clearly identifies the continuing need to optimize both the 'software' – through a commonly applied regulatory framework of transparent, simple and robust rules (e.g., to allocate existing interconnector capacities efficiently) – and the 'hardware' – through substantial investments in new interconnector capacities allowing the desired creation and optimization of an EU-wide electricity system (rather than the continuation of largely isolated national systems). The importance particularly of the 'hardware' component in reaching this goal was recently underlined by the European Commission in the form of a call for the "speedy implementation of all measures to meet the target of achieving interconnection of at least 10% of their installed capacity for all Member States"[4] (European Commission, 2015, p. 2) as part of a broader framework strategy for a resilient Energy Union with a forward looking climate policy.

2.2 Evidence on electricity market integration in Europe

Limiting ourselves to contributions that focus particularly on electricity market integration in the European Union, the existing literature can be subdivided further into studies trying to estimate the benefits of market integration and those that aim at identifying the current degree of market integration.

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[4] Current interconnection levels vary partly substantially between Member States with, in sum, 14 Member States being above the 10 percent threshold, 2 Member States (France and Germany) meeting the requirement exactly and the remaining 12 Member States being located below the 10 percent threshold (including larger countries such as Italy, the United Kingdom, Spain or Poland as well as countries located on islands (see European Commission, 2015, p. 5 for the full list).

Starting off with the more general studies on the benefits of electricity market integration, a detailed survey by Booz & Company et al. (2013) further subdivides the existing literature into (1) studies estimating the benefits of full market integration, (2) studies estimating the benefits of market coupling[5], and (3) studies estimating the benefits of market liberalization[6]. Concentrating on the first category of studies here, Neuhoff et al. (2013) quantify the effect of further integration of European electricity markets (excluding the UK, Ireland, Sweden and Finland) and the benefits that would be created for the utilization of additional wind capacity. In their simulations the authors, inter alia, estimate annual savings of (mainly) fuel costs in a range from €0.8 to €2.0 billion (depending on the penetration of wind power). Other contributions include Leuthold et al. (2005), Green (2007) and Pellini (2014). Very recently, Newbery et al. (2015) estimate the potential benefit to the European Union of coupling interconnectors to increase the efficiency of trans-border trading. They find that – in the short run – the gains could be as high as €3.3 billion per year with about one-third coming from day-ahead coupling and another third from shared balancing.

Turning to a selection of the (more specific) literature that aims at identifying the current degree of market integration, several studies apply pairwise price tests such as price ratios, correlations and cointegration analysis to study the degree of market integration and typically find an increase in integration over time. Examples include Mjelde and Bessler (2009), Zachmann (2008) and Robinson (2007). Nitsche et al. (2010) provide a detailed assessment of market integration and competition in the European electricity wholesale sector. In particular, they provide an initial discussion (and subsequent application) of relevant indicators for measuring the degree of market integration including specifically the study of price correlations and/or price convergence with respect to (1) day-ahead spot exchange market prices, (2) price spreads as suggested by interconnector prices or (3) future prices. Inter alia, their analysis of the latter two indicators suggests that markets are more strongly interlinked than their findings for the first indicator – persistent day-ahead spot exchange market price dispersions – would suggest. Finally, aiming at identifying the (geographically) relevant antitrust market, Böckers and Heimeshoff (2014) study the convergence process of European wholesale electricity markets from 2004 to 2011 using national bank holidays as exogenous demand shocks. By estimating a reduced form model they find that the impact of national holidays (in one country) on prices in the

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[5] See, e.g., De Jong et al. (2007) and Kristiansen (2007a, 2007b).

[6] See, e.g., Pollitt (2009a, 2009b, 2012).

neighbouring countries has increased with respect to Germany and Austria as well as Belgium and the Netherlands. Although achieving interesting results, demand dynamics are only considered through seasonal dummies and the actual degree of integration is not identified as the authors do not investigate how large the impact of these exogenous demand shocks on prices would have been without cross-border congestions due to constrained interconnector capacity. In the present paper, we apply a novel approach to estimate such counterfactual prices which enables us to estimate the degree of market integration.

3 Market Integration and Unilateral Policy Reforms

The successful creation of internal markets crucially depends on both the harmonization of the initially separate policies in the different Member States and the step-wise integration of the separate markets though substantial investments in cross-border infrastructures (in combination with efforts to optimize cross-border trade mechanisms). Section 2.1 above has sketched the substantial activities of the European Commission to extend interconnector capacities all over Europe thereby promoting the goal of an integrated market for electricity.

Although there is no doubt that these measures are likely to create substantial benefits for society (see Section 2.2 above), an increasing integration of European electricity markets also increases the potential impact of unilateral policy reforms on neighbouring countries, i.e., the spot prices for electricity become increasingly dependent on unilateral reforms of single Member States. Although the respective impacts can very well be positive in the sense that prices fall in neighbouring countries in the aftermath of a unilateral reform of another country, negative impacts cannot be ruled out, which might raise policy discussions or even storms of protest (in the worst case damaging the idea of Europe).

Furthermore, such negative impacts are unlikely to be limited to short-term price increases but likely also comprise impacts on (substantial and far-reaching) medium- and long-term investment decisions and could even result in failures of national energy policies. For example, if the German government decides to grant further subsidies for the production of renewable energies, the improved interconnection of the German-Austrian and French markets may have a knock-on effect on, e.g., the profitability of an investment of a French company into the construction of a thermal power plant in France. In fact, there are already discussions to install mechanisms to reduce interconnection aiming at protecting national electricity markets from externalities through unilateral policies by interconnected neighbours, i.e. “grid-locks” between Germany and Poland (see Puka and Szulecki, 2014).

Against this background, we concentrate on an empirical analysis of the impacts of two distinct unilateral policy reforms in Germany: the phase-out of nuclear power plants after the Fukushima incident in March 2011 and the promotion of renewable energy production that started in the year 2000 and was reformed several times since then. The choice to study these two reforms was not accidental but is motivated by their clear differences. First, while the nuclear phase-out was a single and clear cut unilateral decision with no other comparable decisions being made by other European countries, the promotion of renewables has also become a policy tool in other European countries and the respective policies have been reformed several times (at least in several neighbouring countries).

Second, we expect the impacts of both types of policy reforms to be opposed. While the removal of a substantial fraction of nuclear power is likely to increase spot prices (provided that cross-border capacities are available and sufficiently large), the promotion of renewable energy production is likely to create a downward trend on price as generation from renewables with zero marginal costs reduces the residual demand from conventional generation (the so called ‘merit-order effect’). Our empirical investigation below not only tests whether the two unilateral reforms caused the expected effects, but also quantifies them in terms of percentage price changes in neighbouring countries due to Germany’s unilateral policy reforms. First, as a backdrop, the following two sections will provide more information on the two German policy reforms – the nuclear phase-out and the promotion of renewables.

3.1 Nuclear phase-out in Germany

For several decades, the use of nuclear power has been a point of intensive discussion in German politics and the general public. While the conservative-liberal governments tended to promote the use of this relatively cheap and reliable energy source, the social-green government decided in 2002 to phase-out nuclear power plants entirely by 2022. After a further change in government in 2005, the again conservative-liberal coalition decided in 2010 to delay the phase-out of some plants to the year 2036.

The events of Fukushima in March 2011 severely impacted peoples trust in nuclear energy and eventually led the conservative-liberal government to fundamentally change the nation’s energy policy. In particular, the government unexpectedly decided to shutoff all the six active nuclear power plants that were opened before 1981 – an event of some significance: 6.3GW of capacity, around 7 percent of installed conventional capacity and 12% of average German load, was permanently removed from the system at a stroke, with significant impacts on nuclear plant output, as indicated in Figure 1 below.

