Electricity (De)Regulation and Innovation*

Marianna Marino † Pierpaolo Parrotta‡ Giacomo Valletta§

Abstract

In this paper we study the effect of deregulation on innovation in the electricity sector using a sample composed of 31 OECD countries. Exploiting sharp reductions in the level of product market regulation, explicitly linked to changes in the legal framework, we perform a difference-in-difference analysis by matching data retrieved from the OECD International Regulation, OECD Patent Grants, and UN World Development Indicators databases. Our main findings suggest that a decrease in regulation intensity, following a significant reform, has a negative impact on patents (granted by the European Patent Office). Moreover, this impact is mainly due to the degree of market contestability. Consistent with the results of Aghion et al. [1], we also find evidence of an inverted U-shaped relationship between regulation and innovation. This may imply that the effect of deregulation on innovation depends on the strength of the deregulatory process.

JEL Classification: K23, L51, L94, O31.

Keywords: Product market regulation, patents, innovation, electricity.

*We thank the editor Marianne Feldman and three anonymous reviewers. We are also grateful to the participants of the ENERGY Conference 2018. The usual disclaimer applies.

†Corresponding author. ICN Business School, 86 rue Sergent Blandan, 54000 Nancy, France; BETA, Bureau d'Économie Théorique et Appliqué; and NoCeT, Norwegian Centre for Taxation, Norwegian School of Economics. E-mail: marianna.marino@icn-artem.com

‡ICN Business School, 86 rue Sergent Blandan, 54000 Nancy, France; BETA, Bureau d'Économie Théorique et Appliquée; IZA, Institute for the Study of Labor; Tuborg Research Centre for Globalization and Firms, Aarhus University; and NoCeT, Norwegian Centre for Taxation, Norwegian School of Economics. E-mail: pierpaolo.parrotta@icn-artem.com

§EDHEC Business School, 24 avenue Gustave Delory, 59057 Roubaix, France. E-mail: giacomo.valletta@edhec.edu

1 Introduction

Economic and technological reasons are behind the fact that network industries like electricity (but also gas, telecommunication and transport) have typically been tightly regulated. Regulation would concern structural aspects of the industry (e.g., entry conditions, ownership, vertical integration) but also the performance of the operators (tariffs and quality standards) hence having an impact on profits and possibly biasing the willingness to innovate (Vogelsang [46]).

The liberalization wave that has concerned the electricity industry over the last 30 years (alongside other network industries) has had the main purpose of introducing competition into the sector (or, at least, in some parts of it) in order to foster efficiency hence affecting, among other things, the incentives to invest in innovation. At a theoretical level, the effect of deregulation on innovation is rather ambiguous: if deregulation increases competition, where competition is scarce, then companies might be pushed to innovate in order to increase the competitive gap between them and their rivals. If competition becomes too intense then imitation may become a more profitable option than innovation (Aghion et al. [1]).

There are some recurrent elements characterizing the reforms implemented over the last three decades across many OECD countries: vertical separation of potentially competitive segments (i.e., generation, marketing and retail supply) from segments that will continue to be regulated (i.e., transmission and distribution), the formation of wholesale and retail power markets open to the entry of new competitors, the privatization of state-owned utilities, the establishment of an independent regulator and the implementation of a system of third-party access to the transmission and the distribution systems. In spite of the consensus about the fact that these are the key ingredients for deregulation to achieve the objectives of economic efficiency and security of supply, at least in the short term (Al-Sunaidy and Green [2], Jamasb and Pollit [28]), these positive effects may be offset by possibly lower rates of innovation associated with the liberalization process in the long term, as observed by Jamasb and Pollit [29].

This paper tries to assess, at an empirical level, if the drastic changes in product market regulation, induced by the intense reform process observed in many OECD countries, have brought significant changes in the incentives to innovate of the firms operating in the electricity industry. More precisely, we try to determine if, and to what extent, the substantial changes in the legal and regulatory framework, specifically aiming at relaxing or dismantling regulations restricting efficiency enhancing competition, were responsible for changes in the number of patents in the electricity sector and whether these changes were not just part of a pre-existing trend. Of course, the reform process has been far from homogeneous across OECD countries both in terms of timing and in terms of main policy objectives. The possibility of comparing the heterogeneous evolution of the reforms over time and across countries will be key in our study.

The greater availability of data (across countries) has led to an increasing interest towards the economic effects of regulation. For example, it has been shown that regulatory restrictions might have detrimental effects on infrastructural investment (Alesina et al. [3]) and employment (Bertrand and Kramartz [10]) while increasing prices (Martin et al. [33]) in the regulated sectors.

When it comes, more specifically, to the relationship between deregulation and innovation in the electricity industry the evidence is rather mixed. Jamasb and Pollitt [29] provide a series of theoretical arguments and descriptive evidence that liberalization has had negative effects on innovation in the sector. Also Sanyal and Gosh [41], who describe the impact of the 1990s U.S. electricity reform on patenting, find that the introduction of the reform led to a net decrease of patenting by electric equipment manufacturers. On the other side of the spectrum, in a recent study involving the electricity industry of 15 EU countries, Cambini et al. [14] find that a decrease in the intensity of regulation has rather had a positive impact on innovation both in terms of R&D expenditure and in terms of patenting activity.

In order to solve this puzzle we use a panel of 31 OECD countries to study how sharp changes in regulation intensity occurred in the electricity industry, associated with a reform of the legal framework, have affected its innovativeness: the idea is to progressively compare countries that have experienced a profound liberalization process with countries that have not experienced yet such a change. We do so by implementing a difference-in-difference analysis in which the pre- and post-treatment period is identified by a sharp decrease in the within country regulation intensity that is accompanied by a change in law. In order to measure the intensity of regulation we use the OECD index of product market regulation in non-manufacturing sectors (NMR index hereafter) drawn from the International Regulation database (Conway and Nicoletti [17]). This index has been devised specifically to measure regulations that affect competition in markets where competition is feasible (other types of regulations or policy objectives are are not taken into account). This measure of regulation is a weighted average of four low-level components, which vary from 0 to 6 (with 0 denoting the lowest degree of regulation), each providing, respectively, a measure of entry regulation, of the degree of vertical integration of the market, of the market share of the dominant player(s), of the presence of the state as a shareholder. Innovation is measured by the number of patents granted within the electricity sector by the European Patent Office (EPO hereafter).

Our main results suggest that two forces are at work. On the one hand, deregulation is generally associated with a higher number of patent grants at EPO. On the other hand, the effect of (further) deregulation on innovation, after a sharp decrease in regulation intensity, is negative: a 1 % reduction in the NMR index during the post-reform period significantly decreases the number of patent grants by 1.76 %. The latter effect appears to be driven mainly by the reduction of entry barriers associated with the regulatory framework, i.e., a greater degree of market contestability decreases firms' incentives to innovate extensively.

