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R&D, Patenting and Market Regulation: Evidence from EU Electricity industry

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ABSTRACT

In this paper we study the effects of the changes in the level of product market regulation on the industry-level innovation intensity in the Electricity sector across 16 European countries during years 1990-2009. We matched data on R&D budgets and EPO patent applications from IEA and Eurostat Databases and indexes of market regulation conditions from OECD, in order to test the impact of deregulatory policies on the propensity to innovate in new energy technologies. Our findings indicate an increase in the aggregated Electricity R&D and in patenting activities following market deregulation. Our measure of market regulation intensity is based on the aggregation of three factors that capture respectively entry barriers, public ownership and vertical integration. Econometric results suggest that policies aimed at a reduction in vertical integration have a positive impact on both industry-level R&D and patenting. The reduction of public ownership of incumbent operators and entry barriers are mostly associated to a significant increase in R&D expenditures. In the paper we discuss the implication of this evidence in light of the current trend in investment in the electricity sector in Europe.

JEL Classification: L94, O31, O32

Keywords: Innovation. Patents. Regulation. Electricity.

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1 Introduction

Over the last two decades, European Union (EU) member states have implemented widespread reforms in product markets with the aim of stimulating competition, increase efficiency and raising rates of investment and innovation. Recent economic literature has focused on the role of institutions and market reforms in shaping economic performance and, in particular, innovative activity across countries (Aghion and Griffith, 2005).

Changes in the degree of product market competition affect the incentives firms face to engage in innovative activity, but it is ambiguous whether the impact on such incentives is positive or negative. On the one hand, enhancing competition increases the incentives for companies to invest in innovation: in a more competitive market, firms may have greater incentive to reduce costs and increase efficiency with respect to monopoly because the potential cost savings from a reduction in marginal production cost is the only way to ensure temporary profits[1]. On the other hand, when competition becomes too intense, imitation activities become more attractive due to the reduced profitability of inventions (Aghion et al., 2005). Substantial market concentration can instead encourage innovation for at least two reasons. The profit generated by monopolists are a stable financial source for Research and Development (R&D) projects and the prospect of substantial monopoly profit can be a compelling reason to undertake this kind of investment (Schumpeter, 1942). If entry in the market is also subject to some sort of regulatory obligation, entry barriers also affect innovative activities, though their impact may differ according to the degree of technological development of different industries[2].

In markets characterized by limited competition mainly due to technological reasons, such as the so called network industries (e.g. telecommunication, energy and transport industries), regulation over entry conditions, prices and service quality impacts firm's profitability and indirectly the incentives to invest in innovation (Vogelsang, 2002 and 2010; Joskow, 2008). Guthrie (2006) shows that regulation does affect the investment incentives of regulated firms and their market values as well as the quantity and quality of the goods that firms produce. However, regulatory interventions in the market has considerably evolved in the last decades. While under the prevalent regulatory

[1] Griffith et al. (2010), for example, provide empirical evidence that the EU market reforms carried out under the EU Single Market Programme (SMP) were associated with increased product market competition, as measured by a reduction in average profitability, and with a subsequent increase in innovation intensity and productivity growth for manufacturing sectors.

[2] Aghion et al. (2009) finds that incumbents' productivity growth and patenting is positively correlated with foreign firm entry in technologically advanced industries. The plausible explanation can be 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.

framework in the 1970s, in both the EU and the U.S., monopolies and public utilities had weak or biased incentives to innovate, from the 1980s most of the Western countries started implementing market reforms to spur firms to make productivity gains and achieve innovations. At the same time, these new regulatory principles aimed at limiting the rents of the subject firms which were often used for large R&D projects and other innovation activities.

The impact of regulation on the incentive to invest and to innovate is thus still unclear. While liberalization and market deregulation have been shown to significantly and positively impact infrastructure investment (Alesina et al., 2005), the effect of regulation on investment in innovation and intangible assets requires further investigations, since as stated by Alesina et al (2005), "[it] is theoretically ambiguous and more empirical work is needed before we can reach definitive conclusions on the impact of deregulation on overall dynamic efficiency" (page 819). This paper aims at filling this gap.

The purpose of this paper is to study the effects of the changes in the level of market regulation on the input and output of research activities within the Electricity sector, namely the R&D budget and the European Patent Office (EPO) applications. We matched data from the Organisation for Economic Co-operation and Development (OECD), the International Energy Agency (IEA) and the Eurostat Database to empirically test the impact of market reforms, such as deregulation and privatization, by applying a set of fixed-effects panel models.

We focus on the electricity industry because, among all the regulated sectors, firms in this sector are typically the largest network firms (by revenue) and their economic impact at country level is extremely large for both consumers and firms. Indeed, electricity firms reach a top position in Europe for tangible investment (Guthrie, 2006), for market capitalization and for their extremely generous dividend payments[3]. Furthermore, over the last thirty years, this sector has been the object of sweeping reforms that have changed many aspects of the industry. Such reforms aimed at liberalizing the market and at privatizing the state-owned monopolies to raise firm efficiency and improve service quality. These reforms are characterized by considerable heterogeneities among European countries and are still largely incomplete[4]. This heterogeneity provides grounds for interesting comparisons which we intend to exploit in this study.