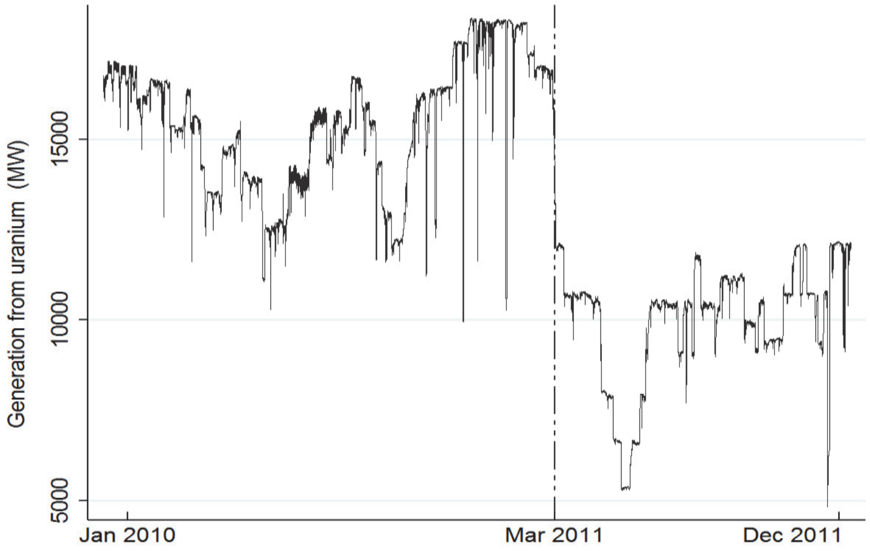

Figure 1: Generation from German nuclear power plants before and after the nuclear phase-out

Note: The dashed vertical reference line indicates the time of the permanent closure of the 6.3 GW that had be taken offline in March 2011 directly after the Fukushima Daiichi nuclear incident. We also observe an additional, however, temporary drop in generation from nuclear sources – at the minimum only close above 5 GW – in May and June 2011 which was caused by obligatory security checks of the remaining nuclear plants. Source: Grossi et al. (2014)

As shown in Figure 1, the nuclear phase-out caused an immediate reduction in the generation of German nuclear power plants from, on average, about 15 GW before the Fukushima incident to about 10 GW, on average, afterwards. The removal of such a significant fraction of generation capacity is naturally expected to cause price increases on the spot market. This is particularly the case for a removal of nuclear capacity given its typical role as base load power source (consistently generating, at low marginal costs to satisfy minimum demand). Ceteris paribus, the removal of a significant fraction of this capacity forces a switch to more expensive (lignite, hard coal or gas-fired) power plants – located nearer to the right-hand side of the supply-cost curve (merit order) – in order to meet demand (e.g. Knopf et al., 2014).

The existing literature on particularly the (price) effects of nuclear power plant closures confirms the general argument. Grossi et al. (2014) investigate the impact of the phase-out on the German market itself and find prices in Germany to have increased – most significantly in hours of low demand, while only a small price increase was found in hours of high demand caused by increased market power. In a related exercise with some parallels to Grossi et al. (2014), a recent contribution by Davis and Hausman (2015) examines the effects of an unexpected closure of a nuclear power plant in California. The authors show that the lost nuclear generation was met largely by increased in-state natural gas generation (leading to an increase in generation costs). Furthermore, they also found that the closure created binding transmission constraints, causing short-run inefficiencies and potentially making it more profitable for certain plants to act non-competitively. Focusing on Germany's nuclear phase-out, Kunz and Weigt (2014) provide a survey of the impact since 2011 and an outlook to 2023 and conclude that, first, the impacts of the phase-out were modest without creating any major disturbance and, second, in the future, reduced nuclear generation is likely to be replaced by both increased domestic generation (especially by using renewable technologies) and imported generation.

3.2 Promotion of Renewables in Germany and neighbouring countries

Although the nuclear phase-out sketched in the previous section certainly caused additional pressures for an extension of renewable energy production in Germany[7], the country had started the promotion of such technologies long before the Fukushima incident in March 2011. For example, in 2000, the so-called German Renewable Energy Act ('Erneuerbare-Energien-Gesetz', EEG) came into force. The act was designed to promote the growth of renewable energy production in Germany by implementing three basic principles: (1) Investment protection through guaranteed feed-in tariffs, unlimited priority feed-in into the grid and connection requirement, (2) Subsidies paid not by taxes but by every consumer as an EEG surcharge that is included in the

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[7] Given the CO2 targets Germany has committed itself to a simple replacement of nuclear generation capacity with conventional generation capacity – based on fuel types such as lignite or hard coal – is not feasible due to the consequential substantial increase in CO2 emissions.

electricity bill[8] and (3) Feed-in tariffs decreasing at regular intervals to create cost pressures (and innovation incentives) on energy companies.

The EEG was successful in the sense that, according to Borenstein (2012) and Joskow (2011), Germany must nowadays be considered as the world's pioneer in renewable energy from wind and especially solar sources. Capacity in these areas has been growing rapidly, boosted by significant subsidies. According to the German Ministry for Economic Affairs and Energy (2014), in late 2011, wind capacity reached almost 30GW with photovoltaic power capacity following close behind with about 25GW (out of a total system listed capacity of 175GW). In sum, in the year 2011, more capacity had been added through renewables (wind: 1.9GW; solar: 7.5GW) than had been removed by the nuclear phase-out.

However, as noted by Grossi et al. (2014), renewable capacity is at best one side of the coin because, first, these sources are nowhere near being used as intensively as conventional sources, and second, they are not "biddable" in the same way as coal, gas and pumped hydro plants are (Joskow, 2011). While an average thermal plant can provide around 50 percent of its total theoretical capacity over a year, wind hovers around 20 percent and photovoltaic only around 11 percent. Assuming an average utilization rate of a nuclear plant of about 75 percent, the 6.3GW of removed capacity would have produced 41TWh over a typical year. The increased capacity in wind and photovoltaic, however, would on average produce only just over 10.5TWh over the year. Thus in terms of production, there is a big net loss across these fuels and Germany is more likely to be on the upward sloping part of the supply-cost curve (despite the increased capacity). Furthermore, the – under currently imposed regulations – 'must-take' nature of wind and solar and its impact on the remainder of the system must be taken into account when designing and operating the electricity system (see, e.g., Lechtenböhmer and Samadi, 2013; Grossi et al., 2014).

Before we turn to our empirical analysis, it is important to point out that – in contrast to the decision to phase-out nuclear power plants – promotions of renewable energy production was not only introduced (and incrementally extended) in Germany, but also in its neighbouring countries. For example, Figure 2 below plots the respective

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[8] In 2014, the EEG surcharge was 6.24 ct/kWh. It is, however, important to note that energy intensive industries are widely exempted from paying the surcharge – a procedure which led the European Commission to open an in-depth investigation on its compatibility with European state aid rules. In November 2014 the EC decided that the surcharge reduction is mostly in line with the aid guidelines, however, partly has to be paid back because it gave the beneficiary companies an undue advantage over their international competitors. The decision was later challenged by the German government (see http://europa.eu/rapid/press-release_IP-14-2122_en.htm, last accessed on 11 July 2015).

country shares of intermittent renewable energy in gross final energy consumption between 2010 and 2012.

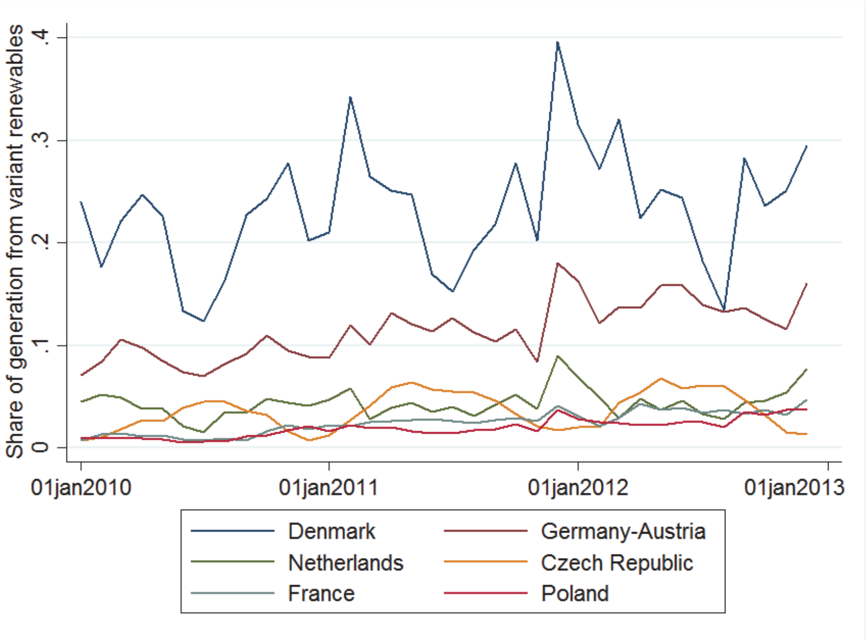

Figure 2: Share of intermittent renewable energy in total electricity generation (2010-2012)

Note: Legend is ordered from highest to lowest shares of renewable energy generation in total energy generation. Renewables include wind and solar. Switzerland not included because of negligibly small intermittent renewables.

