Industry and Innovation

ISSN: 1366-2716 (Print) 1469-8390 (Online) Journal homepage: https://www.tandfonline.com/loi/ciai20

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To cite this article: Carlo Cambini, Federico Caviggioli & Giuseppe Scellato (2016) Innovation and market regulation: evidence from the European electricity industry, Industry and Innovation, 23:8, 734-752, DOI: 10.1080/13662716.2016.1206464

To link to this article: https://doi.org/10.1080/13662716.2016.1206464

Published online: 10 Jul 2016.

INDUSTRY AND INNOVATION, 2016
VOL. 23, NO. 8, 734–752
http://dx.doi.org/10.1080/13662716.2016.1206464

Innovation and market regulation: evidence from the European electricity industry

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ABSTRACT
This paper studies the effects of changes in the level of product market regulation on the industry-level innovation intensity in the EU electricity sector during years 1990–2009. In order to test the impact of deregulatory policies on the propensity to innovate in energy technologies, we match data on R&D budgets and European Patent Office patent applications from International Energy Agency and Eurostat Databases with the Organisation for Economic Co-operation and Development indexes of product market regulation. The analysis addresses innovations in the traditional electricity-related technologies, but keeping aside renewable energy technologies. Findings show an increase in patenting activities following market deregulation, measured along three factors: entry barriers, public ownership and vertical integration. In particular, econometric results suggest that policies aimed at reducing vertical integration – i.e. to unbundle networks from energy generation and supply – have a positive impact on innovation activity. Results are robust to the introduction of controls for country-level public R&D expenditures in the electricity field.

KEYWORDS
Innovation; patents; regulation; electricity

JEL CLASSIFICATION
L94; O31; O32

1. Introduction

Over the last two decades, the European Union (EU) has introduced widespread reforms in product markets with the aim of stimulating competition, increasing firm's efficiency and raising rates of investment and innovation.

The impact of such structural and institutional reforms on economic performance, and in particular on innovation, has been at the centre of the debate in the recent economic literature (Aghion and Griffith 2005). Market liberalisation and competition affect the incentives firms face to engage in innovative activity but their impact is still ambiguous. A more intense competitive environment incentivises firms to reduce costs and increase efficiency with respect to monopoly and this in turn induces firms to invest in innovation as a way to gain market shares.[1] However, once competition becomes too intense, imitation activities

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[1]Griffith, Harrison, and Simpson (2010), for example, provide empirical evidence that the EU market reforms carried out under the EU Single Market Programme were associated with increased product market competition, and with an increase in innovation intensity and productivity growth for manufacturing sectors.

become also attractive because of the lower profitability of inventions (Aghion et al. 2005). In sum, competition helps sustaining innovation, but up to a limit.[2]

The ambiguous effect of competition and market liberalisation on innovation also characterises the regulated network industries, such as the electricity sector. For a long time these industries have faced a reduced level of competitive pressure due to the presence of vertical integration, barriers to entry and state ownership, and they have been subject to a strict ex ante regulation. In these industries, regulation over entry conditions, prices and service quality impacts firm's profitability and indirectly the incentives to innovate (Vogelsang 2002, 2010; Joskow 2008). Nonetheless, regulatory interventions have considerably evolved in the last decades, both in the EU and the United States (US). From an early regulatory framework with rather weak incentives to innovate, in the mid-eighties, most of the EU countries, and not only, started implementing structural market reforms to introduce liberalisation and incentive based regulation with the aim of enhancing firms' productivity gains and spurring innovation and infrastructure investments. At the same time, one of the goals of the new regulatory setting was to extract firms' rents due to asymmetric information and therefore to limit firms' profit, which in turn negatively affects R&D and other innovation activities. In short, the impact of regulation on the incentive to invest and to innovate is still unclear. While liberalisation and market deregulation have been shown to significantly and positively impact infrastructure investment (Alesina and Ardagna 2005), the effect of regulation on investment in innovation and intangible assets requires further investigations. This paper aims at filling this gap.

The purpose of this paper is to study the effects of the country-level changes in the intensity of market regulation on the innovation activities in the European electricity sector, as proxied by the yearly number of new patent applications at the European Patent Office (EPO). In the empirical analysis, we make use of country-level data from the Organisation for Economic Co-operation and Development (OECD), the International Energy Agency (IEA) and the Eurostat Database, in order to test empirically the impact of market reforms, such as deregulation and privatisation.

We focus on the EU electricity industry because, among all the regulated sectors, the companies active in such sector have historically been the monopolistic providers of the service and the main inventors of new technologies until the start of the market reforms in mid-nineties. This characteristic is peculiar of the EU energy markets during the past three decades. Differently, in the US the process of market regulation started before, in the seventies. As an effect, in the nineties the US utility and energy operators were no longer the main generators of innovations.[3]

In addition, electricity companies are among the largest network firms (by revenue) in Europe and their economic impact at country level is extremely large in terms of consumers and organisations. Electricity firms also reach a top position in Europe for tangible investment (Guthrie 2006), for market capitalisation and for their extremely generous dividend

[2]Entry barriers also affect innovation. Aghion et al. (2009) finds that incumbents' productivity growth and patenting is positively correlated with foreign firm entry in technologically advanced industries. The authors claim that that innovation is pushed by the threat of technologically advanced companies entering the markets in sectors close to the technology frontier. In laggard sectors, entry discourages innovation, because incumbents' expected rents are decreased from innovating.

[3]For an analysis of the evolution of the US energy market with specific reference to innovation trends, see Sanyal and Ghosh (2013).

payments.[4] Furthermore, over the last 30 years, this sector has been the object of sweeping reforms that have changed many aspects of the industry. Such reforms aimed at liberalising the market and at privatising the state-owned monopolies to raise firm efficiency, improve service quality and incentivise investment in infrastructure and innovation (see Alesina and Ardagna (2005) and Griffith, Harrison, and Simpson (2010) for the energy industry see Pollitt 2012). These reforms are characterised by considerable heterogeneities among European countries and are still largely incomplete: in some countries, like Spain, Germany and the UK, electric operators have been privatised, while in France, Italy and Sweden, the government still controls relevant shares of the incumbent firms. In terms of market liberalisation, in some countries (such as the UK, Italy and Spain) regulators impose a vertical separation of network activities (transmission and distribution) with the more competitive segment of the markets (generation and retail), while others (Austria, Germany, France and Hungary) still have a vertically integrated electric industry. These different approaches to market reform led to a very heterogeneous degree of market openness across EU countries (ACER 2014).[5] This heterogeneity across EU member states is what makes our comparison interesting from a policy point of view, and what we intend to exploit in this study.