Innovation in the electricity industry is one of the key pillar for sustaining the economic growth in Europe in the next coming years. Huge financial support has been provided by the European

[3] See Bortolotti et al. (2013) for an analysis of market values in regulated EU firms and Bremberger et al. (2014) for dividend policy in the EU electricity industry.

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

Commission (EC) under the 7th Research Framework Programme (FP7): 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 effectively move 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.[5] In the period 2008-13, 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, UK, Italy, Germany and Spain - amounting to €3.15 billion investment (JRC, 2014)[6].

These evidences highlight how in next decades innovation is 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 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 policymakers to adopt specific reforms to promote R&D.

Our paper contributes to the existing literature in two ways. First, to the best of our knowledge, it is the first analysis at EU level that investigate the effect of regulation and liberalization reforms on innovation – measured *both* in terms of R&D expenditures and patenting[7] – in the European electricity industry. Previous studies focused on the Telecommunication[8] and the energy industry in the US where deregulation reforms started at the beginning of the 1990s, a decade before the EU, and market structure is rather different[9]. Second, in order to quantify the effect of regulation on firms' innovation incentives, we use an index that captures the pace and intensity of liberalization

[5] For a recent analysis on smart grids and innovations in distribution networks, see Lo Schiavo et al. (2013).

[6] 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.

[7] 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. They do not consider however the impact on patenting like we do in our paper.

[8] Using data from the US telecommunication industry, Prieger (2002) finds evidence on a negative influence of stricter regulation on service innovations proposed by telecommunications providers.

[9] Sanyal and Gosh (2013) modeled the impact of the 1990s U.S. electricity deregulation on patenting, and found that, after deregulation, the increased competition effect decreased innovation by 18.3% while the appropriation effect increased innovation by 19.6%.

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 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 and of specific guidelines for its implementation. This index has been used in previous studies to assess the impact of regulation on fixed aggregate investment (Alesina et al., 2005); however, to the best of our knowledge, there are no 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 the previous studies, it is worth to note the work by Blind (2012) which 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 differs from the study of Blind (2012) for several aspects. First, we focus on one specific industry and the corresponding technological domain, as well as the specific market regulation framework, while the analysis by Blind, though more general in terms of industry coverage, does not focus on the detailed market features (i.e. the level of barriers to entry, the degree of vertical integration and the role of state ownership). Second, in order to improve the robustness of the analysis, we employ two measures of innovation: the R&D expenditures and the number of patents filed at the EPO, while Blind's paper focuses on a specific patent indicator[10]. Third, we include in the analyses some tests on the impact of the regulatory reforms with time lags to investigate the presence of potential delayed effects after the implementation.

Our methodological approach that consists in using both industry-level R&D budgets and patenting activity is driven by the objective of capturing the effects of a variations 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

[10] The patent indicator used by Blind (2012) is the count of triadic patents (patents filed in the U.S. in Japan and at the EPO), consistently with the presence of non-EU countries in the analyzed data. Triadic patents are more valuable and allow the comparison among world countries but, with reference to our analysis, they risk to neglect the innovative contribution of country-specific operators.

certain country and year accounts also for the innovations carried out by firms in different sectors (e.g. ICT, Mechatronics, Instruments) provided that they have a direct application to the electricity industry[11]. Our results show that a decrease in the regulation level is positively associated to an increase in the national R&D expenditure in the Electricity sector and consistently to an increase in the national patent activities in the Electricity technological domain. The former effect seems particularly due to a change in the allowed level of public ownership, while the latter to a reduction in the level of vertical integration.

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. In Section 3 the data collection process, descriptive statistics and the trends of the most relevant variables are shown. Section 4 provides the results of the econometric analyses which are further discussed in Section 5.

2 Framework of analysis

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 EU countries which constitute our unit of analysis. In particular, the study focuses on country- and industry-level data from year 1990 to 2009 in order to identify the correlation in time between different indicators of intensity of regulation and both the R&D expenditure and the patent filings in the electric sector.

The main independent variable is the index of Product Market Regulation developed by the OECD (Conway and Nicoletti, 2006). In particular the OECD index of Product Market Regulation measures the regulation intensity in the electric sector[12]. 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 downstream and upstream 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 liberalized and takes into account the presence of third party access to existing transmission and distribution networks, the

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

[12] 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).

freedom of choice of consumers and the presence of a liberalized wholesales power market (pool). This measure is particularly interesting to test the effect of entry barrier 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, the negative effect for the potential entrant companies might exceed the innovation incentives for the incumbents, leading to an aggregate net decrease in the innovation activities at the industry level.

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[13]. The 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 less intense, profit may increases and innovation may be more intense. The state ownership is also characterized by bad 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[14]. 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[15]. 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

In our model specification we will also use a variable "Entry&Vert" which is calculated as the average of the components "EntryReg." and "Vert.Integr.". Such variable specifically captures the aggregate change in the competition level in the industry and proxies the degree of market liberalization.

[13] 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.