As shown in Figure 2 (in relative terms), Denmark and Germany-Austria are the ‘intermittent variable renewable leaders’ with shares reaching (on average) 25 percent and 15 percent, respectively, in 2012. France, the Netherlands, the Czech Republic and Poland lag far behind all with shares around 5 percent of renewable energy in gross final energy consumption in 2012. The intermittent nature of generation from wind and solar will make it necessary – as part of our empirical analysis below – to control for these effects in order to isolate the impact of the German reforms on the respective spot prices.

4 Empirical analysis

To what extent are neighbouring countries affected by Germany’s unilateral policy decisions? Ceteris paribus, in a highly integrated market, both actions – the sudden nuclear phase-out and the expansion of renewables through support schemes – may be expected to cause substantial knock-on effects while if the country is not integrated at all with Germany, we would expect zero impact either of renewables or of phase-out.

Combining this with information on the existence of import and export cross-border congestion can therefore also be used to measure the degree of market integration. More importantly, however, the degree of interdependence raises the question of whether the project of integrating European energy markets is in danger if unilateral decisions of certain Member States have substantial effects, not only on short-term prices, but also on medium- and long-term investment decisions in neighbouring countries.

This section provides an empirical assessment of the impacts of the two unilateral energy policy reforms in Germany on wholesale electricity prices in its directly connected neighbours: the Netherlands, France, Poland, the Czech Republic, Switzerland and Denmark (West and East). Spain is used for a placebo test since it is unconnected directly or indirectly with Germany and therefore would not be expected to be affected by either change.[9] Section 4.1 describes the construction of the data set and presents the descriptive statistics, Section 4.2 describes our modelling approach. The estimation results are in Section 4.3 and Section 4.4 provides a discussion of the implications of our findings for the future integration of internal markets in general and internal electricity markets in particular.

4.1 Data set and descriptive statistics

For the time period from January 2010 to December 2012, we have collected and merged data from several sources to create the rich, unique data set used for our empirical analysis. Our dependent variables are country-specific wholesale (spot) day-ahead prices obtained from the respective power exchanges: EPEX Spot for Germany-Austria, France and Switzerland, Elspot for the two Danish zones (West and East), PXE for the Czech Republic, PPX for Poland and APX for the Netherlands. All price series are collected on an hourly basis and later transformed into daily averages, in order to maintain analytical tractability.

Turning to our independent variables, we introduce a subdivision into common and individual covariates. Starting with the individual variables, hourly data on observed

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[9] German and Austrian markets are fully integrated and therefore considered as single market. Although Germany and Belgium are neighbouring countries, they currently do not have a direct interconnector. However, according to Jauréguy-Naudin (2012), the TSOs of the two countries were considering the construction of an HVDC line with a capacity of 1000 MW. The project is unlikely to be finalized before 2016-2017. Furthermore, the existing (small) interconnector between Germany and Sweden is excluded due to data unavailability. Spains interconnection with France is very limited.

load in each country was obtained from ENTSO-E, while information on hourly forecasted generation from the intermittent renewables wind and solar (for each country) stems from the commercial data provider Eurowind GmbH. Last but not least, to control for cross-border congestion, we have collected hourly data on the import and export interconnectors available for trade (ATC): partly from the respective transmission system operators (TSOs) TransnetBW, 50 Hertz, Amprion (all three Germany), TenneT (Germany and the Netherlands), RTE (France), Energienet.dk (Denmark), CEPS (Czech Republic), PSE (Poland) and SwissGrid (Switzerland) and partly – due to changes in the responsibility for the allocation of interconnector capacity – from the Auction Offices CAO (for the Central Western Europe (CWE) area) and CASC (for the Central Eastern Europe (CEE) area). We use this information to calculate daily import and export congestion indices, respectively, defined as the percentage of hours of a day at which the respective interconnectors were congested. Congestions prevent further trans-border trade which would otherwise continue until prices equalize and arbitrage possibilities vanish. As common variables, we include monthly European hard coal and natural gas price indices (base year 2005) – obtained from the Federal Statistical Office of Germany – and an EU ETS carbon emission price index (which was downloaded from Thomson Reuters Datastream). All three variables will be used as cost drivers in our empirical analysis below.

Last but not least, as load is likely endogenous, we have to instrument for it in our econometric analysis below. Our instruments for load are the current level of industrial production as well as air temperatures in each country. While monthly industry production indices are gathered from Eurostat (base year 2010) and OECD (for Switzerland only) websites, data on daily air temperatures in many cities in Germany and its neighbouring countries have been downloaded from Mathematica 9 (WeatherData and CityData). This data constitutes the basis for the calculation of population-weighted temperature indices.[10] The descriptive statistics for the resulting data set are reported in Table 1 below.

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[10] To avoid problems of quadratic transformation, the temperature indices are converted into degrees Fahrenheit which always take positive values within our data.

Table 1: Descriptive statistics

	DE-AT	**FR**	**NL**	**CH**	**DKE**	**DKW**	**PL**	**CZ**	**ES**
Dependent Variable									
Price (Euro/MWh)	46.09	47.81	48.49	52.27	47.97	43.59	45.87	45.58	44.76
	(16.00)	(25.46)	(13.75)	(17.34)	(35.23)	(15.03)	(9.93)	(15.91)	(15.53)
Individual Variables									
Load (GW)	62.31	56.21	12.51	5.66	1.55	2.30	16.49	7.20	29.20
	(11.43)	(12.92)	(2.39)	(1.10)	(035)	(0.52)	(2.79)	(1.25)	(3.13)
Wind (GW)	4.97	1.10	0.53	-	0.89	0.89	0.31	0.03	4.25
	(4.12)	(0.95)	(0.47)	-	(0.78)	(0.78)	(0.30)	(0.03)	(2.37)
Solar (GW)	2.20	0.27	-	-	-	-	-	0.02	0.77
	(3.61)	(0.45)	-	-	-	-	-	(0.04)	(0.28)
Import ATC (GW)	12.10	2.19	2.51	4.34	0.52	0.90	0.53	1.11	-
	(1.03)	(0.58)	(0.38)	(0.24)	(0.16)	(0.44)	(0.29)	(0.53)	
Export ATC (GW)	6.75	2.61	2.12	0.69	0.50	0.81	0.24	2.21	-
	(0.90)	(0.60)	(0.39)	(0.23)	(0.20)	(0.28)	(0.24)	(0.46)	
Import Congestion	0.22	0.18	0.10	0.23	0.29	0.32	0.48	0.42	-
Index (0-1)	(0.25)	(0.38)	(0.31)	(0.42)	(0.45)	(0.47)	(0.50)	(0.49)	
Export Congestion	0.31	0.28	0.30	0.62	0.23	0.13	0.43	0.38	-
Index (0-1)	(0.29)	(0.45)	(0.46)	(0.48)	(0.42)	(0.34)	(0.50)	(0.49)	
Common Variables									
Gas Price Index	164.85	164.85	164.85	164.85	164.85	164.85	164.85	164.85	164.85
	(22.85)	(22.85)	(22.85)	(22.85)	(22.85)	(22.85)	(22.85)	(22.85)	(22.85)
Coal Price Index	174.66	174.66	174.66	174.66	174.66	174.66	174.66	174.66	174.66
	(9.98)	(9.98)	(9.98)	(9.98)	(9.98)	(9.98)	(9.98)	(9.98)	(9.98)
Carbon Price Index	8.40	8.40	8.40	8.40	8.40	8.40	8.40	8.40	8.40
	(4.16)	(4.16)	(4.16)	(4.16)	(4.16)	(4.16)	(4.16)	(4.16)	(4.16)
Instruments for Load									
Temperature (°C)	9.83	12.71	10.30	10.30	8.32	8.59	8.83	9.41	17.16
	(8.00)	(6.61)	(6.26)	(7.61)	(7.03)	(7.20)	(8.99)	(8.62)	(6.40)
Industry Prod. Index	104.94	101.24	101.97	102.74	106.72	106.72	106.56	104.57	96.36
	(7.67)	(9.78)	(5.16)	(2.50)	(9.26)	(9.26)	(8.17)	(8.57)	(10.50)

Notes: Descriptive statistics show daily means of hourly values and standard deviations (in parentheses); 'Import' and 'Export' variables always represent the flow direction from the German perspective. For countries with missing values for solar and wind generation, the respective values were too low to be measured. For countries outside the European Currency Union daily exchange rates from Thomson Reuters are used for the transformation. Though Spain has no interconnection with Germany we include it for the application of a placebo test.