The European Commission (EC) provided huge financial support under the seventh Research Framework Programme (FP7) in order to sustain innovation in the electricity industry in the next coming years: from 2007 to 2012, the FP7 Energy Theme supported about 350 projects with some €1.8 billion. In 2008, the EC established the Strategic Energy Technology (SET) Plan in order to adopt a technology push framework of the EU's energy and climate policies. Public and private investments in technological development for the SET-Plan sectors increased from € 3.2 billion in 2007 to € 5.4 billion in 2010; the EC has estimated that €8 billion per year are needed to move effectively forward the SET-Plan actions (European Commission 2013). Innovation in the electricity industry is related not only to the development of new generation technologies (primarily, the development of renewables technologies), but also to the construction of newly and highly innovative infrastructures that combine updated electricity technologies with the ICT ones. These new infrastructures are known as smart grids.[6] In the period 2008–2013, EU investment in smart grid projects was consistently above €200 million per year, reaching €500 million in 2011 and 2012, for an overall 460 R&D projects – mostly concentrated in France, the UK, Italy, Germany and Spain – amounting to €3.15 billion investment (JRC 2014).[7]

These evidences point out how in next decades innovation will be pivotal in the evolution of the Electricity industry. At the same time, the presence of sector-specific regulation largely affects the return firms can gain from these innovative investments. Studying the interplay

[4]See Bortolotti, Cambini, and Rondi (2013) for an analysis of market values in regulated EU firms and Bremberger et al. (2016) for dividend policy in the EU electricity industry.

[5]For an overview of the regulatory and privatisation reforms in the European electricity sector, see Cambini, Rondi, and Spiegel (2012) and Pollitt (2012).

[6]The development of smart grids requires investment in conventional network assets and the adoption of innovative solutions in order to carry on a more efficient planning and operation of the grid, by means of improved automation and control of network components and end-users' participation. Similarly, demand response requires technical innovation, i.e. intelligent systems located at the customer's site and connected to end-users' appliances (smart meters). Finally, the system needs to offer possibilities for innovative uses of electricity, as in the case of electro-mobility. In sum, the innovations related to smart grid projects are mostly on the adoption of automation, ICT components and bidirectional networks (such as smart metering), i.e. technological changes on the network. For a recent analysis on smart grids and innovations in distribution networks, see Lo Schiavo et al. (2013).

[7]A recent report by the European Network of Transmission System Operators for Electricity (Entsoe 2013) show that by 2020 the aggregate investment in smart grids in Europe will amount approximately to €100 billion.

between innovation incentives and the degree of market regulation is therefore important to provide clear policy guidelines to sustain investment in innovation in the coming years and help policy-makers to adopt specific reforms to promote R&D.

Our paper is related to the branch of the recent literature on the interplay between market liberalisation and innovation. Jamasb and Pollitt (2008) present a survey of the economic literature on the impact of liberalisation on innovation and conclude that liberalisation has a potentially negative effect on energy R&D investments and, hence, on long-term innovation in the sector, though without presenting quantitative evidence. Focusing instead on the UK case, Jamasb and Pollitt (2011) collect data on the patenting activities of main distribution and transmission companies, distinguishing between renewables and non-renewables technologies. They find a downward trend of patenting at the time of liberalisation then followed by an increased activity in the post-reform years, especially since the 2000s. However, they also find that market reforms lead to a reduction in R&D expenditure and associated public budget cuts. A decline in innovative activities has been found by Nemet and Kammen (2007) with respect to the US patenting in renewable technologies (wind and solar power).

The nexuses between public interventions and innovation in the electricity industry have been addressed in recent years by several scholars that have specifically focused on the area of renewable energy innovations. Previous studies show that, during the market reform period, many governments introduced different types of environmental and technological policies that lead to a sharp increase in renewable support policies and in turn to an upturn in public R&D and in patenting in renewables (Jamasb and Pollitt 2011, 2015). Other studies analyse the relationship between renewables support, competition and R&D showing that renewable energy policies are more effective in fostering green innovation in countries characterised by more liberalised energy markets (Nesta, Vona, and Nicolli 2014; Nicolli and Vona 2014).

Differently from previous studies, in this paper we deal with innovations in the traditional electricity-related ('brown') technologies. This is because, across European countries, policies for renewable energies have mainly consisted in tariff subsidisation or direct financial support of private R&D projects, while in this paper we focus on the indirect effect on innovation incentives in a mature sector engendered by policy interventions that alter the competition dynamics. Moreover, in the paper we make an effort to identify such indirect effect exerted by market regulation, net of the impact of public R&D spending in the electrical field.

This paper contributes to the existing literature in two ways. First, there are no extant contributions that have empirically analysed at the European level the effects of regulation and liberalisation reforms on innovation in the specific electricity industry using patent data.[8] Previous studies focused on the telecommunication and the energy industries in the US (Prieger 2002; Sanyal and Ghosh 2013), where deregulation reforms started well before the nineties and the market structure is rather different, or in the UK only (Jamasb and Pollitt 2011). Second, in order to quantify the effect of regulation on firms' innovation incentives, we use an index that captures the pace and intensity of liberalisation and deregulation reforms, the OECD index of product market regulation drawn from the International Regulation Database by Conway and Nicoletti (2006). The index is an average of several

[8]For example, Bassanini and Ernst (2002) find a negative correlation between the intensity of product market regulations and the intensity of research and development expenditure in OECD countries. However, they do not consider the impact on patenting as we do in our paper.