[14] Gao et al. (2014) found similar results by analyzing the effect of a set of deregulation reforms in China on the efficiency of electricity generation at a firm level: the increase in privatization is associated to a positive impact on both labor and material input efficiency although taking a few years to materialize.

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

Higher values of the components of the index are associated to a more intense regulatory framework and a less liberalized market, while a 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 variable "Entry&Vert"[16]. 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 input and output of the research activities in the Electricity industry.

3 Dataset and summary statistics

The final dataset was built by matching different sources. Data on the regulation index, the R&D in the electric industry has been collected from the OECD STructural ANalysis Database (STAN) which reports the data processed by the International Energy Agency (IEA)[17] at country level from year 1990 to the latest available. The index of regulation in the electricity sector is one of the seven provided by the OECD as a qualitative index of the regulatory provisions in the corresponding sectors Telecom, Electricity, Gas, Post, Rail, Air Passenger Transport, and Road Freight (Conway and Nicoletti, 2006)[18].

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[19].

The examined European countries[20] are the following: Austria (AT), Belgium (BE), Czech Republic (CZ), Germany (DE), Denmark (DK), Spain (ES), Finland (FI), France (FR), United Kingdom (GB), Greece (GR), Ireland (IE), Italy (IT), Norway (NO), Portugal (PT), Sweden (SE) and Slovak Republic (SK)[21]. Data availability is not balanced for all of them. In addition to missing data point, Czech Republic and Slovak Republic were born reached their independence in 1993: for historical compliance we limited their data starting from 1993.

[16] The three subcomponents are correlated and thus cannot be tested contemporarily.
[17] IEA (2013), "R&D Budget", IEA Energy Technology R&D Statistics (database).doi: 10.1787/data-00488-en . Please note that almost all of the studied variables, including and total national gross R&D expenditure and GDP are also available in the STAN database, as common repository of IEA and EUROSTAT data.
[18] Updated information are available at: http://www.oecd.org/eco/reform/indicatorsofregulationinenergytransportandcommunicationsetcr.htm .
[19] http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home .
[20] Countries with only one available observation of the regulation index have been excluded from the analysis (Slovenia and Estonia).
[21] European countries such as Slovenia, Estonia, Hungary, Poland and Luxembourg report no or very scarce data points for the regulatory index or the electric R&D.

Patent counts are calculated from querying the OECD RegPat Database[22] 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 centers.

The RegPat dataset 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[23]. 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[24]. 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 common 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 et al 2002; Caviggioli, 2011). The following Table 1 provides the description and summary statistics of the variables used in the econometric analyses.

INSERT TABLE 1 HERE

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

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

[24] De facto by excluding all the patent kind codes and grouping the results on the residual part of the publication number.

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, UK was a significantly deregulated environment far before the other countries. The trend of the aggregate index shows comparable values 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.

INSERT FIGURE 1 HERE

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 to 8% of the total new patent filing portfolio for the analyzed 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 behaviors. 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.

INSERT FIGURE 2 HERE

INSERT FIGURE 3 HERE

In order to further investigate 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

[25] Our elaboration from RegPat data.

of the corresponding countries of their headquarters: RWE for Germany, EDF for France, Enel for Italy and Iberdrola for Spain. The U.K. market, characterized by a larger number of players, is not represented since all the searched companies have very small patent portfolios[26]. The chart shows that such incumbents have limited patent portfolios and are reducing the number of filings, with the only exception of RWE. The joint analysis of the data reported in Figure 2 and Figure 3 suggest that a non-negligible share of the patenting activities is carried out by technology providers, research centers and other firms operating in adjacent markets and it is not 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. In the following section we specifically test whether such negative correlation between market regulation intensity and innovation investments holds after accounting for country specific characteristics.

4 Results

The econometric analyses use OLS panel models to investigate the relationship between each of the two dependent variables, the R&D budget and the patents in the electric industry, and the regulation index (and each of its components). A fixed-effect model[27] was used to control for time-invariant unobserved heterogeneity among the analyzed countries.

The first group of fixed effects models estimates the impact of the changes in the regulation system, proxied by the IEA regulation index (and its components), on the R&D budget in the Electricity industry weighted by the size of the domestic Electricity market, measured with the total electric consumption. The 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]. The electrical energy consumption expressed in TeraJoule is derived from the EUROSTAT database per country and year. The ratio thus represents the amount of dollars in electric R&D per used Joule. The percentage of R&D on GDP at country level has been included as control for the models with the ratio R&D on Electricity consumption as dependent variable, in order to account for the country level propensity to invest in R&D. The model specification is the following:

[26] We searched the patent filings of Centrica, Scottish and Southern Energy and Viridian and found less than 5 documents each.