Table 1 shows some variation in the spot prices for electricity (expressed in Euro per MWh) between Germany and its neighbouring countries. As electricity is a homogeneous good, significant price differences indicate imperfectly integrated markets. In fact, spot prices are found in a range from Denmark (West) with an average price of €43.59 up to Switzerland showing an average price of €52.27, i.e., an about 19.9 percent higher price.[11]

Turning to the individual variables, load differs substantially between the countries. While the German-Austrian and French markets are of roughly equal size (62.31 GW compared to 56.21 GW), all other neighbouring market are substantially smaller with the next largest – the Netherlands and Poland – showing less than a third of the size (12.51 GW and 16.49 GW, respectively).

Information on renewables in the form of electricity production through either wind or solar is limited. While Germany-Austria is found to have the by far largest amount in both categories (4.97 GW and 2.20 GW) the is relatively small. In fact, while wind accounts for roughly 8 percent of the overall load in Germany-Austria the share of solar lies at about 3.5 percent.

With respect to import and export capacities, Germany has by far the largest capacities available for trade (Available Transfer Capacities, ATC) in both categories. However, surprisingly because Germany is a net exporter, interconnector capacities for export (6.75 GW) are roughly half of the size of import capacities (12.10 GW). A comparable asymmetry (in relative terms) is only found for Switzerland, while the remaining countries have roughly equal export and import capacities (albeit at a substantially lower absolute level). The main reason is that interconnector capacity from Switzerland to Germany is around five times higher than in the opposite direction. The derived import and export congestion indices – defined as the percentage of hours of the day at which the respective interconnectors were congested (thereby hindering further trans-border trade) – reveal that, in terms of imports, congestion appears to be a minor issue for the Netherlands (10 percent) while the opposite is true for Poland (48 percent) and the Czech Republic (42 percent). For exports, the spectrum reaches from 13 percent in case of Denmark (West) to 62 percent for Switzerland.[12] The congestion variables for Germany take into account all congestions and cross-border capacities Germany shares with its interconnected neighbouring countries – while for Germany's neighbours only their interconnection with Germany plays a role for our purpose – and thus differ in their calculations. They are constructed as follows: First, we interact the hourly congestion dummies in each

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[11] Dickey-Fuller and Phillips-Perron tests clearly reject the null hypothesis of a unit root in the underlying price and load series; test statistics reported in Table A.1 in the Annex.

[12] We define congestion as the existence of a price difference between Germany and a certain neighbour in a certain hour.

country with the transfer capacity available for trade in the respective hour (ATC) and build the hourly sum over all countries. Second, we divide the sum by the sum of ATC's in all countries in the respective hours (also including all ATC from interconnectors which are not congested), formally

$$Cong_t^{imp(exp)} = \frac{\sum_{i,t}^{K} DC_{i,t}^{imp(exp)} \times ATC_{i,t}^{imp(exp)}}{\sum_{i,t}^{K} ATC_{i,t}^{imp(exp)}}$$

with $Cong_t^{imp(exp)}$ representing the congestion variable for Germany for imports and exports, respectively. $DC_{i,t}^{imp(exp)}$ is a dummy indicating the existence of import and export congestions, respectively, in country i and hour t while $ATC_{i,t}^{imp(exp)}$describes the respective import and export ATCs, respectively, between neighbour i and Germany in hour t. Finally, we compute daily averages from the hourly import and export congestion indices.

However, our congestion index variables cannot easily be interpreted as meaningful measures for the degree of integration. For example, price differences can occur even if interconnector capacity is not fully utilized (e.g., depending on the type of allocation of interconnector capacity). Particularly in explicit auctions – as used between Germany and Switzerland, Poland and the Czech Republic – expectation errors of electricity traders can cause such price differences (although there is still some interconnector capacity available).[13] Furthermore, price differences – in case of congestion of the respective interconnectors – can differ significantly between countries. For instance, in case of congestion, the price difference between Germany and the Czech Republic is, on average, 5.13 €/MWh, while it is, on average, 15.96 €/MWh when the interconnector between Denmark East and Germany is congested because Danish electricity generation (and thus its price) is much more intermittent due to their high share of generation from wind as shown in Figure 2.

In implementing our approach, we assume that interconnector capacities are exogenous in the short run and unaffected by the event we analyse. Expansion of interconnector capacity is a long-term matter and the variation in the transfer capacity is based on technical calculations according to the ENTSO-E method and reflects the physical realities of the grid adjusted a (varying) security margin.[14] We also assume

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[13] In our empirical analysis below, we exclude such cases by assuming a state of congestion only as soon as the price difference exceeds 1 €/MWh. Our results are found to be largely robust to either price differences of 1 percent, 5 percent and 10 percent or 0 €/MWh.

[14] A detailed description of the calculation procedure is provided by ENTSO-E at: http://www.amprion.net/sites/default/files/pdf/Approved%20capacity%20calculation%20scheme.pdf

national fuel-fired generation capacities are exogenous and unaffected by the event in the short-term and generation from renewables is particularly exogenous due to fixed feed-in tariffs and quota obligations provided through national renewable support schemes.[15] Hence, endogeneity from reverse causality should not be a particular issue.

Turning back to the remaining descriptive statistics shown in Table 1 above, the common variables – gas, coal and carbon price indices – are European indices therefore showing no variation between the different countries. However, the instruments for load again differ between countries with the average temperature (in degrees Celsius) highest for France (12.71 degrees) and lowest for Denmark East (8.32 degrees), while the industry production index shows the largest value for Denmark (106.72) and the lowest value for France (101.24).

4.2 Empirical approach

Our empirical approach is subdivided into two steps. First we estimate the impact of unilateral German policy decisions – the nuclear phase-out and the recent expansion of renewables resulting from national support schemes – on prices in its (interconnected) neighbouring countries and the German-Austrian market itself. As both the nuclear phase-out and generation from renewables are exogenous, our study has a quasi-experimental character. In the second step we additionally control for the (price-increasing or price-decreasing) impact of congested interconnectors through the inclusion of import and export congestion variables, respectively, in order to estimate the impact the nuclear phase-out and renewable generation would have had on the neighbouring markets in the absence of cross-border congestions. The degree of market integration is then calculated as the ratio between the estimated policy decisions' impacts before and after controlling for congestion. For instance, if we find that Germany's nuclear phase-out has caused a 10 percent price increase in a particular neighbouring country before controlling for congestion and 20 percent afterwards, we measure the degree of integration between these two markets is 50 percent.

Technically, we estimate the following two equations (with all non-indicator variables in logs)

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[15] While most countries use some form of feed-in tariff, some countries decided to also introduce quota obligations, tenders, exemption from energy taxes or instruments as part of which a fraction of the revenue of general energy taxes finance renewable energy sources. See Council of European Energy Regulators (2013) or Ragwitz et al. (2012) for a detailed comparison of renewable support schemes throughout Europe.

$$P_{i,t} = \alpha_1 + \beta_{1i} L_{i,t} + \delta_{1i} NPO_{i,t} + \vartheta_{1i} RE_{i,t} + \varphi'_{1i} X_{i,t} + \sigma'_{1i} Cal_{i,t} + \varepsilon_{i,t} \quad (1)$$

and

$$P_{i,t} = \alpha_2 + \beta_{2i} L_{i,t} + \delta_{2i} NPO_{i,t} + \vartheta_{2i} RE_{i,t} + \varphi'_{2i} X_{i,t} + \sigma'_{2i} Cal_{i,t} + \theta'_i Cong_{i,t} + \varepsilon_{2,t} \quad (2)$$

with $P_{i,t}$ denoting average wholesale prices in country *i* at day *t*, $L_{i,t}$ representing load and $X_{i,t}$ being a vector of covariates including input price indices for hard coal and natural gas, carbon emission prices and forecasted generation from wind and solar in country *i* at time *t*. *Cal* is a vector of calendar variables including weekday and month dummies. *NPO* and *RE* are our variables of interest representing, respectively, the supply-side shock dummy variable resulting from the German nuclear phase-out (*NPO*) in March 2011 and the electricity generation by the intermittent renewables (*RE*) wind and solar promoted by national support schemes. *RE* is defined as the sum of wind and solar. Equation (2) only differs from equation (1) through the inclusion of the additional *Cong* vector containing the variables indicating the daily percentage of hourly import and export congestions. From the parameters estimated in (1) and (2) the degree of integration (*DoI*) can be formalized as $DoI^{NPO}_{i \neq DE\_AT} = \frac{\delta_{1i}}{\delta_{2i}}$ and $DoI^{RE}_{i \neq DE\_AT} = \frac{\vartheta_{1i}}{\vartheta_{2i}}$, respectively, for Germany's neighbours and $DoI^{NPO}_{DE\_AT} = \frac{\delta_{2i}}{\delta_{1i}}$ and $DoI^{RE}_{i=DE\_AT} = \frac{\vartheta_{2i}}{\vartheta_{1i}}$, respectively, for the German-Austrian market itself.