indicators which vary from 0 to 6 (lower numbers indicate a greater degree of openness) and allow for entry barriers, the vertical structure of the market, the market share of the dominant player(s), the presence of the state as a shareholder and the presence of regulatory controls on retail prices. This index has been used in previous studies to assess the impact of regulation on fixed aggregate investment (Alesina and Ardagna 2005). However, to the best of our knowledge, there are few studies on innovation that use the aggregate OECD index as well as its sub-indexes to point out how different market features (the presence of entry barriers, the degree of vertical integration, the presence of state ownership) affect the incentives to innovate in the EU electricity industry. Among them, Blind (2012) studies the impact of six different indexes of governmental regulation – comprising economic, social, environmental and institutional regulations following the general OECD (1997) taxonomy – and quantifies the effect on innovation in 21 OECD countries using panel data for the period between 1998 and 2004. Our analysis, differently from the study of Blind (2012), focuses on the detailed market features (i.e. the level of barriers to entry, the degree of vertical integration and the role of state ownership) and includes some tests on the impact of the regulatory reforms with and without time lags to investigate the potential delayed effects after the implementation. Nesta, Vona, and Nicolli (2014) also use the OECD index of product market regulation to study the interplay between competition and innovation in green (i.e. renewables) technologies that are not the object of our analysis.

Our methodological approach is driven by the objective of capturing the effects of a variation in market regulation conditions also on upstream/adjacent markets. These markets might benefit from an increase in the demand for innovative products and solutions from the operators in the electricity sector. Indeed, the country-level data on yearly patent filings, used in this paper, have been collected based just on the technological area of application. Hence, we are not simply measuring the patent filings of the firms directly subject to the product market regulatory framework. The total patenting level for a certain country and year accounts also for the innovations carried out by firms in different sectors (e.g. ICT, Mechatronics and Instruments) provided that they have a direct application to the electricity industry.[9]

Our econometric results show that a decrease in the index of product market regulation, hence, an increase in the degree of market liberalisation, is positively associated with an increase in the country-level innovation activities as captured by new patent filings in the electricity technological domain. The effect seems particularly driven by policies leading to a reduction in the level of vertical integration in the industry. Such result is robust to introduction of controls for the public R&D spending in the electricity sector that might indirectly affect the domestic patenting output.

Our results are in line with the findings of Jamasb and Pollitt (2011) on the positive mid-run effect of market deregulation on patenting in the UK and with the evidence provided by Prieger (2002) for the US telecom industry. Differently, the results in Sanyal and Ghosh (2013) suggest a negative relationship between deregulation and innovation in the US energy industry: although the time frame is similar to the one in this study, the US context is different from the European since the former has experienced a much longer process of market reform with respect to the latter. Hence, the joint interpretation of these findings seem to suggest that the impact of market deregulation policies on innovation

[9]Numerous recent radical innovations in the electrical distribution area (e.g. smart meters) are indeed based on complex platforms with the integration of technologies from different sectors.

is indeed contingent on the status of market reforms. In the early phases of liberalisation and vertical unbundling, a positive effect seems to prevail, while in a longer time horizon dynamic efficiency issues are more likely to emerge, asking for regulatory policies that do not undermine innovation investments.

The structure of the paper is the following. Section 2 provides details on the research framework and, in particular, on the OECD index and its sub-components; furthermore, the data collection process, descriptive statistics and the trends of the most relevant variables are shown. Section 3 provides the results of the econometric analyses and their discussion. Finally, Section 4 concludes and presents potential policy implications.

2. Data-set and methodology

This paper investigates the effects of the changes in the level of market deregulation in the electricity industry on national R&D budget and EPO patent applications across a sample of 16 European countries for which sufficient data points are available from year 1990 to 2009. In particular, the study focuses on country- and industry-level data in order to identify the correlation in time between different indicators of intensity of regulation and the patent filings in the electric sector by controlling for both the R&D expenditure and the electricity demand.

The key independent variable is the index of product market regulation developed by the OECD (Conway and Nicoletti 2006). The OECD index of product market regulation measures the regulation intensity in the electric sector.[10] It can take values between 0 and 6 and it is calculated as the average of three different sub-indicators: 'Entry regulation', 'Public ownership' and 'Vertical integration' ('EntryReg.', 'Publ.Own.', 'Vert.Integr.'). The value of each component is determined from the answers to questionnaires the OECD regularly submitted to experts. Low values of the index are associated with the presence of competition in all segments of the relevant sector as well as with vertical separation between transmission, distribution and generation firms. High values are associated with the presence of a less competitive and more closed market.

The sub-index 'EntryReg.' measures how market entry is feasible and liberalised and takes into account the presence of third party access to existing transmission and distribution networks, the freedom of choice of consumers and the presence of a liberalised wholesale power market. This measure is particularly interesting to test the effect of entry barriers on innovation (Aghion et al. 2005), as it can give rise to two competing hypothesis. On the one hand, protected market incumbents might invest more resources in risky innovation activities thanks to the reduced competitive pressure. On the other hand, if entry conditions favour competition, incumbents may decide to invest more due to the so-called 'escape competition effect', leading to an aggregate net increase in the innovation activities at the industry level.[11]

The second component, 'Publ.Own.', is defined by the level of the public–private ownership structure of the largest companies in the main segments of the electricity industry.[12] The

[10]The OECD provides indicators for electricity, gas, transport, post and telecommunications with the aim to measure policy setting and formal government regulation (http://www.oecd.org/eco/pmr).

[11]This mechanism is particularly relevant in the energy sector and especially for green technologies (see Jacobsson and Bergek 2004; Nesta, Vona, and Nicolli 2014; Nicolli and Vona 2014).

[12]The element value is determined by the answers to the question 'What is the ownership structure of the largest companies in the generation, transmission, distribution, and supply segments of the electricity industry?' with the options 'Private', 'Mostly Private', 'Mixed', 'Mostly Public', 'Public' ranging from 0 to 6.

presence of state control is generally associated with a sort of indirect 'market protection' by the government to limit competition in the market and insulate their own firms from market competition. Therefore, if state ownership is high in the market, competition is more likely to be less intense, profit may increases and innovation may be more intense. However, the presence of state ownership in a firm is also characterised by potentially lower economic performance due to multiple non-economic goals that these firms may pursue for political purposes (Shleifer and Vishny 1994), leading to a waste of economic resources that in turn limit innovative activities.[13] Hence, even in this case, the impact of public ownership on innovation is not ex ante predictable.