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

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

$$(\text{R\&D for electric industry / Electric energy consumption})_{i,t} = \beta_0 + \beta_1(\text{Regulation Index})_{i,t} + $$

$$+ \beta_2(\text{R\&D / GDP})_{i,t} + \varepsilon_{i,t} \qquad (1)$$

where $i = 1, 2 ... N$ is the country identifier, $t = 1, 2 ... T$ represents the years; β_0 is the intercept; and β_1, β_2 the regression coefficients. We also run model specifications similar to (1) with the variable "Entry&Vert" and each of the three low-level indicators ("EntryReg.", "Publ.Own.", "Vert.Integr") as independent variable. All these models were then tested by including one or two year lags 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 second set of models uses the number of patents covering technologies in the electric industry (a country's inventive activity) as dependent variable. In order to identify such inventions in the patent database (OECD RegPat), we relied on the International Patent Classification (IPC)[29] 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 World Intellectual Property Organization (WIPO) associates to Electricity technologies; specifically, with reference to the WIPO Concordance Table[30] which matches IPC subclasses and technological domains, it takes into consideration all the EPO patents with at least one IPC code among those in the category "Electrical machinery, apparatus, energy": the list includes 29 IPC subclasses[31]. The results of the econometric analysis with such patent count are reported in the following tables. 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"[32]. The results are similar to those found with the first type of patent indicator and thus are not shown. Similarly to the model specifications related to the electric R&D, those with the patenting activities as dependent variable include the control variables R&D on GDP and the national electricity consumption in order to consider the propensity to invest in R&D at country level and the electricity demand. The model specification is the following:

$$(\text{Patent in Electricity Sector})_{i,t} = \beta_0 + \beta_1(\text{Regulation Index})_{i,t} + \beta_2(\text{Electricity Consumption})_{i,t} + $$

$$+ \beta_3(\text{National R\&D})_{i,t} + \varepsilon_{I,t} \qquad (2)$$

[29] The complete list of available codes can be accessed on the official WIPO website (http://web2.wipo.int/ipcpub/).
[30] http://www.wipo.int/ipstats/en/statistics/technology_concordance.html accessed in September 2014
[31] The subclasses associated to the field "Electrical machinery, apparatus, energy" according to the WIPO Concordance Table are listed in the annex.
[32] The subclasses of such category are listed in the annex.

Similarly to the first set of models we estimated the panel regression with the variable "Entry&Vert" and with each of the three index components as main independent variable and by applying one and two lags to study potential delays on the effects of a change in the regulation index.

The following tables 2 and 3 report the results of the sets of panel regressions. Models from 1 to 6 in Table 2 test the effects of the changes in the regulation index (baseline model 1 and model 2), in the variable "Entry&Vert" (model 3) and in each sub-component (models 4, 5 and 6) on the ratio of the electric R&D budget on Electricity consumption by controlling for the percentage of national R&D on GDP. Models from 7 to 12 are similar to the previous six but the independent variables are lagged by one year.

INSERT TABLE 2 HERE

The estimates indicate a significant negative relationship between the regulation index (and its components) and the national electric R&D divided by the electric consumption. Since a higher level of the index corresponds to a more regulated environment, the results suggest that fostering entry and competition is positively associated to an increase in the contemporary and the subsequent R&D expenditure at the industry level. The results are similar when including each of the three components and the composed sub-index "Entry&Vert."; furthermore, the largest effect is associated to the changes in the allowed level of public ownership, proxied by the component "Public Own.". The overall results for the electricity sector suggest the presence of an impact of public policies for fostering competition not only on fixed investments as found by Alesina *et al.* (2005) but also on innovation expenditure and intangible assets. The analysis of the estimates when introducing one year time lags shows similar results while longer time lags shows no significant coefficients[33] . The evidence on the impact of the regulatory index variable on R&D expenditure is robust to the inclusion of an indicator of the average aggregate R&D effort at the country level.

The following Table 3 presents the results of the regression models in which we focus on the output of the innovation processes: the yearly count of a country's EPO patents in the Electricity domain is used as dependent variable, in a way similar to the previous set of regressions. The models from 1 to 6 test the effects of the changes in the regulation index (baseline model 1 and model 2), in the variable "Entry&Vert" (model 3) and in each sub-component (models 4, 5 and 6) by controlling for

[33] Results are not reported but are available on request

the percentage of national R&D on GDP and the Electricity consumption; models from 7 to 12 show lagged independent variables.

INSERT TABLE 3 HERE

The findings are similar to those for the electric R&D with a significant negative relationship between the regulation index (and the sub-components “EntryReg.” and “Vert.Integr.”) and the patent filings in the electric domain. It is confirmed that changes aiming at a more deregulated system generally increases the number of electric patents, a measure of R&D output. However, differently from the previous set of models, in this case the sub-component “Public Ownership” does not seem to have an impact on the yearly number of electricity patents. The variables associated to a reduction of the entry barriers and of the vertical integration have a significant impact on the increase of the amount of patent filings. Such effects are particularly driven by the change in the level of vertical integration. The control variables R&D on GDP and electricity consumption shows positive significant coefficients, robust across all the models.

5 Conclusion

The European Electricity sector has been characterized 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 realized in a period of huge structural policy reforms aimed at liberalizing the industry and spurring competition and efficiency.

In this paper we investigated whether and to what extent such policy interventions have induced innovation investments. The innovation activities at country level have been captured by applying two complementary approaches. The first has focused on the financial inputs, the national Electric R&D budget, and it is therefore specifically associated to the industry most relevant players. The second approach has been derived by analyzing 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 both R&D spending and the patenting activity. 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. A reduction in the share of public ownership of the largest Electric companies on average is associated to an increase in industry level R&D investments. The result is in line with the literature raising concerns about state ownership which may be related to an inefficient use of economic resources and limited innovation commitment (Shleifer and Vishny, 1994).