We also find that the prominence of these two forces depends on the regulatory environment in which the reforms take place. In countries where, on average, the liberalization process has been more substantial, a further loosening of the regulatory burden, after a major reform, decreases the number of patent grants. The opposite happens in countries where the liberalization process has been weaker. Thus, the effect of deregulation on innovation, after a drop in regulation intensity, depends on whether the deregulation process has already been more or less extensive. To support this result we also find descriptive evidence of an inverse U-shaped relationship between deregulation and innovation. This relationship is positive when the level of the NMR index is high (to put it differently, deregulation fosters innovation if the market is tightly regulated), it reaches its peak at some intermediate level of the NMR index and starts decreasing afterward (deregulation hampers innovation once the market liberalization process is already fairly advanced). Assuming that a lower level of the NMR index can be associated with more competition, this relationship is remarkably consistent with the one between competition and innovation described by Aghion et al. [1].

The paper is organized as follows. Section 2 describes the relevant literature. Section 3 offers a brief overview of the deregulation process of the electricity sector in OECD countries. Section 4 presents the data, describes the empirical model and provides descriptive statistics and prima-facie evidence of the relationship under analysis. Section 5 discusses the empirical findings. Section 6 concludes the paper. The Appendices provide further descriptive and empirical evidence.

2 Literature review

Since the 80s, major reforms of the electric power industry have been introduced virtually everywhere in OECD countries. Reforms were first introduced in developed countries (United States, Australia, Europe) as well as, developing countries (Chile and Brazil). They have also progressed gradually in the former Soviet Union, Eastern Europe and Asia, but they have been slow to arrive in Africa and in the Middle East (Bacon and Besant-Jones [8]). This deregulation wave has been part of a wider set of legal and institutional changes involving several industries that were typically heavily regulated.

Several studies have already focused on the effect of deregulation on several economic variables. Barone and Cingano [9] study the effects of regulation on downstream manufacturing activities to understand how regulation in services affects the economic performance of such industries. They find that in countries with less service regulation one can observe faster value added, productivity and export growth in manufacturing industries using services more intensively. Liberalization and market deregulation have also been shown to significantly and positively impact infrastructure investment (Alesina et al. [3]) whereas, when it comes more specifically to R&D expenditure, Bassanini and Ernst [7] find a negative correlation between the intensity of product market regulations and the intensity of R&D expenditure in 18 OECD countries.

At a more specific level, the studies aiming at assessing the impact of liberalization in the electricity industry have primarily focused on prices and cost efficiency often attaining mixed conclusions. Steiner [44], using a panel dataset of 19 OECD countries for the 1987-1996 period, tries to assess the separate effect of different aspects of the reforms. Unbundling is not associated with significantly lower prices but with a lower industrial to residential price ratio and higher capacity utilization rates and lower reserve margins. The introduction of a wholesale market reduces prices and the ratio of industrial to residential prices. For third party access the sign on prices and the price ratio is negative but not significant. It is also not significant for the cost efficiency measures. Privatization has a positive impact on prices and price ratios but has no significant effect on the cost efficiency measures.[1] Another study by Fiorio, Florio and Doronzo [23] also looks at the impact of the regulatory reforms, in 15 EU countries, on household electricity prices over the 1978-2005 period. To measure the extent of the reform they use some components of the NMR index that we use in our study and they try to see how certain reform elements - public ownership, entry regulation and vertical integration - affect prices separately. They find that the reform variables do not affect prices in a statistically significant way.[2]

The evidence about the relationship between liberalization and innovation, and its theoretical understanding, seems even less straightforward. At a theoretical level, the debate on the relationship between innovation and competition, assuming that less regulation fosters competition, goes back to Schumpeter who famously argued that the prospect of an increased market power and large scale foster innovation (Schumpeter

[1]Hattori and Tsutsui [26] find similar results in a replication of Steiner's study for the same 19 OECD countries and extend it through 1999.

[2]Using the same sample and reform variables, and relying on their self-assessed satisfaction, Fiorio and Florio [22] find that a higher consumers' satisfaction is associated with public ownership of electricity industry.

[42]). By contrast, Arrow [5] has argued that a firm earning substantial profits, resulting from its substantial market power, would rather focus on the protection of the status-quo instead of investing resources in trying to find a disruptive new technology. As argued by Motta [34] a "middle ground environment, where there exists some competition but also high enough market power coming from the innovative activities, might be the most conducive to R&D output". This is also probably the best way to describe the theoretical and empirical relationship between competition and innovation that has been proposed by Aghion et al. [1]. If competition is low, an increase in competition may boost the incremental increase in profits resulting from innovation thus encouraging R&D investments aiming at "escaping competition". On the contrary, too much competition may lead to more rapid and complete imitation that could reduce post-innovation rents of laggard firms and thus their incentive to catch up with the leader.

One of the first attempts to provide some evidence of the relationship between liberalization process and innovation, specifically for the electricity industry, is the paper by Dooley ([18]) that describes reductions in energy R&D investments occurring in several advanced countries following the deregulation of their respective energy sectors. The author argues that such reduced level of investments, occurred both in the public and private sectors, tends to shift the focus of investments towards shorter-term R&D. Thus, despite the short-term benefits experienced by customers who eventually face lower energy prices, a breakdown of energy R&D investment is very likely to have long-term negative impacts on national energy sectors, the economies, and environmental well-being. This view is reinforced by the observations of Jasmab and Pollit [29] and Sterlacchini [45]: from 1990 to 2004, the most advanced economies of the world have experienced an important reduction of the R&D expenditures devoted to energy or electricity. Moreover, patenting activity in the UK electricity sector seems to follow a similar path as that of R&D investment, as reported by Jasmab and Pollit [30]. However, these papers just describe a trend so that it is not possible to infer the actual impact of the reform, within each country, and across countries, on innovation in the electricity industry.

To the best of our knowledge very few studies attempt, more specifically, to find a more precise empirical relationship between some measure of innovation (R&D expenditure, number of patents) and some measure of the intensity of regulation (over time) within each country. A recent example is given by Cambini et al. [14]. The study matches industry-level data (for the electricity sector) on R&D budgets and EPO applications with the NMR index (or its sub-components), in order to test the impact of liberalization on the propensity to innovate. Deploying a fixed-effects panel analysis, they provide evidence of an increase in the aggregated electricity R&D and patenting activities following market deregulation. In particular, policies aimed at a reduction in vertical integration have a positive impact on both industry-level R&D and patenting while policies aimed at the reduction of public ownership of incumbent operators and the reduction of entry barriers mostly affect R&D expenditures.[3] Another recent contribution focuses more precisely on the role of deregulation in affecting the trends of quantity and quality of innovation, in the electric equipment manufacturing sector, in the Unites States. Using patents as a metric for innovation, Sanyal and Ghosh [41] find that the 1992 Energy Policy Act had a specific role in the decline of patents granted to electricity equipment manufacturers. Indeed, they show that an increase in competition in the downstream generation sector, due to the reform, adversely affected the innovation behavior of electric equipment manufacturers.

3 Historical background

The production and the supply of electricity have been typically considered a key aspect of economic activity with considerable social and environmental consequences.