Finally, the 'Vert.Integr.' item assesses the degree of vertical separation between the different segments of the electricity industry.[14] When companies simultaneously control the relevant infrastructures (transmission and distribution networks) and operate in upstream and downstream markets, these firms have a considerable market power and can behave in a way to limit market entry by alternative companies and in turn competition. Hence, when competition is less intense the above-described (both positive and negative) effects on innovation may emerge. Notably, the use of this indicator allows us to address a key gap in extant literature on the relationship between vertical integration and innovation output as highlighted by Jamasb and Pollitt (2008, 1,002).

Similar to Alesina and Ardagna (2005), in our model specification, we will also use the variables 'Entry + Vert' and 'Entry × Vert' which are calculated, respectively, as the average and the product of the components 'EntryReg.' and 'Vert.Integr.'. Such variables specifically capture the aggregate change in the competition level in the industry and proxy the degree of market liberalisation.

Higher values of the components of the index are associated to a more intense regulatory framework and a less liberalised market, while lower values of the index are associated with a more deregulated and open industry. In our econometric models, we test the overall regulation index for the electricity market, each of the three sub-indexes separately as well as the combined variables 'Entry + Vert' and 'Entry × Vert'.[15] The econometric analysis employs a set of fixed-effect panel models in order to estimate the presence of correlations between the regulatory framework (or the level of competition) and the output of the research activities in the electricity industry.

The final data-set was built by matching different sources. Data on the regulation index, the R&D in the electric industry and for renewable energy sources (RES) have been collected from the OECD STructural ANalysis Database (STAN), which reports the data processed by the IEA[16] at country level from year 1990 to the latest available.

The information about the electrical energy consumption and the percentage of R&D expenses on gross domestic product (GDP) have been retrieved from the EUROSTAT database.[17]

[13]Gao and van Biesebroeck (2014) found similar results by analysing the effect of a set of deregulation reforms in China on the efficiency of electricity generation at a firm level: the increase in privatisation is associated to a positive impact on both labour and material input efficiency although taking a few years to materialise.

[14]For example, Gugler, Rammerstorfer, and Schmitt (2013) show that ownership unbundling has a negative effect on aggregate investments in the capital stock, i.e. in generation, distribution and transmission assets.

[15]The sub-components are correlated and thus cannot be tested contemporarily.

[16]Please note that almost all of the studied variables, including total national gross R&D expenditure and GDP are also available in the STAN database, as common repository of IEA and EUROSTAT data.

[17]http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home.

The examined European countries are the following: Austria (AT), Belgium (BE), the Czech Republic (CZ), Germany (DE), Denmark (DK), Spain (ES), Finland (FI), France (FR), the United Kingdom (GB), Greece (GR), Ireland (IE), Italy (IT), Norway (NO), Portugal (PT), Sweden (SE) and the Slovak Republic (SK). Data availability is not balanced for all of them for several reasons. European countries such as Slovenia, Estonia, Hungary, Poland and Luxembourg report very scarce data points for the regulatory index or the R&D values. The Czech Republic and the Slovak Republic reached their independence in 1993, hence their data are included since then.

Patent counts are calculated from querying the OECD RegPat Database[18] by selecting the residence country of the inventors as criterion to assign the EPO patents to the corresponding examined nation. The inventor criterion reflects the origin of the inventive activity and ensures a good match with statistics on R&D, which specifically relate to the R&D expenditures within a country (OECD 2009). Moreover, the use of the address of the inventor allow us to assign the patents filed by large multinational companies to a specific country, under the hypothesis that inventors live in the proximity of their respective corporate research centres.

The RegPat data-set includes EPO applications and grants. Generally, the examination and grant process leads to the generation of one or more patent documents associated to the same invention, starting from the application to the eventual grant.[19] Since we are interested in the impact of the regulation framework on the generation of patent protected inventions, we improved the identification of the single inventions by collapsing the patent count on the application number.[20] Such approach determines that if an invention is associated, for instance, to one patent application, one search report and one grant, it is not counted three times but only once. Furthermore, the patents are counted by residence country of the inventors and by earliest priority year, in this way aiming to stay as close as possible to the place and time of origin of the protected invention. Patent data have been commonly used to proxy innovation (Pavitt 1983; Griliches 1990; Lanjouw and Schankerman 2004). The most relevant advantages are related to patent data objectivity (in the sense that they have been processed and validated by a third party, the examiners), to their public availability and, finally, to the provided information (Greenhalgh and Longland 2005). The main limitation is that not all the innovations can be patented and, in some cases, the companies might prefer to keep them protected through secrecy. At a country level, several studies relied on patents to assess national innovativeness (e.g. Eaton and Kortum 1996; Grupp and Schmoch 1999; Furman, Porter, and Stern 2002; Caviggioli 2011).

In order to identify the inventions covering technologies in the electric industry in the RegPat database, we relied on the International Patent Classification (IPC),[21] which provides specific codes for the patented technologies. Two alternative definitions of a country's 'Electricity' patent portfolio were computed. The first is based on the IPC codes that the

[18]http://www.oecd.org/sti/inno/oecdpatentdatabases.htm.

[19]Other potential documents that can be produced and electronically registered are the search report or the amendment files. All of them are characterised by a different kind code, that is a two-digit code at the end of the patent publication number.

[20]De facto we dropped all the patent kind codes and grouped the results on the residual part of the publication number. The process is similar to the generation of patent families, but in this case, we focus on the EPO only and collapse the patents on the common application number (see, for instance, Dernis and Khan 2004).

[21]The complete list of available codes can be accessed on the official World Intellectual Property Organization (WIPO) website (http://web2.wipo.int/ipcpub/).