Given this basic set-up, correct identification of the impact of Germany's energy policy reforms on neighbouring countries crucially depends on an appropriate modelling of the supply curve. Generally, endogeneity is likely to play a role due to the joint causality between electricity demand and supply.[16] We therefore use instrumental variables (IV) and employ industrial production as well as temperatures and their squares as excluded instruments[17] . We thus have the following first stage regression:

$$L_{i,t} = \alpha_3 + \beta'_{3i} Instr_{i,t} + \delta_{2i} NPO_{i,t} + \vartheta_{2i} RE_{i,t} + \varphi'_{2i} X_{i,t} + \sigma'_{2i} Cal_{i,t} (+\theta'_i Cong_{i,t}) + \nu_t \quad (3)$$

The first-stage F-statistic always exceed the weak ID critical values from Stock-Yogo (see Table A.1 in the Annex) which suggests that load is identified by the instruments. This suggests our instruments are legitimate Regarding the remaining variables, we

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[16] Even though demand is often considered as being perfectly inelastic, recent demand-side management activities basically aim at reacting to price signals and therefore question the assumption of perfectly inelastic demand.The Durbin-Wu-Hausman test for endogeneity will support this view later.

[17] Temperature can be thought as an instrument because hotter temperatures increase electricity demand through the need for cooling, while colder temperatures require more electricity for heating purposes. The squared term is included to capture a possible nonlinear relation.

believe that endogeneity is not a major issue. Fuel prices and carbon emission rights are traded at the supranational level in Europe, renewables have zero marginal costs and – as mentioned above – also receive fixed feed-in tariffs and similar privileges due to national support schemes. With regard to the congestion variables we have already argued that price differences are mainly driven by the available interconnector capacity and differences in the generation structure, i.e. different composition of thermal power plants and renewable capacity. Interconnector capacity expansion and power plant constructions takes place at a very slow pace.

As the shape of the supply curve is unknown and likely non-linear, we model it as flexibly as possible by estimating a semiparametric partially linear regression model with Robinson's (1988) double residual method. Consider a partially linear regression model of the type

$$P_i = \theta_0 + \boldsymbol{Z}_i\theta + m(L_i) + \varepsilon_i \quad with \quad i = 1, \ldots., N \tag{4}$$

where P_i represents spot prices in country *i*, Z_i is the row vector of control variables, and θ_0 is the intercept term. Variable L_i represents load and enters the equation in a non-linear way according to a non-binding function *m*. ε_i is the disturbance, assumed to have $E(\varepsilon|L) = 0$, an assumption which we will later relax. The double residual methodology applies conditional expectation on both sides leading to

$$E(P_i|L_i) = \theta_0 + E(\boldsymbol{Z}_i|L_i)\theta + m(L_i) \quad with \quad i = 1, \ldots., N \tag{5}$$

and through subtracting equation (5) from equation (4), we get

$$P_i - E(P_i|L_i) = \big(\boldsymbol{Z}_i - E(\boldsymbol{Z}_i|L_i)\big)\theta + \varepsilon_i \quad with \quad i = 1, \ldots., N \tag{6}$$

where $P_i - E(P_i|L_i) = \varepsilon_1$ and $\boldsymbol{Z}_i - E(\boldsymbol{Z}_i|L_i) = \varepsilon_2$ reflect the two residuals. In a two-step procedure we first obtain estimates of the conditional expectations $E_n(P_i|L_i)$ and $E_n(\boldsymbol{Z}_i|L_i)$ from some non-parametric (kernel) estimations of the form $P_i = m_P(L_i) + \varepsilon_{1i}$ and $Z_{ki} = m_{X_k}(L_i) + \varepsilon_{2k}$ with *k=1,..,K* indexing the control variables entering the model parametrically. After inserting the estimated conditional expectations in equation (6), the Robinson method enables us to estimate the parameter vector θ consistently without explicitly modelling $\mathrm{m(L_i)}$ by a standard non-intercept OLS regression and we obtain $\hat{\theta} = (\hat{\varepsilon}_2'\hat{\varepsilon}_2)^{-1}(\hat{\varepsilon}_2'\hat{\varepsilon}_1)$. Finally, $m(L)$ is estimated by regressing $\big(P - Z\hat{\theta}\big)$ on L non-parametrically.

The endogenous nature of the non-parametrically modelled variable L, however, yields $E(\varepsilon|L) \neq 0$. As standard IV-techniques such as 2-SLS and GMM are not feasible in the context of endogenous variables that are non-linear in parameters, we apply a two-step residual inclusion control function and add the residuals ν fitted in the linear prediction of L in equation (3) as control function to the semi-parametric regression model stated in equation (6) (see Blundell and Powell, 2004 and Imbens and Wooldridge (2009), respectively).

In a next step we apply Hardle and Mammen's (1993) specification test to assess if the nonparametric fit can be approximated by a parametric polynomial alternative. The specification test is based on squared deviations between parametric and non-parametric regressions. Critical values are simulated values obtained by wild bootstrap. The test results justify a polynomial adjustment for load of order 2 for all countries (see Table A.2 in the Annex). This information on the supply curve enables us, in a second step, to correctly model the shape of the supply curve parametrically through the inclusion of squared load as a second endogenous variable and, in addition, to consider correlation between the disturbances across countries through the estimation of system-wide two-step GMM. We instrument for the square of load with $\hat{L}^2$, the square of the first stage prediction of load from equation (3).

4.3 Estimation results

Based on the description of our empirical approach, Table 2 presents our main estimation results. Columns (1) and (2) report the results of the semiparametric estimation by Robinson’s (1988) method – excluding or including congestions – and columns (3) and (4) report the results of the parametric estimation by two-step IV GMM (see Table A.1 in the Annex for the respective first-stage test statistics). Note that – in columns (1) and (2) – the reported coefficients stem from 16 separate regressions (which we do not report for the sake of clarity and brevity[18]).

Starting with a comparison of the regression results of the Robinson estimator and two-step system IV GMM, Table 2 shows very similar results in terms of both the direction and the size of the coefficients for the two estimation approaches.[19] We therefore concentrate our further discussion on the results from the system GMM model shown in columns (3) and (4) which for the reasons given above arguably generates more efficient estimates.

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[18] The full set of regression tables is available from the authors upon request.

[19] The only exception is Poland for which a small, negative (but insignificant) effect of the promotion of renewables in Germany is found (for the case of no congestions controls) when using the Robinson estimator; however, an application of the GMM model results in a – still small and negative – but now also significant coefficient.

Comparing the estimation results excluding congestion controls, the expectation of a positive impact of the nuclear phase-out on spot price is confirmed for all neighbouring countries except Poland, while the promotion of renewables in Germany pushed prices down. In particular, in the estimates uncontrolled for cross-border congestions the nuclear phase-out caused large price increases in Germany-Austria itself (16 percent), but also in its neighbouring countries France (16 percent), DK East (18 percent) and the Czech Republic (19 percent). The promotion of renewables, however, led to price decreases particularly in Germany-Austria (0.21 percent for a 1 percent increase in generation from renewables), Denmark West (0.15 percent) and the Czech Republic (0.17 percent).[20]

Turning to the results of our estimations including congestion controls, a comparison of the respective values in columns (3) and (4) shows diverging results for the size of the coefficients while their direction and general significance remain unaffected (again with the exception of Poland). In particular, we find (absolute) size reductions for both unilateral decisions – nuclear phase-out and promotion of renewables – for Germany-Austria indicating that a higher degree of market integration would have absorbed the impact of German reforms on the German-Austrian market itself to a greater extent. In turn and as expected most neighbouring countries (France, Switzerland and Denmark East and West) exhibit larger (absolute) coefficients when controlling for congestion – the impact of Germany's reforms would have been higher if the markets were fully integrated, while the Czech Republic and the Netherlands show no or only very small changes in the respective coefficients suggesting full market integration of these markets with the German-Austrian market.