The regulation of the electricity industry has traditionally been motivated by the existence of natural monopoly conditions, externalities, and public good characteristics. These derive from technical and economic features that are shared by other network industries (high fixed cost, social utility) but also from features that uniquely pertain

[3] Relying on data from the telecommunication industry, Prieger [40] finds a similar relationship between regulation intensity and service innovations proposed by telecommunications providers in US.

to this sector (e.g., non-storability, the supply must be able to adapt constantly to a demand that fluctuate continuously). These elements, taken together, have brought about the idea that the entire production process, consisting of the generation stage (the actual production of electricity), the distribution (construction and management of the grid) and sale to end-users, could have been better handled by a (natural) monopolist.[4]

For this reason, the regulated industry would usually be characterized by the presence of a vertically integrated firm (publicly or privately owned) enjoying a (legal) monopoly position in its local geographical area. Such a structure would often fail to deliver an efficient outcome. In developed countries, the industry would often suffer from inefficiencies typically involving large-scale investments to the detriment of cost minimization (Averch and Johnson [6]) and innovation. In developing countries, the industry would typically suffer from even more radical problems like shortages of capacity and infrastructure underinvestment (Bergara et al. [11]).

During the 80's, primarily in western countries, technological (Joskow [31]) and political (Green [24]) change have created pressures in favor of different institutional arrangements meant to enhance the efficiency of the system. Specifically, at the generation and at the supply stage, scale economies were more quickly exhausted so that they could be considered potentially competitive activities, even if transmission and distribution could still be characterized by conditions of natural monopoly, externalities and public goods.

Ever since, the regulatory framework of the electricity supply industry has begun to change rapidly. Most OECD countries have introduced reforms meant to stimulate competition by attempting to liberalize the industry.[5] More specifically, several countries have progressively passed new laws aiming at fostering competition in electricity generation and retailing by unbundling these functions from the transmission and distribution part of the business, granting access to new entrants to the existing networks,

[4]A clear description of the specificities of the electricity industry and of its functioning can be found, among others in Steiner [44].

[5]A detailed overview of the reform process in OECD countries is provided by Al-Sunaidy and Green [2].

and creating well designed markets where price is determined by supply and demand.

The first OECD country passing a reform going in this direction was the Unites States. The Public Utility Regulatory Policies Act (PURPA, 1978) was the first attempt to separate generation from transmission by imposing to utility firms to buy electricity from qualified facilities. Chile is also considered another pioneering country in the liberalization of the electricity sector (Pollit [38]). In Australia, the state of Victoria set up a pool in 1994, followed by New South Wales in 1996, at the same time New Zealand also established its Wholesale Electricity Market.

In Europe, the deregulation wave of the electricity industry started in England and Wales at the end of the 80s (Electricity Act 1989) when the industry was restructured and privatized (Green and Newbery [25], Newbery and Pollitt [37], [36]). Moreover, the Electricity Pool of England & Wales was created with the objective of setting up a competitive market for generation. The final step of the reform was to enable final consumers to choose their electricity retailer. Norway followed in 1990 (Energy Act) giving customers a choice of supplier and creating its own electricity pool. In 1996 the pool was joined by Sweden (whose deregulation process had started already in 1991 with the Governmental Bill 1990/91:87) giving birth to the world's first international electricity market (Nord Pool). Spain can also be considered an early reformer. The process started with the privatization of two public electric utilities, Red Electrica and Endesa, between 1988 and 1999. In 1994 the Law 40/1994 was passed. The law mandated the legal unbundling of the transmission network and created an independent joint public-private transmission system operator.

In the meantime, also the The European Commission started to push toward an EU-wide policy of electricity deregulation. In particular the Commission directives of 1996 [19] and 2003 [21] were putting forward an institutional setting aimed at the creation of a European competitive electricity market. The directives had the dual objective of requiring, on the one hand, a certain level of deregulation, at national level, to each Member State and, on the other hand, to fix trading rules and favor cross-border transmission links across Member States. The main objectives, fixed by the second directive, were to obtain by July 2007, the complete unbundling of the several segments of the market in each Member State, free entry at the generation level, full market opening, promotion of renewable resources, definition of the functions of the regulator, the creation of a single European market for electricity.[6]

4 Data

In this section, we report the data sources used to build up the final data set and the related variables. We also present our empirical model and discuss the descriptive statistics and provide some preliminary evidence.

4.1 Data sources and variables

To perform our empirical analysis, we combine three data sources: (i) OECD ETCR Data Regulation (Electricity industry), (ii) OECD Patent Grants (Priority date, IPC H – Electricity) and (iii) UN World Development Indicators.[7] We retrieve our policy variable, the NMR index of the electricity industry (which measures the regulation intensity of the sector), and outcome variable, patent grants at EPO, from the first and second data sources, respectively. The latter source allows us to gather information at the country-year level on GDP growth rate, exports and imports as shares of GDP; all included in our analysis as covariates to control for macroeconomic fluctuations or trade shocks.

The final data set comprises information on 31 OECD countries[8] for the 1985-2010 period, yielding 765 observations (see *Table 1*). Selection of time period and

[6]The European Commission has also complemented its effort in achieving the objectives fixed by the Directives by keeping under the scrutiny of competition law the incumbent electricity utilities whenever they were abusing of their pre-existing market power in the newly liberalized market (European Commission [20]).

[7]We also make use of OECD R&D data (Electricity, gas, steam and air conditioning supply; water collection, treatment and supply) and OECD Patent Grants (Priority date, ENE – Climate change mitigation technologies related to energy generation, transmission or distribution) to obtain the empirical evidence reported in the Appendix B.

[8]Australia, Austria, Belgium, Brazil, Canada, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea (South), Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, South Africa, Spain, Sweden, Turkey, United Kingdom.

countries in the sample is determined by data availability or identification of a sharp change in NMR index associated with a change in the legal framework. Because of the missing observations, our panel is unbalanced. All of the reported findings refer to the electricity industry, being the latter our sole unit of analysis.

Our policy variable is part of a set of indicators that has been built by the OECD to provide a measure of industrial regulations that restrain efficiency-enhancing competition in several regulated sectors.[9] The NMR indices cover energy, transport and communication over the 1975-2013 period in OECD countries. Each sectoral index is built with the sole purpose of quantifying regulatory measures that restrict competition whenever market conditions are otherwise open to it, any other policy goal, like environmental sustainability, is not taken into account.

For each sector, the NMR index is equal to the weighted average of four *low-level* numerical components computed using a specific algorithm. The information gathered is objective (as opposed to survey-based) since it is based on specific measurement criteria related to regulations and markets.[10] Each component measures respectively, on a scale from 0 to 6 (from least to most restrictive), the presence of barriers to entry, the amount of state control, the degree of vertical integration and concentration (market structure). Each of them provides a measure of a different kind of restriction to competition.

We use the NMR index for the electricity sector. Like the other sectoral indices it can take value between 0 and 6 and it is calculated as the weighted average, with equal weights, of the four components mentioned above.[11] A low level of the index denotes a low level of regulation, and possibly a high level of competition, within the sector.

The component *Entry Regulation* (NMR-entry) focuses on terms and conditions

[9] More details on the NMR indices can be found in Conway and Nicoletti [17], who provide an in-depth description of the indicators for each non-manufacturing industry. These indices are complementary to indicators of economy-wide regulation also published by the OECD (see Conway et al.) [16].