WIPO associates to electricity technologies. The reference is the WIPO Concordance table[22] that matches IPC sub-classes and technological domains: all the EPO patents with at least one IPC code among those in the category 'Electrical machinery, apparatus, energy' are considered (the corresponding 29 IPC sub-classes are listed in the Annex 1). The second indicator of electricity patents serves as a robustness check and sums all the EPO patent filings reporting the specific IPC class 'H02' which includes all the inventions related to the 'Generation, conversion, or distribution of electric power'.[23]

Notably, the set of IPC patent classes used in our analysis is almost completely non-overlapping with the set that covers the renewable energy field. For example, Nesta, Vona, and Nicolli (2014) in order to retrieve renewable energy patents use a set of 173 IPC and only four of these are present also in our data-set.[24] The following Table 1 provides the description and summary statistics of the variables used in the econometric analyses.

In Figure 1, we report the trend of the OECD index for selected EU countries, jointly with the yearly values of all the three sub-components of the index. The chart shows the common downward trend across countries during the observed years. However, it is possible to appreciate the heterogeneity in the timing and the patterns of deregulation policies. By way of example, the UK was a significantly deregulated environment far before the other countries. The trend of the aggregate index shows comparable values for Germany and Spain. However, the breakdown at sub-component level highlights the differences: for instance, Germany reduced the level of public ownership years earlier than Spain, which on the contrary implemented policy reforms aiming at vertical 'disintegration' and unbundling.

Concerning the output of the country-level innovation activities, Figure 2 shows the yearly average aggregate patenting trend in the electricity technological domain for all the 16 countries in our sample (reference to the right axis) and the yearly average number of electric patents filed by the largest examined countries (reference to the left axis). It is worth stressing that, although inventions in the electric sector – a relatively mature field – represent during the observed years just 7–8 per cent of the total new patent filing portfolio for the analysed countries,[25] our data reveal that innovation is still ongoing with an increasing trend. The patenting trends in the electric technology domain present different sizes and behaviours. The inventive activity of Germany is the largest in terms of electric patent filings, while Spain, even if filing the smallest amount of patents among the selected countries, is the one with the highest increase, doubling the number of electric patents filed in the first decade of the examined period.

In order to investigate further the drivers of such positive trend in patenting activity, Figure 3 shows the patent filings of four of the largest incumbent companies in the electric market as representative of the corresponding countries of their headquarters: RWE for Germany, EDF for France, Enel for Italy and Iberdrola for Spain. The UK market, characterised by a larger number of players, is not represented since all the searched companies have very small patent portfolios.[26] The chart shows that those incumbents have limited

[22]http://www.wipo.int/ipstats/en/statistics/technology_concordance.html accessed in September 2014.
[23]The sub-classes of such category are listed in the Annex 1.
[24]Most of the IPC codes of renewable energy technologies belong to the following areas: 'Production or use of heat' (F24J), 'Wind motors' (F03D), 'Machines or engines for liquids (F03B)'. Such classes are not considered in this study. In order to ascertain that there is no significant overlapping between our database and RES technologies, we verified that only 2.7 per cent of the patents in our sample have an IPC code belonging to the RES list in Nesta, Vona, and Nicolli (2014).
[25]Our elaboration from RegPat data.
[26]We searched the patent filings of Centrica, Scottish and Southern Energy and Viridian and found less than five documents each.

Table 1. Summary statistics of the country-level variables between 1990 and 2007.

Variable name	Description	Source	Obs	Mean	SD
$(\text{Patents})_{i,t}$	EPO patent applications in the field 'Electrical machinery, apparatus, energy', according to the WIPO concordance table	OECD REGPAT	282	206.54	426.58
$(\text{Index})_{i,t}$	Regulation index [0–6]	IEA, OECD STAN	276	3.27	1.88
$(\text{Entry reg.})_{i,t}$	Component of the regulation index: entry regulation	IEA, OECD STAN	276	2.80	2.54
$(\text{Public own.})_{i,t}$	Component of the regulation index: public ownership	IEA, OECD STAN	276	4.04	1.91
$(\text{Vert. integr.})_{i,t}$	Component of the regulation index: vertical integration	IEA, OECD STAN	276	2.98	2.28
$(\text{Entry} + \text{vert})_{i,t}$	Average of the components 'EntryReg.' and 'Vert.Integr.'	IEA, OECD STAN	276	2.89	2.31
$(\text{Entry} \times \text{vert})_{i,t}$	Product of the components 'EntryReg.' and 'Vert.Integr.' divided by 6	IEA, OECD STAN	276	2.21	2.47
$(\text{Elec. R\&D})_{i,t}$	Public R&D budget in the electric domain in Million USD for each country *i* in any year *t* (in logarithm)	IEA, OECD STAN	234	1.76	1.25
$(\text{RES R\&D})_{i,t}$	Public R&D budget for RES in Million USD for each country *i* in any year *t* (in logarithm)	IEA, OECD STAN	240	2.77	1.23
$(\text{R\&D on GDP})_{i,t}$	Percentage of Total national R&D on GDP for each country (Gross Expenditure on R&D – GERD) *i* in any year *t*	EUROSTAT	263	1.71	0.83
$(\text{Electricity consumption})_{i,t}$	Final Electrical energy Consumption (Tera-Joule) for each country *i* in any year *t* (in logarithm)	EUROSTAT	282	5.74	1.01

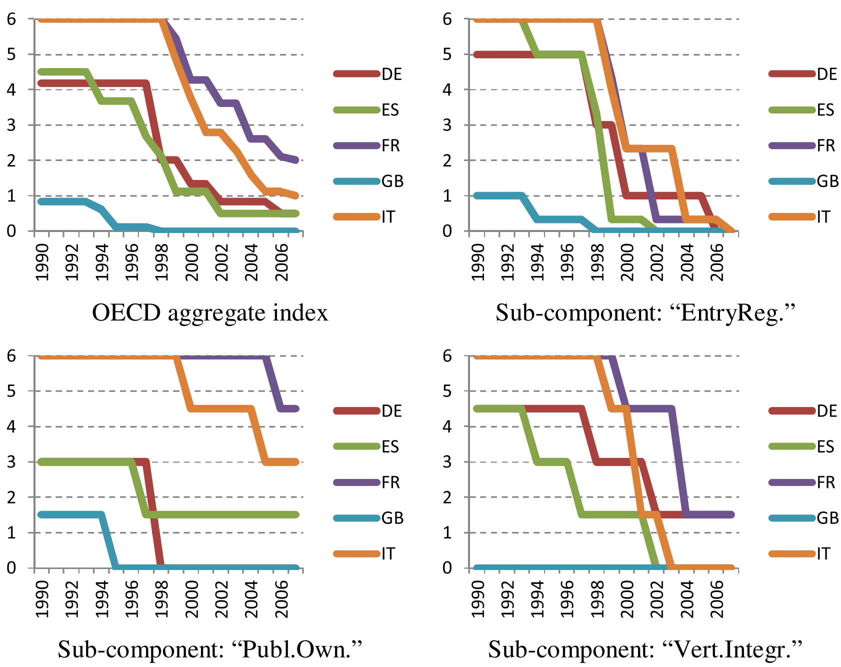

Figure 1. Trends of the indicator of product market regulation in the electric sector provided by the OECD and its three sub-components for selected EU countries.