The sub-components of the regulation index that capture the level of market entry barriers and of vertical integration show similar results on both the sector R&D budget and the patent intensity. The policies aiming at increasing the degree of vertical separation between the transmission and the generation segment of the electricity industry have a positive effect in particular on the sector patenting activities. This suggest that market reforms that introduce unbundling (i.e. decrease the level of vertical integration) and that reduce the entry barriers promote an increase in the demand of new technologies and solutions. Such demand is mostly addressed by technology suppliers which 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 to competition and introducing lighter regulatory remedies (i.e. reducing barrier to entry and introducing unbundling of operations) generates a stimulus for innovation[34], 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 specialized 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.

[34] Our results confirm previous findings by Priger 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.

6 References

Aghion, P., Bloom, N., Blundell, R., Griffith, R. and Howitt, P., 2005. Competition and Innovation: An Inverted-U Relationship. Q. J. Econ. 120(2), 701-728.

Aghion P., Griffith R., 2005. Competition and Growth: Reconciling Theory and Evidence. Cambridge: MIT Press.

Aghion, P., Blundell, R., Griffith, R., Howitt, P., and Prantl, S., 2009. The Effects of Entry on Incumbent Innovation Productivity, Rev. Econ. Statistics 91, 20–32

Alesina, Alberto, and S Ardagna., 2005. Regulation and Investment. J. Eur Econ Assoc 3 (June): 791–825.

Bassanini, A., Ernst, E., 2002. Labour Market Institutions, Product Market Regulation, and Innovation: Cross Country Evidence. ECO/WKP (2002) 2. OECD, Paris.

Blanchard, O.J., Wolfers., J., 2000. The Role of Shocks and Institutions in the Rise of European Unemployment: The Aggregate Evidence. Econ. J., 110, 1–33.

Blind, K., 2012. The Influence of Regulations on Innovation: A Quantitative Assessment for OECD Countries. Res. Policy 41 (2), 391–400.

Bortolotti, B., Cambini, C., Rondi, L., 2013. Reluctant Regulation, J. Comp. Econ., 41(3), 804-828.

Bremberger, F., Cambini, C., Gugler, K. P., Rondi L., 2013. Dividend Policy in Regulated Firms. Available at SSRN: http://ssrn.com/abstract=2277595 or http://dx.doi.org/10.2139/ssrn.2277595 .

Cambini C., Rondi L., Spiegel Y., 2012. Investment and the Strategic Role of Capital Structure in Regulated Industries: Theory and Evidence. In J. Harrington and Y. Katsoulacos (Eds.), Recent Advances in the Analysis of Competition Policy and Regulation, E. Elgar Publishing.

Caviggioli F., 2011. Foreign applications at the Japan Patent Office: An empirical analysis of selected growth factors. World Pat. Inf. 33, 157–167.

Conway, P, Nicoletti, G., 2006. Product Market Regulation in the Non-Manufacturing Sectors of OECD Countries: Measurement and Highlights. OECD Economic Studies, OECD Economics Department Working Paper No.530.

Djankov, S., La Porta, R., Lopez-De-Silanes, F., Shleifer, A., 2002. The Regulation of Entry. Q. J. Econ. 117(1), 1–37.

Eaton J, Kortum S., 1996. Trade in ideas - patenting and productivity in the OECD. J Int Econ 40:251-78.

Ebell, M. and Haefke, C., 2009. Product Market Deregulation and the U.S. Employment Miracle. Rev. Econ. Dynamics, Elsevier for the Society for Economic Dynam., 12(3), 479-504.

Entsoe, 2013. European Grids – Perspectives. Presented at the First European Energy Congress, 14-15 May 2013, Brussels.

European Commission, 2013. Energy Technologies and Innovation. COM(2013) 253, Brussels, 2.5.2013.

Furman, J.L., Porter, M.E., Stern, S., 2002. The determinants of national innovative capacity. Res. Policy 31, 899-933.

Gao H., van Biesebroeck, J., 2014. Effects Of Deregulation And Vertical Unbundling On The Performance Of China's Electricity Generation Sector, J. Ind. Econ. LXII (1).

Greenhalgh, C., Longland, M., 2005. Running to Stand Still? The Value of R&D, Patents and Trade Marks in Innovating Manufacturing Firms. Int. J. Econ. Business, 12(3),. 307–328.

Griffith, R., Harrison, R., Simpson., H., 2010. Product Market Reform and Innovation in the EU. Scand. J. Econ. 112 (2), 389–415.

Griliches, Z., 1990. Patent statistics as economic indicators: A survey. J. Econ. Lit., 28(4), 1661–1707.

Grupp H, Schmoch U., 1999. Patent statistics in the age of globalisation: new legal procedures, new analytical methods, new economic interpretation. Res Policy, 28:377-96.

Guthrie, G., 2006. Regulating Infrastructure: The Impact on Risk and Investment. J. Econ. Lit, 44(4), 925-972.