[10] The value of each component is determined from the answer to questionnaires sent by the OECD to experts on a regular basis. As mentioned also in Conway and Nicoletti [17] even if this approach involves a degree of discretion (in the choice scores and aggregation weights) it has nonetheless the merit of being rather transparent and consistent over time and across sectors.

[11] For certain countries and for certain years the component on market structure is missing. Whenever it is the case, the total index is built giving equal weight to the three available components.

for potential entrants to access the industry and the possibility of choice of supplier for consumers. More precisely, it gathers together a measure of the possibility of third party access to existing transmission and distribution networks, a measure of the extent to which consumers can choose among different suppliers and, finally, it includes information on the presence of a liberalized wholesale market for power, which has been historically a central aspect of the liberalization process of the electricity sector in most OECD countries. The Entry Regulation component hence provides, as far as regulation is concerned, an indirect measure of the contestability of the market.

The second component, *Public Ownership* (NMR-public_own), aims at measuring the level of public ownership (ranging from fully private to fully public) of the largest companies operating in the various segments of the whole industry. This component also keeps track of mixed ownership situations involving natural monopoly segments that remain under public ownership. The inclusion of this dimension may be helpful in detecting soft regulations often characterizing the management of public companies, which may enjoy state guarantees and low financial stringency that could negatively affect their economic performance (Shleifer and Vishny [43]). Privatization is not necessarily a condition for liberalization: competition and incentive-based regulation may still be a viable option in presence of publicly owned companies. Nonetheless, there are compelling arguments suggesting substantial economic benefits deriving from privatization, in particular if it is associated with effective market design, competition and regulation (Newbery [35]).

The third component, *Vertical Integration* (NMR-vert_int), is meant to measure the degree of separation between several segments of the whole industry, in particular between electricity generation and transmission. This latter aspect is crucial for a successful reform as it aims at separating potentially competitive segments of the market (generation, retail) from others (transmission, distribution, system operation) that present the typical features of a natural monopoly and should be regulated as such. A successful separation of generation and transmission activities is seen as a decisive element to attain sufficient competitive pressures in the wholesale electricity markets (Joskow [32]; Newbery [35]), to simultaneously avoid anti-competitive actions by incumbent power producers and to guarantee non-discriminatory network access to others. Unbundling can take different forms: functional, accounting, legal, or ownership separation, the latter one being the most effective in fostering competition (Jamasb and Pollitt [28]).

The fourth component, *Market Structure* (NMR-market_str), provides a measure of the degree of concentration (and hence, indirectly, of competitiveness) of the various segments of the whole market by measuring the market share of the largest company in each segment.

Using an indicator rather than a more direct measure of competition such as the market share or the number of competing firms presents the advantage of "mitigating" the potential endogeneity issue arising when attempting to measure competition (Cette et al., 2013). Bourls et al. [12] argue that these indicators have the clear advantage of accounting for three major issues: the endogeneity bias, the effects of competitive pressures in upstream industries on downstream industries and the role played by public policies that affect competition. Unlike widely used indicators exploited for this type of analysis when looking at market power or market structure, which are not univocally related to product market competition, the OECD NMR indicators provide a more direct link to policy and regulation.

Our outcome variable is the number of patents granted by the EPO (1985-2010) in the section (IPC) H, which refers to the electricity industry.[12] Patents are often used as a reliable measure of innovation because they are subject to formal tests of 'novelty' and 'non-obviousness'. Patents may be seen as 'successful innovations' and typically have a close link to inventions. There could exist a number of drawbacks in using patent counts as a measure of innovation. For instance, some innovations are not patented because firms prefer to protect their inventions using other methods, such as secrecy or lead time. In addition, differences across countries and industries in the patent law and regulations affect the propensity to patent and make more difficult a

[12]The outcome variable used in the analysis reported in the Appendix B is the number of environmental patent grants at EPO (Priority date, ENE – Climate change mitigation technologies related to energy generation, transmission or distribution).

comparison over time. We partly cope with some of these issues as we (i) focus on a single industry, (ii) include controls for time and country specific effects, and (iii) perform a number of robustness checks on a relatively homogeneous group of countries in terms of patent law and regulations (e.g., European countries). A further critique, raised by Jamasb and Pollitt [28], concerns the fact that some patents relevant to the electricity sector are classified under classes different from H (e.g., F03 "Machines or engines for liquids" and G21 "Nuclear physics; nuclear engineering"). Although we agree that the patent class H may not include all patents relevant to the electricity industry, the OECD database does not inform on such patent classes and therefore we focus exclusively on IPC H, which is however a good proxy at the country level of the innovations introduced in the electricity sector.

4.2 Estimation strategy

In our estimation strategy we exploit sharp changes (i.e., drops) in the NMR index (i.e., the regulation intensity) of the electricity sector to identify the effect of deregulation on innovation. We use the introduction of such significant reforms (treatment) as basis for a difference-in-differences (DID hereafter) approach, comparing countries experiencing drops in regulation (treated) to countries that are still subject to a relatively stable and high regulatory regime (controls or untreated), before and after the treatment occurs. The empirical model, estimated by OLS, takes the following form:

$$ln\_patents_{it} = \alpha + \beta ln\_NMR_{it} + \gamma PolicyChange_{it} + \quad (1)$$

$$\delta ln\_NMR_{it} \times PolicyChange_{it} + \eta_i + \theta_t + X'_{it}\omega + \varepsilon_{it},$$

where i refers to the country and t to the year. $ln\_patents$ is the log-transformation of the patent count at the country-year level. The variable ln_NMR is the log-transformation of the NMR index. $PolicyChange$ is a dummy variable indicating whether the drop in the regulation occurred or not in a given country. Our key variable is $ln\_NMR \times PolicyChange$, the interaction between ln_NMR and $PolicyChange$, that carries the DID coefficient δ. The variables η and θ control for unobserved country fixed effects and symmetric business cycle shocks, respectively. We also run model specifications similar to that described by equation (1) with the variables $ln\_NMR-entry$, $ln\_NMR - public\_own$, $ln\_NMR - vert\_int$ and $ln\_NMR - market\_str$ (the log-transformation of the components NMR-entry, NMR-public_own, NMR-vert_int and NMR-market_str) respectively replacing the variable ln_NMR. We add 0.10 to both the patent count and some regulatory components (NMR-entry, NMR-public_own, NMR-market_str) to include observations that would otherwise be associated with missing values. Except for the dummy variables, we take the main variables in log-levels to ease the interpretation of the estimates, which therefore are elasticities. The matrix X includes further controls at the country-year level, namely GDP growth rate, and exports and imports as shares of GDP. ε is assumed to be an idiosyncratic term, unrelated with the other independent variables. However, the standard errors are robust and clustered at the country level, i.e., we de facto allow for correlation between residuals.

The presence of systematic differences between the treatment and control groups in the sample is not an issue because the DID methodology does not rely on random assignment to treatment (Angrist and Pischke [4], and Cameron and Trivedi [15]). Indeed, the identifying assumption is that the two groups follow the same trend in absence of treatment. This is likely to happen in our setting because (i) we include country and year fixed effects, which are not included in a standard DID approach, (ii) the treatment and control groups are not fixed over time, i.e., at a given point an untreated country enters in the treatment group when it is subject to a sharp change in the regulation index.