Notes: Clockwise from the top left: OECD index, the sub-components 'EntryReg.' 'Vert.Integr.' and 'Publ.Own'.

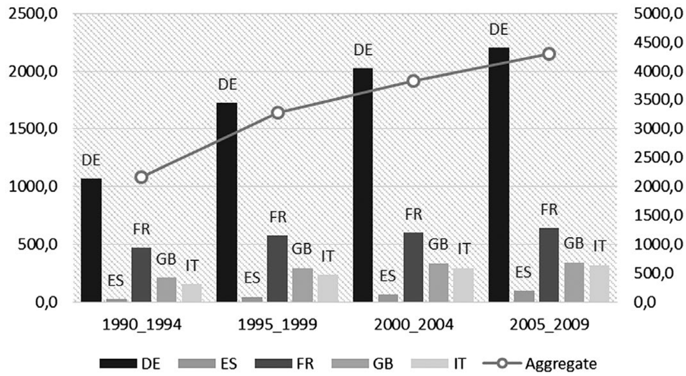

Figure 2. Yearly average values of EPO applications in the electric sector in four time frames for the aggregate trend of all the 16 countries in the sample (line with reference to the right axis) and for the largest examined nations (histogram with reference to the left axis).
Notes: Elaboration from OECD RegPat.

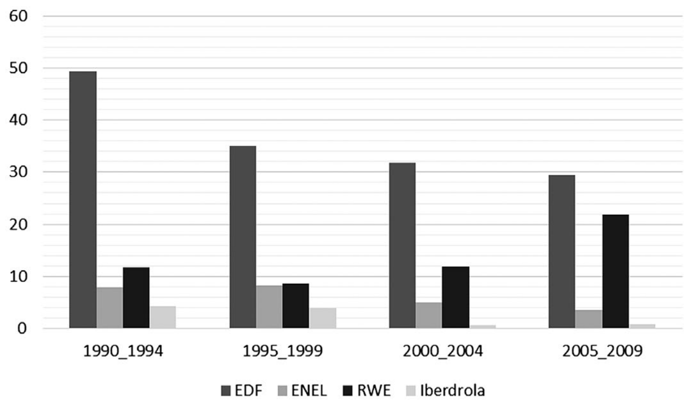

Figure 3. Average yearly inventions of selected companies in four time frames measured as INPADOC family IDs.
Notes: For a definition of INPADOC families see Dernis and Khan (2004).

patent portfolios and are reducing the number of filings, with the only exception of RWE which incurred in a non-negligible number of M&A processes, especially during 2000s which might have expanded the corporate patent portfolio as well. The joint analysis of the data reported in Figures 2 and 3 suggests that technology providers, research centres and other firms operating in adjacent markets carry out a non-negligible share of the patenting activities, which is no longer concentrated in the hands of the largest market players. This evidence might suggest that the deregulation process has led to an increased overall innovation effort by the main players in the sector mostly through the acquisition of externally generated products and solutions.

3. Results

The econometric analyses are based on Poisson panel data models to investigate the relationship between the yearly number of new patent applications in the electric industry (count dependent variable) and the regulation index (and each of its components). All models include fixed effects to control for time-invariant unobserved heterogeneity among the analysed countries.[27]

The models include a set of controls with a stepwise approach. The percentage of R&D on GDP at country-level accounts for the propensity to invest in R&D. The demand is proxied by the logarithm of electrical energy consumption (TeraJoule), derived from the EUROSTAT database per country and year. The logarithm of the public R&D budget has been defined by the year country value of R&D in the group 6 'Other power and storage technologies' reported in the IEA database.[28] Similarly, the R&D for RES technologies is calculated from the IEA group 3 'Renewable Energy Sources'.[29] All models control for time dummies to account for omitted time-varying element (e.g. political conditions, changes in oil and energy prices). We also run model specifications with the variables 'Entry + Vert' and 'Entry × Vert' and each of the three low-level indicators ('EntryReg.', 'Publ.Own.', 'Vert. Integr') as independent variable. In the model specifications, in addition to the variables capturing the status of product market competition, we use two variables on public investment in R&D as controls. They are the country-level public R&D expenditures in the traditional electricity sector and in the renewable energy domain. Although the dependent variable is based only on patents in the traditional electricity sector, we decided to control also for public spending in renewable as this might have a misplacement effect on innovation in the traditional sector. We checked for the presence of potential collinearity issues. The model specifications turned to be robust after a test for variance inflation factors (VIF test results range from 1.07 to 2.36 across all model specification). All the models were then tested by including one year lag on the index (and correspondingly with the components) in order to consider a certain delay in the response to a change in the regulatory environment.

The following table reports the results of the sets of Poisson panel data regressions. Models from 1 to 7 in Table 2 test the effects of the changes in the regulation index (baseline models 1 and 2), in each sub-component (models 3–5) and in the variables 'Entry + Vert' and 'Entry × Vert' (respectively, models 6 and 7) on the output of the innovation process proxied by the number of electric patents. As a robustness check, we include similar models with the lagged independent variables in the Annex 1.

The estimates indicate a significant negative relationship between the regulation index in models 1 and 2. Models from 3 to 7 show that large part of the correlation between the number of patents and the regulation index and its components is due to one specific sub-index, 'Vert.Integr.', even when combined with the index of entry barriers in 'Entry + Vert' and 'Entry × Vert'. Since a higher level of the indexes corresponds to a more regulated environment, the results suggest the presence of a correlation between an increase in electric

[27]The Hausman test confirmed the application of a fixed-effect model over the random effect estimation. The examined data-sets are unbalanced panels since there are countries (the Czech Republic and the Slovak Republic) that were born in 1993. Furthermore, some data points of certain variables are missing.