Gugler K., Rammerstorfer M., Schmitt, S., 2013. Ownership Unbundling and Investment in Electricity Markets: A Cross Country Study. Energ. Econ., 40, 702-713.

JRC Joint Research Centre, 2014. Smart Grid Projects Outlook 2014. Institute for Energy and Transport, European Commission, Petten, The Netherlands.

Joskow P.L., 2008. Incentive Regulation and Its Application to Electricity Networks. Rev. Netw. Econ., 7(4), 547-560.

Lanjouw, J. O. Schankerman, M., 2004. Patent quality and research productivity: measuring innovation with multiple indicators, Econ. J., 114, 441–465.

Lo Schiavo L, M., Delfanti, E., Fumagalli E., Olivieri, V., 2013. Changing the regulation for regulating the change. Innovation-driven regulatory developments in Italy: smart grids, smart metering and e-mobility. Energ. Policy, 57, 506-517.

Nicoletti, G., Scarpetta., S., 2003. Regulation, Productivity, and Growth: OECD Evidence. Econ. Policy, 18(36), 11–72.

OECD, 1997. The OECD Report on Regulatory Reform: Volume I: Sectoral Studies.Paris

OECD, 2009. Patent Statistics Manual. Paris.

Pavitt K., 1983. R&D, patenting and innovative activity: a statistic exploration. Res Policy 1983;11:33-51.

Prieger, J.E., 2002. Regulation, innovation, and the introduction of new telecommunications services. Rev. Econ. Statistics 84 (4), 704–715.

Prieger, J.E., Heil, D., 2008. The Rules of the Road or Roadblocks on the Information Highway? Regulation and Innovation in Telecommunications. AEI Center for Regulatory and Market Studies, Working Paper 08-15, April. www.reg-markets.org.

Sanyal, P., Ghosh., S., 2013. Product Market Competition and Upstream Innovation: Evidence from the US Electricity Market Deregulation. Rev. Econ. Statistics 95 (March): 237–254.

Schumpeter, J., 1942. Capitalism, Socialism and Democracy, Alan and Unwin, London.

Shleifer A., Vishny, R., 1994. Politicians and Firms, Q. J. Econ., 109(4), 995-1025.

Vogelsang I., 2002. Incentive Regulation and Competition in Public Utility Markets: A 20-Years Perspective. J. Regul. Econ., 22(1), 5-27.

Vogelsang I., 2010. Incentive Regulation, Investments and Technological Change. CESifo Working Paper Series 2964, CESifo Group Munich.

7 Annex

INSERT TABLE 4 HERE

INSERT TABLE 5 HERE

8 Tables

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

Variable name	Description	Source	Obs	Mean	Std. Dev.	Min	Max
(Ratio of electric R&D on Electricity consumption)$_{i,t}$	Ratio of the R&D in the electric domain in Million on the Final Electrical Energy Consumption (USD / Joule) for each country i in any year t	IEA, OECD STAN, EUROSTAT	234	26.03	31.12	0	133.38
(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	0.46	4.13
(Electricity consumption)$_{i,t}$	Final Electrical energy Consumption (Thousands of TeraJoule) for each country i in any year t	EUROSTAT	282	510.98	504.68	42.73	1898.47
(Patents)$_{i,t}$	EPO patent applications in the field "Electrical machinery, apparatus, energy", according to the WIPO concordance table (in logarithm)	OECD REGPAT	282	3.79	1.94	0	7.68
(Index)$_{i,t}$	Regulation index [0-6]	OECD STAN	276	3.27	1.88	0	6
(Entry Reg.)$_{i,t}$	Component of the regulation index: Entry Regulation	OECD STAN	276	2.80	2.54	0	6
(Public Own.)$_{i,t}$	Component of the regulation index: Public Ownership	OECD STAN	276	4.04	1.91	0	6
(Vert. Integr.)$_{i,t}$	component of the regulation index: Vertical Integration	OECD STAN	276	2.98	2.28	0	6
(Entry&Vert)$_{i,t}$	Average of the components "EntryReg." and "Vert.Integr."	OECD STAN	276	2.89	2.31	0	6

Table 2 OLS panel regression analysis with fixed effects. Dependent variable: ratio of electric R&D on Electricity consumption. Models from 6 to 10 calculated with one-year lagged independent variables (Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.10).