4.3 Descriptive evidence

We describe the sample composition and policy reforms in *Table 1* that shows, for each country, the number of observations, the observation period and the year of the policy change (i.e., a sudden drop in the NMR index that can be associated with a regulatory reform) we consider in the analysis. This table also includes the average, the minimum and the maximum value of both the NMR index and the number of patents grants at the EPO over the observation period.

For each country, we look at the pattern of the NMR index over time. For our analysis we always consider (for the sake of consistency) the first sudden reduction of the NMR index (in chronological order, whenever several policy changes occur, and given the availability of data) that can be associated with a regulatory reform. We do not necessarily consider the most drastic one.[13] Interestingly, we are able to associate a change in the legal framework (sixth column in *Table 1*) with each of the policy changes we consider. This table, combined with *Figure 1* and the graphs collected in the Appendix A, provides detailed information on the structure of the sample, the definition of the $PolicyChange$ variable and potential associations between the after-reform period and evolution of patent grants.

Moreover, Figures A1-A4 (Appendix A) describe, for each country, the pattern of each of the four components of the NMR index separately. Clearly, the evolution of the overall structure of the industry is strictly related to the evolution of the regulatory environment. In this sense, looking separately at the change over time of each component gives an interesting account of how, and to what extent, national markets have changed compared to when they where fully regulated (i.e., a publicly or privately owned integrated monopoly subject to tight regulation).

[*Table 1 and Figure 1 about here*]

Figure 2 shows the the average value of the NMR index (i.e., average regulation intensity) in the electricity sector by country over the sample period (1985-2010). As one could already infer from *Figure 1*, the five highest average regulatory intensities are observed for Mexico, South Africa, Iceland, Greece and France, whereas the lowest five are observed for Japan, UK, Spain, Norway and Germany.

[13]The minimal sudden reduction of the NMR index that can be associated with a policy change is 2%, the median reduction is 16%, the average reduction is 23% and the maximal reduction is 80%.

On average, policy changes occur between 1998 and 1999, respectively the mean and median values. This is an interesting information to be used while describing the evolution of the average patent grants in the electricity sector (see *Figure 3*). Indeed, it appears to exist an inverted U-shaped relationship between the number of patents and the NMR index by collapsing our sample by observational year. On the one hand, a decrease in the NMR index can be associated with an increase in patents in pre-reform years (that is, when the level of the NMR index tends to be high). On the other hand, a decrease in the NMR index appears to hamper innovation once the market liberalization process is already fairly advanced. In particular, after-reform years are associated with a decreasing number of patents as a whole. Quite interestingly this is true in spite of the spike in environmental patents grants registered over the same period of time, as shown in *Figure B3* (Appendix B). The fact that environmental patents follow a different path may be explained by an acceleration of environmental regulation pushing innovation toward alternative ways of generating electricity (see Porter and Van der Linden [39]).

The descriptive evidence we just mentioned is remarkably consistent with the results of Aghion et al. [1] who have famously described an inverted U-shaped relationship between competition and innovation. In our framework a very high level of regulation intensity describes a situation where competition is essentially absent. A decrease of the NMR index can then be associated with an increase of the competitiveness of the market. The prospect of new entries may induce the incumbent firms to push on innovation in order to keep a competitive distance with their new rivals. Once some level of competition is already present in the market, further deregulation may lead to a situation where, by the very same reasoning, the prospect of low post-innovation rents may hinder the incentive to innovate.

[*Figures 2 and 3 about here*]

Figure 4 reports a linear fit between patent grants and the NMR index, both taken in log-levels. It emerges a negative relationship between the two variables, i.e. a reduction (strengthening) in the regulatory intensity is positively (negatively) correlated with the number of patents.

A similar relation emerges when plotting averages of R&D expenditure and NMR index (*Figures B1 and B2*) and averages of environmental patent grants and NRM index (*Figures B4*). This is in line with what found by Cambini et al. [14].

[*Figure 4 about here*]

Table 2 reports observations (obs), mean and standard deviation (SD) for the outcome variables (*patents* and *ln_patents*), and the control variables *GDP growth rate*, and *export GDP ratio* and *import GDP ratio*. The table also reports descriptive statistics of the NMR index and its low-level components. A higher regulatory burden seems to be associated with public ownership (NMR-public_own) and vertical integration (NMR-vert_int) compared to the other components, even in the period subsequent to a sharp drop in regulation ($NMR - component \times PolicyChange$). Among the regulatory components, larger reductions are observed for entry regulation (NMR-entry) and market structure (NMR-market_str), which respectively decrease by 79 % and 65 %, whereas both public ownership and vertical integration decrease by slightly more than 50 %.

Significant differences are also reported when contrasting patent grants before and after the policy change. Specifically, *Table 3* shows that, performing a t-test, we observe a significantly larger number of patents granted in the after-reform period independently of the log-transformation. Of course, these are just preliminary and descriptive findings which do not account for time and country heterogeneity and because of that, they may not be interpreted as conclusive.

[*Tables 2 and 3 about here*]

5 Results

Table 4 shows our main findings, i.e. the effect of deregulation on innovation in a DID setting. We gradually augment the specification by including country fixed effects, column (2), year fixed effects, column (3), and time-varying controls, column (4). The estimates typically improve their precision, i.e. show lower standard errors, as the specification includes further controls. Specifically, the inclusion of country fixed effects captures most of the variability in the outcome variable, increasing the explanatory power of the regressions drastically. Except for the specification with no covariates, column (1), estimates are fairly similar in size and R-squared values are always above 90 %, showing a quite good fit of our model.

We infer from the estimates on ln_NMR that deregulation is generally associated with a higher number of patents granted by EPO, consistently with the descriptive evidence shown in *Figure 4*. It also emerges that, ceteris paribus, post-reform periods ($PolicyChange$) are associated with fewer patents, compared to pre-reform ones. When focusing on our treatment variable, $ln\_NMR \times PolicyChange$, we find that (further) deregulation, following a sharp reduction in the intensity of regulation, appears to hinder innovation. Specifically, we find that a 1 % reduction in the NMR index, during the post-reform period, significantly decreases the number of patent grants by 1.76 %. This may imply that an excessively feeble regulatory setting may generate disincentives to innovate, probably due to the lower profitability associated with a tougher competitive environment. Of course, we are not able to directly test such hypothesis because we have no information on firm profitability at the industry level. In any case, any welfare evaluation goes beyond the scope of our study. Nonetheless, this results seems to shed some light on the seemingly conflicting findings concerning the relationship between deregulation and innovation in the electricity sector.

We have also looked, more specifically, at the effects of deregulation on environmental patent grants. As shown in *Table B2* (Appendix B), when implementing our DID analysis, we find that environmental patents appear not to be significantly affected by the NMR index or any of its components. The raise in environmental patent grants documented in *Figure B3* may not be directly linked to the liberalization process.