[28]The group includes the following sub-categories: 'Electric power conversion', 'Electricity transmission and distribution', 'Energy storage' and the residual 'Unallocated other power and storage techs'.

[29]It includes: 'Solar energy', 'Wind energy', 'Ocean energy', 'Biofuels', 'Geothermal energy', 'Hydroelectricity' and 'Other renewable energy sources'.

Table 2. Poisson panel regression analysis with fixed effect. Dependent variable: count of electricity EPO patents.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Variables	Model	Model	Model	Model	Model	Model	Model
$(\text{Index})_{i,t}$	−0.052*** (0.007)	−0.028*** (0.008)					
$(\text{Entry reg.})_{i,t}$			0.002 (0.006)				
$(\text{Vert. integr.})_{i,t}$				−0.022*** (0.006)			
$(\text{Public own.})_{i,t}$					0.002 (0.008)		
$(\text{Entry} + \text{vert})_{i,t}$						−0.012* (0.007)	
$(\text{Entry} \times \text{vert})_{i,t}$							−0.009* (0.005)
$(\text{R\&D on GDP})_{i,t}$		0.398*** (0.032)	0.395*** (0.034)	0.357*** (0.034)	0.392*** (0.033)	0.371*** (0.034)	0.382*** (0.033)
$(\text{Elec. cons.})_{i,t}$		0.268* (0.137)	0.556*** (0.143)	0.354** (0.149)	0.539*** (0.141)	0.456*** (0.148)	0.480*** (0.145)
$(\text{Elec. R\&D})_{i,t}$			0.031*** (0.008)	0.019** (0.008)	0.031*** (0.009)	0.025*** (0.008)	0.027*** (0.008)
$(\text{RES R\&D})_{i,t}$			−0.097*** (0.012)	−0.092*** (0.012)	−0.099*** (0.014)	−0.096*** (0.012)	−0.101*** (0.012)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	257	257	225	225	225	225	225
Groups	16	16	16	16	16	16	16
Loglike	−1,100	−1,021	−894	−886.9	−894	−892.3	−892.4
χ^2	2,887	3,003	3,041	3,055	3,041	3,044	3,043

Notes: Standard errors in parentheses. $*p < 0.10$; $**p < 0.05$; $***p < 0.01$.

patent filings and vertical unbundling. The control variables R&D on GDP and electricity consumption show positive significant coefficients, robust across all the models. The impact of electric and of RES R&D budget report opposite signs: the former is positively related to the yearly amount of electric patents, while the latter is negatively related.[30] The overall results for the electricity sector suggest the presence of a correlation between public policies for fostering competition and not only fixed investments, as found by Alesina and Ardagna (2005), but also innovation output. The analysis of the estimates when introducing one-year or two-year lag shows similar results, while longer time lags shows no significant coefficients.[31] As a robustness check, we estimated the models with an alternative indicator of electricity patents (filings in the IPC class 'H02') finding similar results that are available on request.

4. Conclusions and policy implications

The European electricity sector has been characterised by significant investments in infrastructure and new technological solutions in recent years, suggesting that even in such a mature field there is still room for substantial technological development and innovation activities. These investments have been realised in a period of huge structural policy reforms aimed at liberalising the industry and spurring competition and efficiency.

In this paper, we investigated whether and to what extent policy interventions have induced innovation in the European electricity sector. Differently from previous studies which examined the US context or focused on renewables, in this paper, we target the European market and deal with innovations in the traditional 'brown' electricity technologies. The aim is to study the indirect effect on innovation incentives in a mature sector characterised by policy acts that modify the competition dynamics.

Policy interventions are proxied by changes in the OECD index of electricity market regulation and by its sub-components (entry barriers, vertical integration and state ownership). The innovation activities at country level have been captured by analysing the most relevant technologies in the electricity field through the corresponding patents. The patent-based indicator is meant to estimate the effects of the deregulation on the incentives to invest in the development of new technologies from a broader perspective: in fact, it takes into account also the innovative output of the technology suppliers although operating in different and not directly regulated markets.

Overall, the findings show an average positive effect of the deregulation process on the patenting activity in the electricity technological domain. Furthermore, our framework of analysis enables more fine-grained considerations on the impact of diverse tools of intervention corresponding to the sub-components of the OECD index. In particular, the policies aiming at increasing the degree of vertical separation between the transmission and the

[30]As a further robustness check, we also collected data on fixed investment in the electricity sector from the OECD STAN database. The aim of this further test is to verify that our results survive after controlling for yearly gross (and net) investment in tangible goods. Unfortunately, these data are available only for a small subset of the analysed country-year observations losing more than 40 per cent of original observations. We decided not to report them in the paper (but they are available upon request) because the limited number of observation largely reduces the robustness of the econometric analysis. Anyway, the evidence confirms the results and, as expected, the investment indicator has a positive correlation with the innovation output variable. In particular, even after accounting for investment our results confirm that the link between market liberalisation and innovation is maintained and it is mostly driven by the deregulation through vertical unbundling. We thank an anonymous referee for suggesting this further control.

[31]Results with one-year lag are shown in Table 5 of the Annex 1. The other models are not reported but are available on request.

generation segment of the industry have a positive effect on the sector patenting activities. The result is robust when controlling for the public R&D spending in the electricity sector that might indirectly affect the domestic patenting output. The evidence suggests that market reforms that introduce unbundling (i.e. decrease the level of vertical integration) promote an increase in the demand of new technologies and solutions. Such demand is mostly addressed by technology suppliers that are not directly subject to the regulation. This intuition is confirmed by the evidence on the decreasing trend in recent years in the number of patents filed directly by historic electric operators. Therefore, the overall effect of opening the market and introducing lighter regulatory remedies (i.e. introducing unbundling of operations) generates a stimulus for innovation,[32] and especially so for technology suppliers in the upstream market, that more than compensates the reduced incentives in innovation investment by the incumbent electric firms. In other words, the effect of structural market reforms in the EU electric industry has generated a shift of innovation activities from the electric firms to specialised technologies suppliers.