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[20] Furthermore, a placebo test is conducted on the Spanish electricity market. The Spanish market was chosen because it is not directly connected with Germany but is similar in generation patterns. The indirect connection via France is also relatively low. Therefore, we do not expect German policies to have impacted the Spanish market substantially. Indeed the coefficients of the phase-out and the renewable generation are statistically not different from zero in the GMM estimation and only renewables is slightly significant in the semiparametric estimation. See Table A.4 in the Annex.

Table 2: Estimation results

	(1)		(2)		(3)		(4)	
	Semiparametric IV		Semiparametric IV		System IV GMM		System IV GMM	
Congestion Control	NO		YES		NO		YES	
DE-AT								
Phase-out	0.151***	(0.034)	0.119**	(0.034)	0.164***	(0.030)	0.113***	(0.030)
Renewables	-0.183***	(0.016)	-0.155***	(0.015)	-0.213***	(0.018)	-0.159***	(0.018)
FR								
Phase-out	0.124***	(0.042)	0.169***	(0.038)	0.158***	(0.036)	0.193***	(0.035)
Renewables	-0.083***	(0.013)	-0.133***	(0.017)	-0.074***	(0.013)	-0.113***	(0.015)
NL								
Phase-out	0.083**	(0.031)	0.067**	(0.026)	0.068**	(0.034)	0.065**	(0.035)
Renewables	-0.060***	(0.012)	-0.075***	(0.011)	-0.055***	(0.013)	-0.071***	(0.012)
CH								
Phase-out	0.090**	(0.039)	0.100**	(0.030)	0.071**	(0.035)	0.087***	(0.029)
Renewables	-0.963***	(0.021)	-0.119***	(0.020)	-0.095***	(0.016)	-0.118***	(0.016)
DK East								
Phase-out	0.232***	(0.044)	0.292***	(0.045)	0.179***	(0.049)	0.342***	(0.051)
Renewables	-0.102***	(0.032)	-0.139***	(0.026)	-0.113***	(0.026)	-0.151***	(0.024)
DK West								
Phase-out	0.108**	(0.052)	0.156***	(0.051)	0.089**	(0.045)	0.145***	(0.037)
Renewables	-0.157***	(0.031)	-0.174***	(0.024)	-0.154***	(0.020)	-0.171***	(0.019)
PL								
Phase-out	-0.007	(0.037)	0.063**	(0.031)	-0.006	(0.035)	0.067**	(0.029)
Renewables	-0.013	(0.010)	-0.064***	(0.010)	-0.019**	(0.009)	-0.070***	(0.010)
CZ								
Phase-out	0.186***	(0.034)	0.185***	(0.038)	0.190***	(0.032)	0.187***	(0.029)
Renewables	-0.161***	(0.036)	-0.180***	(0.037)	-0.165***	(0.022)	-0.169***	(0.022)
#Obs.	1095		1095		1095		1095	

Note: The table reports the main results from 16 separate semiparametric regressions in columns (1) and (2) and two regressions using system wide IV-GMM in columns (3) and (4). Parameters of phase-out are transformed through (exp(β[Phase-Out] -1) to also make them interpretable as percentage impact on prices. Standard errors in parentheses; block bootstrap S.E. on weekly blocks for models (1) and (2), Newey-West HAC S.E. for models (3) and (4); the semiparametric models (1) and (2) are estimated by the Robinson (1988) double residual estimator with load modelled non-parametrically; models (3) and (4) estimated through two-step GMM with correlated disturbances; in models (1) and (2) we control for endogeneity through the inclusion of the first stage residual as control function; instruments for the first stage regressions in all equations are temperatures, their squares and industrial production indices in the respective countries; in models (3) and (4) squares of the first stage predictions of load are included as additional instruments to approximate the nonparametric fit through a quadratic function of load; all covariates from equations (1) and (2) are included in the estimated models though not reported for the sake of clarity and brevity; the full set of regression tables is available upon request; significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Although the discussion of the empirical results of the two separate stages – excluding and including congestion controls – already provided valuable insights on the price effects of the two unilateral energy policy decisions of Germany, our ultimate aim is to use these results for the derivation of a measure of the degree of market integration. In Table 3 below, we present the results of the calculation of the ratio of the estimated policy decisions' impacts before and after controlling for congestions.

Table 3: Degree of market integration

	DE-AT	**FR**	**NL**	**CH**	**DKE**	**DKW**	**PL**	**CZ**
Phase-out Index	69%	82%	100%	83%	53%	62%	0%	100%
Renewable Index	76%	67%	78%	81%	76%	91%	29%	98%
Mean	72%	74%	89%	82%	64%	76%	14%	99%

Note: Degree of market integration is the ratio of the coefficients from the GMM estimates in Table 2 (capped at 100%). In the case of Germany the coefficient of phase-out and renewables, respectively from column (4) is divided by the respective coefficient from column (3). For all neighbouring countries the index is computed as the ratio of (3) to (4). Mean refers to the mean value of both market integration indices.

As shown in Table 3, the degree of market integration is, in most cases, similar regardless of whether we measure it for the nuclear phase-out or renewable generation and the cross-country correlation between both types of measures is around 81%. We would expect it to be less than 100%, because the impact is felt differently across countries due to their different circumstances.

Based on the mean of both measures, the Czech market (99 percent) is already fully integrated with the German-Austrian market with the Netherlands (89 percent) and Switzerland (82 percent) somewhat less so. By far the lowest value – suggesting the lowest degree of market integration – is found for Poland (14 percent). The mean value of 72 percent for the German-Austrian market can be interpreted as the average degree of integration of all neighbouring markets with the German-Austrian market.

In order to provide confidence that the effects we examine are indeed associated with interconnection, we employed the same estimation strategy for Spain. In this case, the GMM estimates show both German policy measures had insignificant impacts on Spanish electricity prices, as we would predict given our model. Details are given in Table A4.

Before we turn to a detailed discussion of policy implications of our empirical results, we provide some ballpark figures on the monetary effects of the two unilateral policy reforms of Germany on its neighbouring countries. Table 3 below provides a quantification of the yearly windfall savings and costs as well as the respective (country-specific) net effects of the two unilateral reforms.

Table 4: Windfall savings and costs from unilateral German energy policies[21]

in billion €/year	**DE**	**AT**	**FR**	**NL**	**CH**	**DKE**	**DKW**	**PL**	**CZ**
Costs from phase-out	3.34	0.45	3.06	0.35	0.17	0.10	0.07	0.00	0.48
Savings from RE	1.64	0.22	0.84	0.11	0.09	0.02	0.05	0.05	0.16
Net impact of unilateral policies	-1.70	-0.23	-2.21	-0.24	-0.08	-0.08	-0.02	0.05	-0.32

Based on the estimated coefficients from column 3 in Table 2 and mean values of the control variables we compute hypothetic counterfactual spot prices for each country, i.e., 1) average spot prices in the post Fukushima observation period if there would not have been the phase-out and 2) average spot prices when there would not have been additional renewable extension after the phase-out. We relate these two counterfactual situations with estimated pre-Fukushima spot prices and compute the difference in spot prices between the pre-Fukushima situation and 1) and 2), respectively. Based on that, we estimate the costs from the German phase-out decision but also the savings from the recent renewable extension for each country. Table 4 shows that the resulting monetary effects of the two unilateral reforms are substantial. Concentrating on the respective net impact figures, we find that only Poland – i.e., the least integrated country included into our study – realizes a small net gain of about € 0.05 billion per year in the analysed period. Furthermore, we find that while the smaller (rather well integrated) countries in our data set face small (in absolute terms) net impacts, the two large countries France and Germany experienced substantial negative net impacts of € 1.70 billion for Germany and at € 2.21 billion interestingly an even higher value for France.[22] One explanation for this result is the fact that France uses electricity for heating purposes in winter when it benefits less from Germany's renewable expansion

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[21] The slight differences in the estimates for Germany found here compared to those reported in Grossi et al. (2014) – focusing on Germany only – are due to several differences in the data set and the estimation method. First, data availability issues constrain us here to the observation period from 2010 to 2012 only, while Grossi et al. (2014) are able to additionally include the year 2009 into their data set and analysis. Second, our estimations here are run on a daily basis while Grossi et al. (2014) go down to the hourly level. Third, we were unable to include river-related control variables here as they were not consistently available for all neighbouring countries. Last but not least, the estimation approach followed here is system-wide GMM including all neighbouring countries while Grossi et al. (2014) estimate the respective effects for Germany in isolation.