[*Table 4 about here*]

We also try to disentangle the role specifically played by changes occurring in each of the specific areas of regulation covered by the different components of the NMR index in affecting innovation. In order to do so, we run the model specification described by equation (1) replacing the NMR index with each of its components. *Table 5* reports estimates by regulatory component. In this table and in the following ones, all specifications include the full set of controls. Entry Regulation appears to be the main driver of the overall effect of deregulation on patents, i.e. market contestability seems to be the main factor contributing to a decrease of the incentive of the firms to innovate after a drastic reform has occurred. Indeed, we find that a 1% drop in the variable NMR_Entry, in the post-reform periods, decreases patents grants considerably: the associated elasticity is 3.48. Examining the results for the Market Structure and Public Ownership components, we observe that the treatment variable carries a similar and significant coefficient of about 0.25. This elasticity is however considerably lower (about 14 times) than the one associated with Entry Regulation, showing thus the different relevance of different policy measures when it comes to their impact on innovation. The Vertical Integration component appears not to matter much, given the size of the elasticity and its insignificant statistical level.

[*Table 5 about here*]

Finally, we try to find empirical evidence of the pattern described in *Figure 3*, which shows an inverted U-shaped relationship between the number of patents and the NMR index. In order to do so we divide the sample in two complementary subsets: countries whose average NMR index is respectively below or above the threshold value of 4. Although the choice of this threshold value is somehow arbitrary, it appears to be fairly close to the turning point of the regulation – innovation pattern described by *Figure 3*. The 'below-threshold' sub-sample includes Australia, Austria, Belgium, Brazil, Finland, Germany, Japan, Norway, Spain, and United Kingdom. The 'above-threshold' sub-sample includes the remaining countries. As one can see from *Table 6*, we find that for the 'below-threshold' sub-sample the signs of the coefficients associated with ln_NMR, $PolicyChange$ and $ln\_NMR \times PolicyChange$ are the same as those found for the entire sample (as reported by *Table 3*). However, quite interestingly, the estimates for the 'above threshold' sub-sample show opposite signs. This may entail that a decrease in regulation intensity following a drastic policy change fosters (hinders) innovation in markets with a high (low) level of regulation intensity. This evidence is consistent with the pattern observed in *Figure 3* because it seems to point out that product market regulation may have opposite effects on patenting activity depending on whether one considers countries experiencing a relatively more or less intense liberalization process. Specifically, we find that a 1 % reduction in the NMR index, in the after-reform period, increases the number of patents by 6.79 % for countries belonging to the 'above- threshold' sub-sample, whereas a similar reduction in the treatment variable decreases the number of patents by 2.37 % for the complementary sub-sample.

[*Table 6 about here*]

Finally, *Table 7* reports the robustness checks we perform to evaluate whether and how *(i)* the sample composition, columns (1)-(2), *(ii)* the unbalanced nature of the sample, column (3), *(iii)* a different imputation in the patent count,[14] column (4), *(iv)* taking the lead values of $PolicyChange$ and $NMR \times PolicyChange$, column (5), *(v)* assigning 0 to $PolicyChange$ when the latter is below its median or mean values, respectively, columns (6)-(7), *(vi)* using the patent granted by USPTO (US Patent and Trademark Office) as dependent variable, column (8), affect our results. Specifically, the focus on relatively homogeneous country groups (European and historical EU members) allows us to remove potential bias arising from differences in patent legislations. The exclusion of countries not observed for the whole sample period tests the influence of observations related to country entering the sample later than 1985. Using a different imputation of the dependent variable, and allowing for anticipation effects by taking the first lead of the treatment variable and treatment period are informative checks to corroborate our main findings. Again, redefining both treatment variable and treatment period depending on whether the reduction in the NRM index is larger than 16 % or 23 % (median and mean value associated with the beginning of post-treatment period $PolicyChange$, respectively) does not substantially affect the interpretation of

[14] The argument of the logarithm is $(1 + patents)$ rather than $(0.10 + patents)$.

our results. Lastly, performing the same analysis on an alternative measure of innovation (patents granted by USPTO) in the electricity sector tests the external validity of this analysis and its policy implications. All robustness checks show treatment effects in line with the main results (see *Table 4*).

[*Table 7 about here*]

6 Discussion and conclusions

The electricity industries of most OECD countries have experienced an intense liberalization process over the last three decades. Former state-owned utilities have been privatized and new actors have had the possibility to enter the market introducing competition in the generation and distribution stages. The consequences for consumers and producers have been significant both in terms of productive efficiency and final prices. A more controversial aspect concerns the consequences of deregulation on firms' willingness to innovate.

Our contribution aims at studying empirically the relationship between regulation intensity (measured by the NMR index provided by the OECD) and innovation (measured by patent grants at EPO) taking into account the heterogeneity of the reform process across 31 OECD countries both in terms of timing and intensity. The idea is to identify, for each country, a pre- and post-treatement period associated with a sharp drop in the NMR index (due to a reform of the regulatory framework) and to compare the effect of such changes on innovation. More specifically, we rely on a DID analysis, comparing *treated* countries with *untreated* countries still experiencing a (relatively) higher regulation intensity.

We find that, even if one can associate deregulation, in general, with an increase in patent grants, a further decrease in regulation intensity, after a drastic reform has occurred, has the opposite effect on innovation. Quite interestingly, the main driver of this force seems to be the degree of contestability of the market.

Finally, we divide the sample in two complementary groups: countries with a relatively high regulation intensity and countries with a relatively low regulation intensity (i.e., countries whose average NMR index is, respectively, above and below a value of 4). We find that a further decrease in regulation intensity following a reform has opposite effects on innovation across the two sub-samples reflecting the fact that deregulation may indeed produce two countervailing forces driving innovation in opposite directions, depending on whether one considers countries experiencing a more or less intense liberalization processes in their electricity markets (in line with Aghion et al. [1]).

Our findings may have interesting implications for policy. A drastic liberalization process may yield positive effects in terms of production efficiency and price reduction but may have the unintended consequence of a possible stagnation in innovation (at least in a partial equilibrium perspective). This may be particularly problematic for the electricity sector in light of the fact that demand for electricity is set to grow considerably in the next few years, together with the need to increase the use of more sustainable ways to produce it (IEA [27]). The latter aspect, in particular, is strictly linked to technological progress. Our findings are consistent with the fact that market forces alone may not be able, in the long term, to provide sufficient incentives to innovate to the firms operating in the sector. The study of a direct link between regulations explicitly aimed at the decarbonization of the electricity industry and innovations meant to fulfill this objective (e.g., green patents, green R&D) is beyond the scope of this paper and is left for future research.

References

[1] Aghion P., Bloom N., Blundell R., Griffith R. and Howitt P. (2005). Competition and Innovation: An Inverted-U Relationship. Quarterly Journal of Economics 120:701-728.

[2] Al-Sunaidy A. and Green R. (2006). Electricity deregulation in OECD (Organization for Economic Cooperation and Development) countries. Energy 31:769-787.

[3] Alesina A., Ardagana S., Nicoletti G. and Schiantarelli F. (2005). Regulation and Investment. Journal of the European Economic Association, 3: 791-825.

[4] Angrist, J., & Pischke, J.S. (2009). Mostly Harmless Econometrics: An Empiricist's Companion. Princeton University Press, 2009.