Our analysis provides evidence that market reforms has been generally successful in enhancing innovation in new technologies in the EU electric industry. This implies that the evaluation of alternative policy options needs to account for the potential effects on dynamic efficiency not only in the regulated market, but also in the upstream technology suppliers markets.

Previous findings of Jamasb and Pollitt (2012) in the UK and of Prieger (2002) for the US telecommunication industry support our results. However, the work of Sanyal and Ghosh (2013) suggest a negative relationship between deregulation and innovation in the US Energy industry. Considering the differences between the US and EU contexts, the first characterised by a longer process of deregulation, we argue that the impact of market deregulation policies on innovation is indeed contingent on the status of market reforms. In the early phases of liberalisation and vertical unbundling, a positive effect seems to prevail, while on a longer horizon dynamic efficiency issues are more likely to emerge, calling for ad hoc regulatory policies that stimulate innovation investments. Future research may expand the panel of examined countries by considering potential institutional differences and the global patenting activities.

Disclosure statement

No potential conflict of interest was reported by the authors.

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[32]Our results confirm previous findings by Prieger and Heil (2008) on the telecommunications industry. In their paper, the authors indeed find that lighter regulation spurs both process and product innovation, in particular in the broadband market.

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Annex 1

Table 3. Most relevant IPC sub-classes associated to the field 'Electrical machinery, apparatus, energy' according to the WIPO concordance table.

IPC sub-class	Description
H01B	Cables; conductors; insulators; selection of materials for their conductive, insulating or dielectric properties
H01C	Resistors
H01F	Magnets; inductances; transformers; selection of materials for their magnetic properties
H01G	Capacitors; capacitors, rectifiers, detectors, switching devices, light-sensitive or temperature-sensitive devices of the electrolytic type
H01H	Electric switches; relays; selectors; emergency protective devices
H01J	Electric discharge tubes or discharge lamps
H01M	Processes or means, e.g. batteries, for the direct conversion of chemical energy into electrical energy
H01R	Electrically conductive connections; structural associations of a plurality of mutually insulated electrical connecting elements; coupling devices; current collectors
H01T	Spark gaps; overvoltage arresters using spark gaps; sparking plugs; corona devices; generating ions to be introduced into non-enclosed gases
H02B	Boards, sub-stations or switching arrangements for the supply or distribution of electric power
H02G	Installation of electric cables or lines, or of combined optical and electric cables or lines
H02H	Emergency protective circuit arrangements
H02J	Circuit arrangements or systems for supplying or distributing electric power; systems for storing electric energy
H02K	Dynamo-electric machines
H02M	Apparatus for conversion between ac and ac, between ac and dc or between dc and dc, and for use with mains or similar power supply systems; conversion of dc or ac input power into surge output power; control or regulation thereof
H02P	Control or regulation of electric motors, generators or dynamo-electric converters; controlling transformers or reactors or choke coils
H05B	Electric heating; electric lighting not otherwise provided for
H05F	Static Electricity; naturally occurring Electricity
F21K	Light sources not otherwise provided for
F21L	Lighting devices or systems thereof, being portable or specially adapted for transportation
F21S	Non-portable lighting devices or systems thereof
F21V	Functional features or details of lighting devices or systems thereof; structural combinations of lighting devices with other articles, not otherwise provided for

Note: The complete list is available on the WIPO website.

Table 4. IPC sub-classes of 'H02', 'Generation, conversion, or distribution of electric power'.

IPC sub-class	Description
H02B	Boards, sub-stations or switching arrangements for the supply or distribution of electric power
H02G	Installation of electric cables or lines, or of combined optical and electric cables or lines
H02H	Emergency protective circuit arrangements
H02J	Circuit arrangements or systems for supplying or distributing electric power; systems for storing electric energy
H02K	Dynamo-electric machines
H02M	Apparatus for conversion between AC and AC, between AC and DC or between DC and DC, and for use with mains or similar power supply systems; conversion of dc or ac input power into surge output power; control or regulation thereof
H02N	Electric machines not otherwise provided for
H02P	Control or regulation of electric motors, generators or dynamo-electric converters; controlling transformers or reactors or choke coils

Table 5. Poisson panel regression analysis with fixed effect.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Variables	Model	Model	Model	Model	Model	Model	Model
$(\text{Index})_{i,t-1}$	−0.049*** (0.007)	−0.027*** (0.007)					
$(\text{Entry reg.})_{i,t-1}$			−0.005 (0.005)				
$(\text{Vert. integr.})_{i,t-1}$				−0.019*** (0.006)			
$(\text{Public own.})_{i,t-1}$					0.015** (0.008)		
$(\text{Entry + vert})_{i,t-1}$						−0.015** (0.006)	
$(\text{Entry} \times \text{vert})_{i,t-1}$							−0.016*** (0.005)
$(\text{R\&D on GDP})_{,t-1}$		0.344*** (0.031)	0.338*** (0.033)	0.317*** (0.033)	0.352*** (0.032)	0.322*** (0.033)	0.331*** (0.032)
$(\text{Elec. cons.})_{i,t-1}$		0.243* (0.134)	0.476*** (0.140)	0.344** (0.145)	0.468*** (0.137)	0.397*** (0.144)	0.396*** (0.141)
$(\text{Elec. R\&D})_{i,t-1}$			0.033*** (0.008)	0.026*** (0.008)	0.042*** (0.008)	0.029*** (0.008)	0.030*** (0.008)
$(\text{RES R\&D})_{i,t-1}$			−0.091*** (0.012)	−0.086*** (0.012)	−0.106*** (0.014)	−0.090*** (0.012)	−0.097*** (0.012)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	257	257	225	225	225	225	225
Groups	16	16	16	16	16	16	16
Loglike	−1,106	−1,044	−924.9	−920	−923.3	−922.6	−920.6
χ^2	2,414	2,507	2,539	2,550	2,544	2,544	2,547

Notes: Dependent variable: count of electricity EPO patents; one-year lagged independent variables. Standard errors in parentheses; *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.