VARIABLES	(1) model	(2) model	(3) model	(4) model	(5) model	(6) model	VARIABLES	(7) model	(8) model	(9) model	(10) model	(11) model	(12) model
$(Index)_{i,t}$	-1.849**	-4.503***					$(Index)_{i,t-1}$	-1.780**	-3.900***				
	(0.717)	(0.857)						(0.732)	(0.931)				
$(Entry\&Vert)_{i,t}$			-3.252***				$(Entry\&Vert)_{i,t-1}$			-2.881***			
			(0.662)							(0.716)			
$(Entry\ Reg.)_{i,t}$				-2.656***			$(Entry\ Reg.)_{i,t-1}$				-2.486***		
				(0.582)							(0.625)		
$(Public\ Own.)_{i,t}$					-6.529***		$(Public\ Own.)_{i,t-1}$					-4.795***	
					(1.417)							(1.508)	
$(Vert.\ Integr.)_{i,t}$						-3.051***	$(Vert.\ Integr.)_{i,t-1}$						-2.463***
						(0.672)							(0.717)
$(R\&DonGDP)_{i,t}$		-23.026***	-23.097***	-22.380***	-13.013***	-19.924***	$(R\&DonGDP)_{i,t}$		-17.564***	-17.894***	-17.936***	-7.899*	-14.002***
		(4.544)	(4.696)	(4.759)	(3.780)	(4.443)			(4.960)	(5.107)	(5.145)	(4.032)	(4.790)
Constant	32.364***	82.057***	77.051***	73.817***	75.553***	71.252***	Constant	32.380***	71.019***	67.307***	66.012***	60.075***	59.410***
	(2.362)	(10.059)	(9.729)	(9.636)	(9.865)	(9.267)		(2.451)	(11.170)	(10.747)	(10.583)	(10.719)	(10.132)
Observations	232	232	232	232	232	232	Observations	232	232	232	232	232	232
Rsq within	0.031	0.138	0.125	0.112	0.114	0.111	R2 within	0.027	0.081	0.075	0.074	0.050	0.057
Rsq between	0.081	0.180	0.169	0.162	0.113	0.173	R2 btw	0.068	0.181	0.165	0.160	0.125	0.167

Table 3 OLS panel regression analysis with fixed effect. Dependent variable: count of Electricity EPO patents (in logarithm). Models from 6 to 10 calculated with one-year lagged independent variables (Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.10).

VARIABLES	(1) model	(2) model	(3) model	(4) model	(5) model	(6) model
(Index)$_{i,t}$	-0.200***	-0.086***				
	(0.015)	(0.027)				
(Entry&Vert)$_{i,t}$			-0.060***			
			(0.020)			
(Entry Reg.)$_{i,t}$				-0.040**		
				(0.019)		
(Public Own.)$_{i,t}$					-0.064	
					(0.040)	
(Vert. Integr.)$_{i,t}$						-0.054***
						(0.017)
(R&D on GDP)$_{i,t}$		0.274**	0.265**	0.295***	0.410***	0.303***
		(0.108)	(0.110)	(0.113)	(0.100)	(0.104)
(Elec. Cons.)$_{i,t}$		1.320***	1.385***	1.546***	1.803***	1.523***
		(0.306)	(0.297)	(0.306)	(0.251)	(0.260)
Constant	4.638***	5.201***	5.179***	5.238***	5.464***	5.249***
	(0.054)	(0.342)	(0.345)	(0.350)	(0.338)	(0.338)
Observations	257	257	257	257	257	257
Rsq within	0.400	0.456	0.455	0.445	0.440	0.457
Rsq between	0.027	0.737	0.734	0.742	0.760	0.739

VARIABLES	(7) model	(8) model	(9) model	(10) model	(11) model	(12) model
(Index)$_{i,t-1}$	-0.178***	-0.065**				
	(0.015)	(0.026)				
(Entry&Vert)$_{i,t-1}$			-0.047**			
			(0.019)			
(Entry Reg.)$_{i,t-1}$				-0.024		
				(0.018)		
(Public Own.)$_{i,t-1}$					-0.042	
					(0.038)	
(Vert. Integr.)$_{i,t-1}$						-0.048***
						(0.016)
(R&D on GDP)$_{i,t}$		0.328***	0.321***	0.368***	0.442***	0.338***
		(0.106)	(0.108)	(0.111)	(0.097)	(0.102)
(Elec. Cons.)$_{i,t}$		1.222***	1.265***	1.458***	1.599***	1.315***
		(0.291)	(0.282)	(0.290)	(0.244)	(0.249)
Constant	4.618***	4.958***	4.938***	4.993***	5.111***	4.969***
	(0.053)	(0.334)	(0.336)	(0.341)	(0.334)	(0.331)
Observations	257	257	257	257	257	257
R2 within	0.360	0.424	0.424	0.414	0.412	0.430
R2 btw	0.038	0.759	0.756	0.764	0.774	0.755

Table 4 Most relevant IPC subclasses associated to the field " Electrical machinery, apparatus, energy " according to the WIPO concordance table (the complete list is available on the WIO website).

IPC Subclass	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, substations, 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

Table 5 IPC subclasses of "H02", "Generation, conversion, or distribution of electric power".

IPC Subclass	Description
H02B	Boards, substations, 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.

9 Figures

Figure 1 Trends of the Indicator of Product Market Regulation in the Electric sector provided by the OECD and its three subcomponents for selected EU countries . Clockwise from the top left: OECD index, the sub-components “EntryReg.” “Vert.Integr.” and “Publ.Own.”.