[5] Arrow K. (1962). Economic Welfare and the Allocation of Resources to Invention. In The Rate and Direction of Inventive Activity: Economic and Social Factors, edited by the Universities-National Bureau Committee for Economic Research and the Committee on Economic Growth of the Social Science Research Councils, 609 26. Princeton, NJ: Princeton University Press.

[6] Averch H. and Johnson L.L. (1962). Behavior of the firm under regulatory constraint. American Economic Review, 52:1059-69.

[7] Bassanini A. and Ernst E., (2002). Labour Market Institutions, Product Market Regulation, and Innovation: Cross Country Evidence. OECD Economics Department Working Papers, No. 316.

[8] Bacon R. W. and Besant-Jones J. (2001). Global Electric Power Reform, Privatization and Liberalisation of the Electric Power Industry in Developing Countries. Annual Reviews Energy & The Environment 26:331-359.

[9] Barone G. and Cingano F. (2011). Service Regulation and Growth: Evidence from OECD Countries. Economic Journal, 121:931-957.

[10] Bertrand M. and Kramarz F. (2002). Does entry regulation hinder job creation? Evidence from the French retail industry. The Quarterly Journal of Economics 117:1369-1413.

[11] Bergara M., Henisz W. J. and Spiller P. T. (1997). Political Institutional and Electric Utility Investment: A Cross-Nation Analysis. California Management Review, 40:3-35.

[12] Bourls R., Cette G., Lopez J., Mairesse J. and Nicoletti G. (2010). The Impact on Growth of Easing Regulation in Upstream Sectors. CESifo DICE Report, 8:8-12.

[13] Bourls R., Cette G., Lopez J., Mairesse J. and Nicoletti G. (2013). Do Product Market Regulations in Upstream Sector Curb Productivity Growth? Panel Data Evidence for OECD Countries. The Review of Economics and Statistics, 95:1750-1768.

[14] Cambini C.,Caviggioli F., Scellato G. (2016). Innovation and market regulation: evidence from the European electricity industry. Industry and Innovation 23:734-752

[15] Cameron, A. C., & Trivedi, P. K. (2005). Microeconometrics: methods and applications. Cambridge university press.

[16] Conway P., Janod V. and Nicoletti G. (2005). Product Market Regulation in OECD Countries: 1998 to 2003. OECD Economics Department Working Papers, No.419.

[17] 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.

[18] Dooley J.J. (1998). Unintended Consequences: Energy R&D in a Deregulated Energy Market. Energy Policy 26: 547-555.

[19] European Commission. Directive 96/92/EC of the European Parliament and of the Council of 19 December 1996 concerning common rules for the internal market in electricity. Brussels: Commission of the European Communities; 1996.

[20] European Commission. DG Competition Report on Energy Sector Inquiry, Brussels: Commission of the European Communities; 1997.

[21] European Commission. Directive 2003/54/EC of the European Parliament and of the Council of 26 June 2003 concerning common rules for the internal market in electricity and repealing Directive 96/92/EC. Brussels: Commission of the European Communities; 2003.

[22] Fiorio C.V., Florio M.(2011). Would you say that the price you pay for electricity is fair? Consumers' satisfaction and utility reforms in the EU15. Energy Economics, 33:178187.

[23] Fiorio C.V., Florio M. and Doronzo R. (2007). The Electricity Industry Reform Paradigm in the European Union: Testing the Impact on Consumers. Paper delivered at Consumers and Utility Reforms in the European Union Conference, Milan, June 8-9.

[24] Green R., (2006). Electricity liberalisation in Europe - how competitive will it be?. Energy Policy, 34:2532-2541.

[25] Green R. and Newbery D. (1992). Competition in the British Electricity Spot Market. Journal of Political Economy, 100:929-53.

[26] Hattori T. and Tsutsui,M., (2004). Economic impact of regulatory reforms in the electricity supply industry:a panel data analysis for OECD countries. Energy Policy 32:823832.

[27] International Energy Agency, (2017). World Energy Outlook.

[28] Jamasb T. and Pollitt M. (2005). Electricity Market Reform in the European Union: Review of Progress toward Liberalisation and Integration. The Energy Journal 26:11-41.

[29] Jamasb, T. and Pollitt, M. (2008). Deregulation and R&D in network industries: The case of electricity sector. Research Policy, 7:995-1008.

[30] Jamasb T. and Pollitt M. (2011). "Electricity sector liberalisation and innovation: An analysis of the UK's patenting activities," Research Policy, 40:309-324.

[31] Joskow P. (1987). Productivity growth and technical change in the generation of electricity. Energy 8:1738.

[32] Joskow P. (2008). Lessons learned from electricity market liberalization. The Energy Journal 29:9-42.

[33] Martin R., Roma M. and Vansteenkiste I. (2005). Regulatory reforms in selected EU network industries. ECB Occasional Papers Series, No. 28.

[34] Motta M. (2004). Competition Policy: Theory and Practice. Cambridge: Cambridge University Press

[35] Newbery D. (1999). Privatization, Restructuring, and Regulation of Network Utilities, Cambridge: The MIT Press.

[36] Newbery D. (2006). Electricity Liberalization in Britain and the Evolution of Market Design, in in Sioshansi, F. and W. Pfaffenberger. Electricity Market Reform: An International Perspective, Elsevier, 109-144.

[37] Newbery D. and Pollitt M. (1997). The Restructuring and Privatization of Britains CEGB Was it Worth It? Journal of Industrial Economics, 45:269-303.

[38] Pollitt M. (2004). Electricity reform in Chile. Lessons for developing countries. Competition and Regulation in Network Industries 5:221-262

[39] Porter M. and van der Linde C. (1995). Toward a new conception of the environment-competitiveness relationship. Journal of Economic Perspective 9:97-118.

[40] Prieger J.E. (2002). Regulation, innovation, and the introduction of new telecommunications services. Review of Economics and Statistics 84:704715.

[41] Sanyal P. and Ghosh S. (2013). Product Market Competition and Upstream Innovation: Evidence from the US Electricity Market Deregulation. Review of Economics and Statistics 95:237254.

[42] Schumpeter J. (1942) Capitalism, Socialism and Democracy. New York: Harper & Brothers.

[43] Shleifer A. and Vishny R. (1994). Politicians and Firms, Quarterly Journal of Economics, 109:995-1025.