[22] We treat Germany and Austria as separate markets here (with an average actual hourly load of 54.85 GW for Germany and 7.46 GW for Austria in our observation period).

due to less solar generation.[23] For instance in 2012 solar generation in summer was on average 4.96 GW per hour compared to 0.89 GW per hour in winter. In sum, we find that the nuclear phase-out generated extra costs of about € 8.02 billion per year for Germany and its neighbours, while the promotion of renewables caused windfall savings about € 3.18 billion yearly in the analysed post-phase-out period.[24]

In sum, the main result of our empirical analysis is that most central continental European countries are already highly integrated and thus unilateral policy reforms have significant impacts on neighbouring countries in the case of big countries such as Germany or France.[25] Our results clearly show the substantial impact unilateral policy reforms can have on neighbouring countries in an internal market for electricity and therefore raise the question of policy implications.

4.4 Policy implications

From a policy perspective, the strongest message from our empirical results is a positive one: the identified impact of the two unilateral German energy policy reforms on neighbouring countries is a strong signal of already well integrated national electricity markets in central Continental Europe. Hence, the goal of a single internal electricity market with all the benefits such as an increased (and cheaper) security of supply or a power smoothing and the resulting smoothing in prices is not far away. Furthermore, our results can be interpreted as confirmation for the workability of the market mechanism. The removal of a significant amount of generation capacity (due to the phase-out of nuclear capacity in Germany) led to price increases in Germany and most neighbouring countries thereby signalling to potential investors that the creation of additional generation capacity is (more) likely to generate a positive return on investment. However, admittedly, an inverse (uncertainty-increasing) depressive effect on investment incentives is triggered by the second unilateral policy reform under investigation – the promotion of renewable energy through support schemes.

Given this initial high-level assessment, our empirical results enable us to draw selected implications. We do not broach the much larger question of whether the

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[23] Figure A.1 in the Annex illustrates the different load patterns for Germany/Austria and France.

[24] Technically, we measure industry benefits from renewables in Germany here because German customers have to pay the costs resulting from the difference between the fixed feed-in tariffs for renewables and the wholesale price, the so called EEG surcharge, as a part of their electricity bills. Industry, by contrast, is mainly exempted from paying the EEG surcharge.

[25] Analogously, unilateral policy reforms likely will have no impact – not even in the implementing country – in the case of unilateral policy reform in a small country.

internal market for electricity is a desirable goal, but rather how this goal can be reached with the least cost burden.

Considering the cost implications a little further, a separation into economy-specific, industry-specific and market-specific perspectives appears feasible. First, from an economy-specific (macroeconomic) perspective, increasing prices for electricity act like a VAT increase on the one hand and decrease available income for consumers on the other, thereby having direct impacts on real purchasing power, hence, on industry production and economic growth. Referring to the broader literature on the effects of energy (mostly oil) prices on various macroeconomic indicators for economic growth, research by, e.g., Hamilton (1983), Mork (1989) and especially Kilian (2008) suggests that the identified impacts were mostly substantial but of only temporary nature. Interestingly, in a recent study, Berk and Yetkiner (2014) provide empirical evidence for an enduring relationship between energy prices and economic growth suggesting a strategic importance on energy prices for the future development of an economy. Similar results are shown in Cox et al. (2014). They find higher electricity prices lead to output reductions and a decrease in labour demand. As a consequence, when a nation's unilateral policies have a direct effect on the prices for electricity, it can cause a permanent negative effect on both industry production and economic growth in neighbouring countries.

Second, from an industry-specific perspective, firms for which energy costs are a relatively large share of overall costs face substantial absolute increases in costs causing a competitive disadvantage with respect to foreign competitors (who are either less integrated - and therefore less affected by the policy reform - or located outside Europe). If the respective price increases are permanent and substantial, unilateral policy reforms in one country may cause firm closures – and even changes in industry structures – in neighbouring countries, triggering potentially substantial knock-on effects from, e.g., social and labour market perspectives.

Third, from a market-specific perspective, unilateral policy reforms have a direct impact on investment decisions in neighbouring countries. For example, the NPV calculation of an investor into the construction of a French power plant will depend on the expectation regarding unilateral policy reforms in the neighbouring countries (particularly the larger ones such as Germany and Italy). Ceteris paribus, higher prices – in our case caused by the nuclear phase-out – will make such investments more likely, while lower prices – in our case caused by the promotion of renewables – will reduce the incentives to invest into the construction of a new plant. In any case, unilateral policy reforms of a significant size are likely to cause changes in the incentives to invest in new capacity (and the usage of existing capacities) and will therefore have an impact on the future structure of the European electricity industry. In the worst case scenario, the induced insecurity with respect to expected return on investments can cause underinvestment and thereby having negative externalities on supply security.

What do all these consequences of unilateral policy reforms for neighbouring countries suggest for the future of internal markets in general and electricity market integration in particular? On the surface, there appear to be two drastic solutions to the problem. First, our empirical results and the discussion of (partly) negative impacts on neighbouring countries could be used to promote the need for a further coordination of economic policies in general and energy policy in particular between the different Member States. In the most extreme form, this would lead to a mandatory common energy policy imposed by the European Commission on the respective Member States. However, given the diversity of European countries and the dangers that are likely to be associated with an implementation of such a central solution – e.g., with respect to the general acceptance of the idea of Europe in the population, but also with respect to the expected incompetence of a central Commission when it comes to assessments of local-, region- or country-specific problems – questions the desirability of such an approach.

Second, our empirical results and the discussion of (partly) negative impacts on neighbouring countries could simply be seen as (additional) costs of market integration through increased insecurity with respect to return on investments – that are unlikely to surpass the tremendous benefits of integration – denying any need for further policy actions. Although such an approach appears less dangerous for the idea of Europe, such an extreme view also runs the danger of losing backing from the population once they realise that their jobs are at stake due to a unilateral decision of a particular other Member State.

Given the problems associated with the two drastic solutions, this argues for increased coordination efforts among the affected Member States before unilateral policy reforms (with a Community dimension) are implemented. This is especially true for fundamental decisions such as a short-term removal of (a substantial amount of) capacity from the market, but also for the promotion of renewable energy. For instance, each change in the design of national renewable support schemes will impact all connected countries and potentially countervail their national energy policies. Against this background, it appears to be important to design new rules – or alternatively enforce existing rules – on what types of decisions need discussing or even deciding at the Community level before they are actually implemented. Such a procedure would not only help the respective Member State(s) to become aware of the respective impacts of its decision on neighbouring states – possibly leading to changes in the reform – but would also allow neighbouring countries to accommodate to the expected consequences of the unilateral policy reform. Furthermore, a cooperative solution would also help potential investors to better assess the expected returns of the construction of new power plants. In the medium- and long-run, such signals are important not only to secure the supply of electricity in Europe but also to secure the respective demands at the lowest possible price.

In summary, the externalities of unilateral decisions in one Member State imposed on others demonstrate the importance of a coordinated approach of European energy policy in an increasingly integrated European electricity market. This principle should be kept in mind, in the context of the current discussion in Europe on the necessity of national capacity markets and their impact on cross-border trade and competition.[26]

5 Conclusion

At the constitutional level of every kind of federation, decisions have to be made about the types of decisions that are conducted on the federal level and the types of decisions delegated to the national or local level. Typical examples of the former are foreign or defence policies, while the design of the educational system or certain taxes are examples for the latter. From the perspective of federalism, the foundation and extension of the European Union added a layer above the national level leading, not only to an increased complexity of political decision making, but also forcing the respective national governments to give up part of their decision making powers.