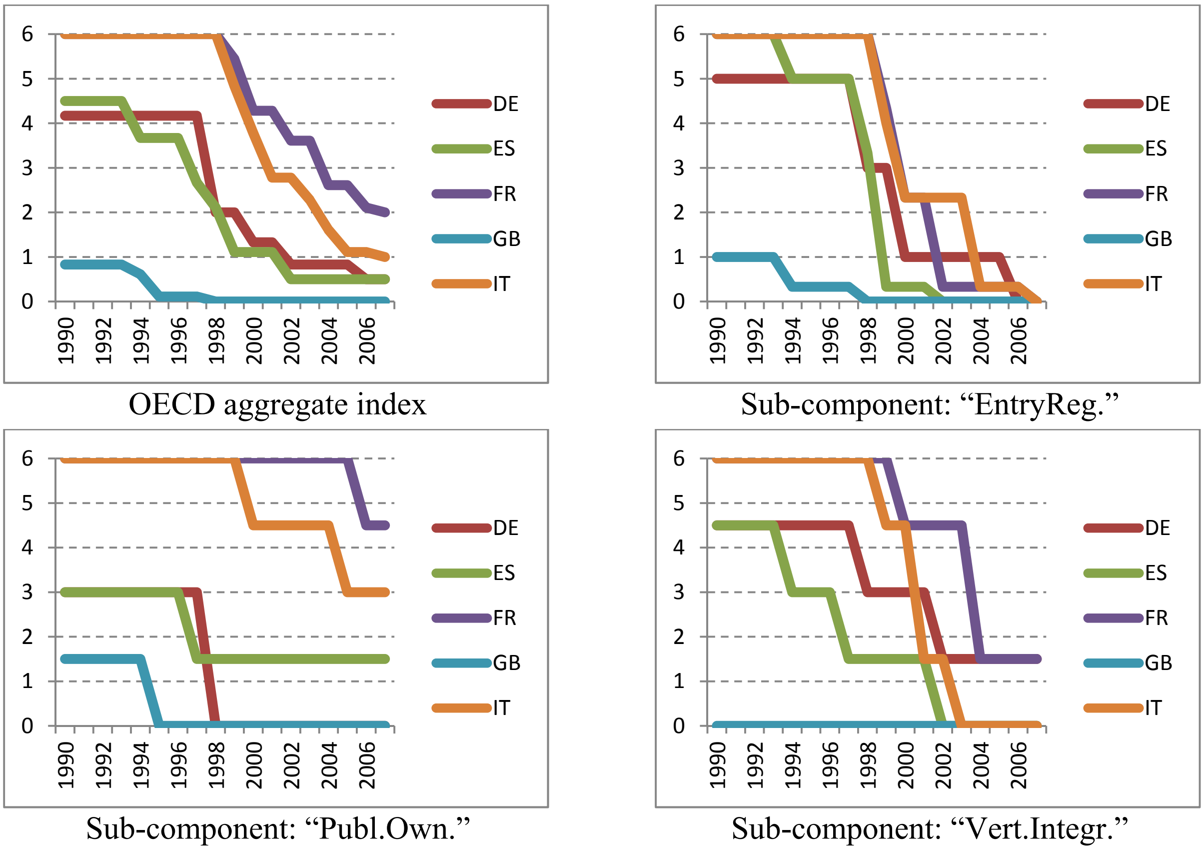

Figure 2 Yearly average values of EPO applications in the Electric sector in four time frames for the aggregate trend of all the 16 countries in the sample (line with reference to the right axis) and for the largest examined nations (histogram with reference to the left axis). Elaboration from OECD RegPat.

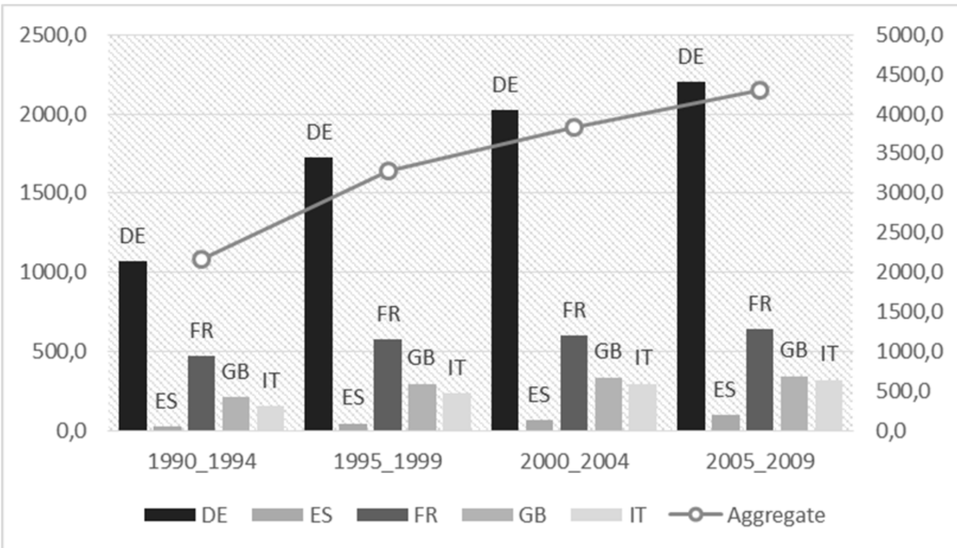

Figure 3 Average yearly inventions of selected companies in four time frames measured as INPADOC family IDs.