In the European Union, the principle of subsidiarity determines the level of intervention, particularly in the areas of competences shared between the EU and the Member States. According to the principle, the EU may only intervene if it is able to act more effectively than Member States, especially when, first, an action has transnational aspects that cannot be resolved by Member States, second, a national action or an absence of action would be contrary to the requirements of the Treaty and, third, an action at European level has clear advantages. By applying the principle of subsidiarity, the European Union aims at bringing its actions and its citizens closer

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[26] Interestingly, in April 2015, the European Commission opened a sector inquiry to investigate these issues in greater detail (see http://europa.eu/rapid/press-release_IP-15-4891_en.htm; last accessed on 11 July 2015).

together by guaranteeing that action is taken at local level where it proves to be necessary.

Although energy markets in general and electricity markets in particular certainly have a Community dimension, it took until 2005 for a first step towards a common policy to be agreed on and in practice, many recent decisions of community dimension were undertaken on the national, rather than the European level (see generally Glachant, 2015). This is particularly the case for – but not limited to – the two recent and significant unilateral policy reforms of Germany – the phase-out of nuclear power plants after the Fukushima incident and the expansion of renewables promoted by fixed feed-in tariffs and unlimited priority feed-in – we have examined.

Applying Robinson's (1988) double residual estimator adjusted by a two stage residual inclusion as well as a system IV GMM, we find that both unilateral reforms had substantial – albeit inverted – impacts on market prices in neighbouring countries. While the phase-out triggered price increases of up to 19 percent, the price reductions caused by Germany's renewable energy support schemes were of similar size for each percent of additional generation from German renewables. By adding controls for the impact of cross-border congestions we construct a counterfactual which enables causal inference on the degree of market integration with Germany's neighbouring countries showing large differences in a range from 14 to 99 percent.

From a policy perspective, the strongest message from our empirical results is a positive one: the identified impact of the two unilateral German energy policy reforms on neighbouring countries is a strong signal of already well integrated national electricity markets in central Continental Europe. Hence, the goal of a single internal electricity market with all the benefits such as an increased (and cheaper) security of supply or a power smoothing and the resulting smoothing in prices is not far away.

However, even if we assume that the political and economic benefits of creating an internal market for electricity are considered so large that they are assumed to trump any cost estimate, it is still important to work towards reaching this goal with the least cost burden. Given the (potentially substantial) knock-on effects of unilateral policy reforms on an economy-, industry- and market-level, it appears unlikely that either of the two drastic solutions – maximizing the powers of the European Union or accepting these knock-on effects as 'collateral damage' of an increasing integration of markets – lead to optimal outcomes.

From our perspective, the externalities of unilateral decision making in one Member State imposed on the others demonstrates the importance of a coordinated approach of European energy policy in an (partly) already well integrated European electricity market. Such a coordinated approach does not necessarily demand that all strategic decisions are made on the European level, however, it demands that they are constantly monitored and their implications are discussed – possibly by still allowing the national states to implement the desired policy changes, but at the same time reducing the negative impact on neighbouring countries. This principle should be kept in mind, not only in the context of the recent European Energy Union targets but also in many other policy areas in which European, national and local decision making bodies have to interact efficiently to maximize the contribution of the European Union for all citizens in its currently 28 Member States.

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Annex

Table A.1: First-stage test statistics

	DE	FR	NL	CH	DKE	DKW	PL	CZ
Robinson Estimator								
First Stage F-Test (Load)	16.91	343.04	43.62	19.20	69.17	34.59	32.45	58.80
Stock-Yogo weak ID test critical values for single endogenous regressor are 13.91(5%) and 9.08 (10%)								
System GMM Estimator								
First stage F-test (Load)	12.80	294.48	32.81	21.68	50.81	26.51	29.36	44.17
First stage F-test (Load_Sq)	17.06	284.19	41.64	22.54	60.69	36.46	45.65	63.31
Kleibergen-Paap Wald F-stat.	14.23	267.08	34.49	32.58	69.12	30.05	21.00	50.48
Stock-Yogo weak ID test critical values for K=2 (endogenous regressors) and L=4 (instruments) are 11.04 (5%) and 7.56 (10%)								
Durbin-Wu-Hausman test of endogeneity for Load (p-value)	0.00	0.00	0.00	0.00	0.24	0.00	0.08	0.63

Table A.2: Hardle and Mammen's (1993) specification test

	DE-AT	FR	NL	CH	DKE	DKW	PL	CZ
Standardized Test Stat.	0.63	1.23	1.34	1.19	0.97	0.86	1.05	0.52
Prob.	0.24	0.33	0.14	0.22	0.46	0.63	0.44	0.54

Note: Hardle and Mammen's (1993) specification test based on bootstrapping with 100 repetitions; H0: parametric and non-parametric fits are not different.

Table A.3: Unit Root tests applied on price and load series

		DE-AT	FR	NL	CH	DKE	DKW	PL	CZ
ADF	Price	-15.12***	-16.15***	-14.23***	-11.51***	-18.17***	-12.83***	-10.33***	-14.50***
	Load	-17.27***	-5.96***	-16.84***	-7.77***	-8.56***	-13.21***	-14.59***	-10.13***
Philipps -Perron	Price	-14.67***	-16.03***	-14.87***	-10.33***	-19.17***	-12.10***	-9.00***	-13.78***
	Load	-1542***	-4.017***	-15.27***	-5.49***	-6.14***	-11.28***	-13.25***	-8.00***

Note: The null hypothesis is that the variable contains a unit root, and the alternative is that the variable was generated by a stationary process.

Table A.4: Placebo test applied on the Spanish electricity market

	(1) Semiparametric IV		(2) System IV GMM	
ES				
Phase-out	0.089	(0.056)	0.073	(0.046)
Renewables	-0.042*	(0.023)	-0.021	(0.019)
#Obs.	1092		1092	

Note: The table reports the main results from a single semiparametric regression in columns (1) while column (2) reports results from a system wide IV-GMM regression in which the impact of Spain is estimated simultaneous with all eight remaining price zones from Table 2. Parameters of phase-out are transformed through (exp(β[Phase-Out] -1) to also make them interpretable as percentage impact on prices. Standard errors in parentheses; block bootstrap S.E. on weekly blocks for model (1), Newey-West HAC S.E. for model (2); the semiparametric model in (1) is estimated by the Robinson (1988) double residual estimator with load modelled non-parametrically; model (2) estimated through two-step GMM with correlated disturbances; in model (1) we control for endogeneity through the inclusion of the first stage residual as control function; instruments for the first stage regressions in all equations are temperatures, their squares and industrial production; in model (2) squares of the first stage predictions of load are included as additional instruments to approximate the nonparametric fit through a quadratic function of load; all covariates from equations (1) and (2) are included in the estimated models though not reported for the sake of clarity and brevity; the full set of regression tables is available upon request; significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

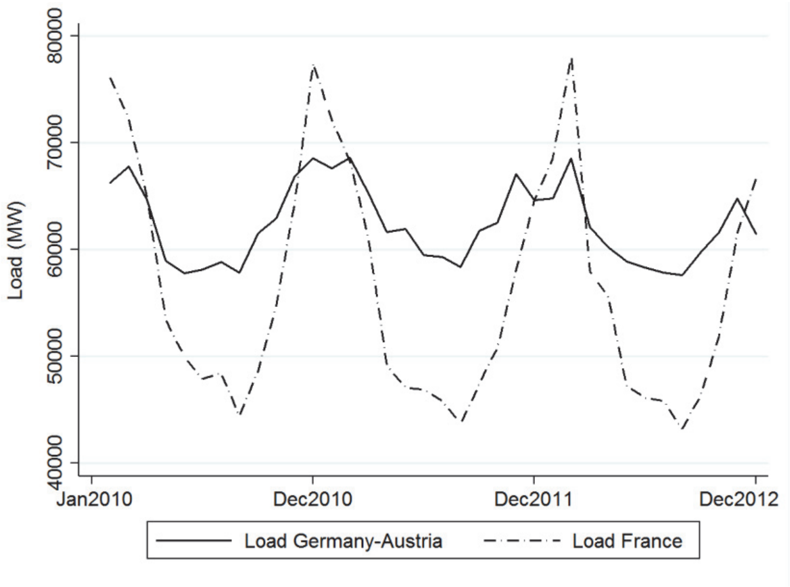

Figure A.1: Difference in load patterns between Germany-Austria and France