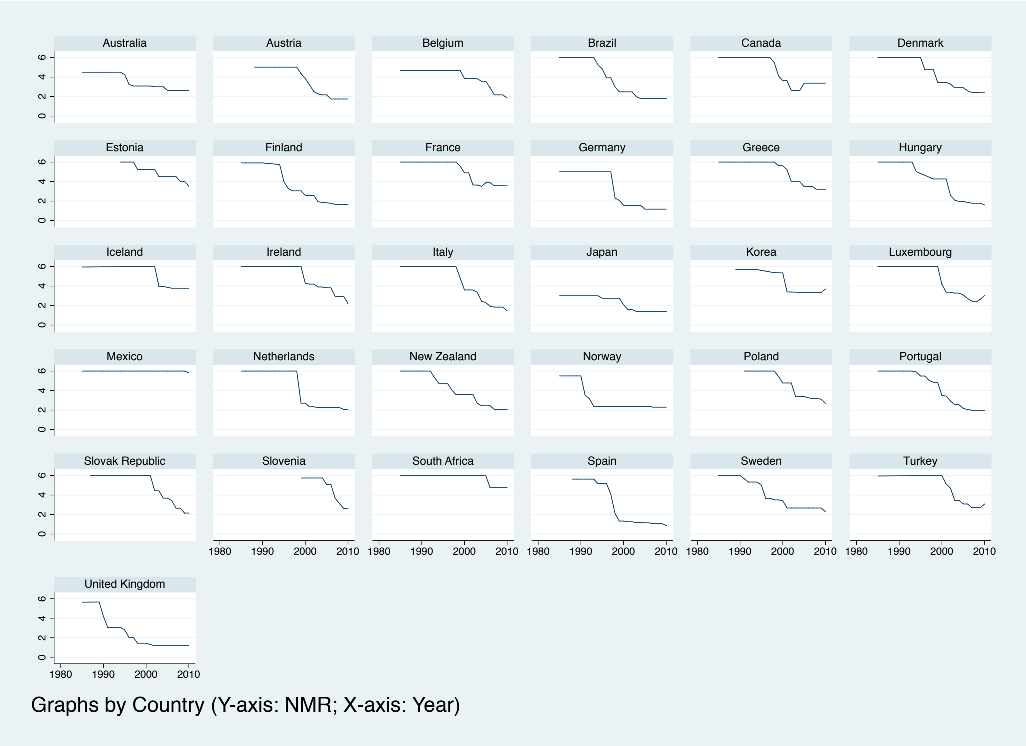
[44] Steiner F. (2001). Regulation, Industry Structure and Performance in the Electricity Supply Industry. OECD Economic Studies, No. 32.

[45] Sterlacchini A. (2012). Energy R&D in Private and State-Owned Utilities: An Analysis of the Major World Electric Companies. Energy Policy 41:494-506.

[46] Vogelsang I. (2010). Incentive Regulation, Investments and Technological Change, CESifo Working Paper Series No. 2964.

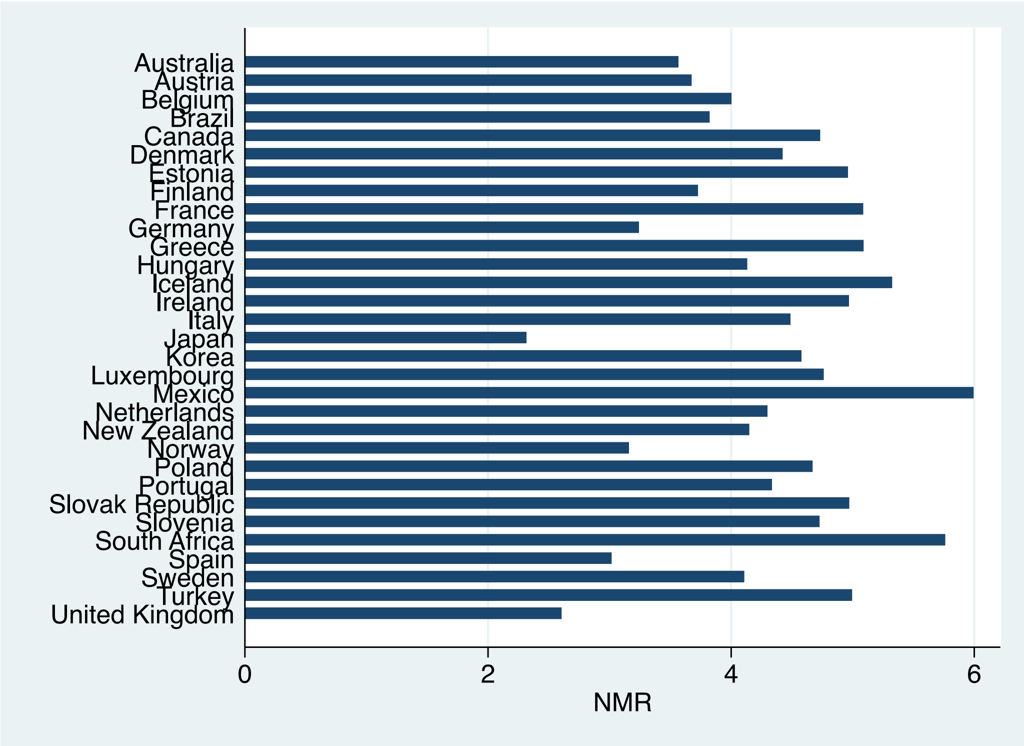
Figures and Tables

Figure 1: *NMR index in the electricity sector (vertical axis) over time (horizontal axis) by country*



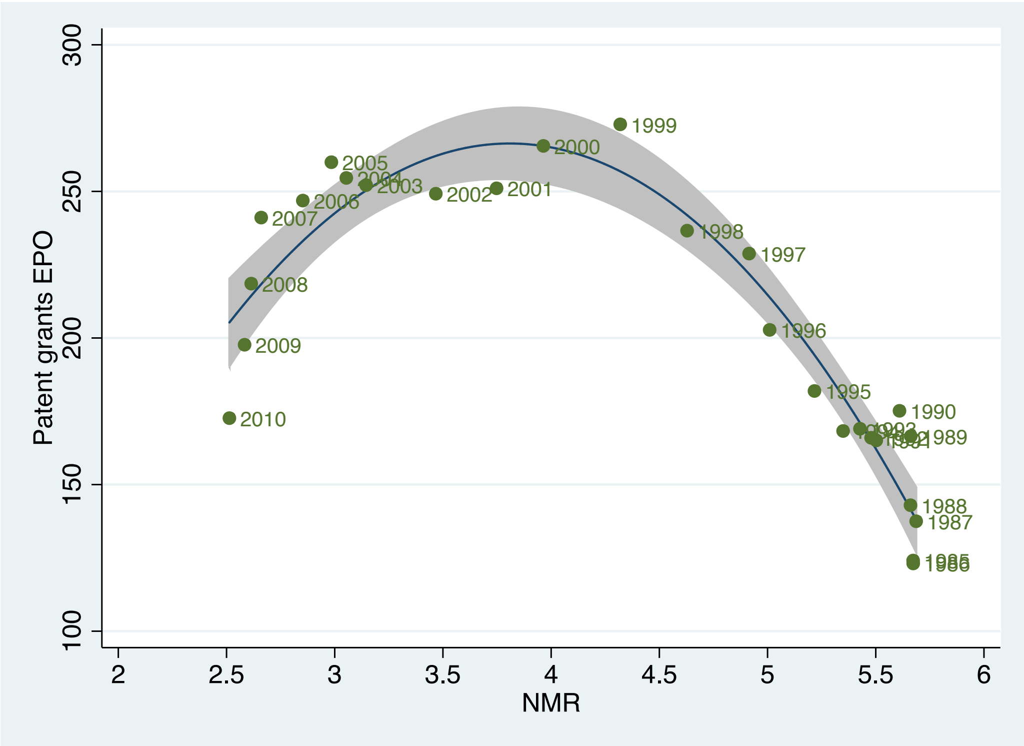
Source: OECD ETCR Data Regulation.

Figure 2: *Average level of the NMR index in the electricity sector by country*



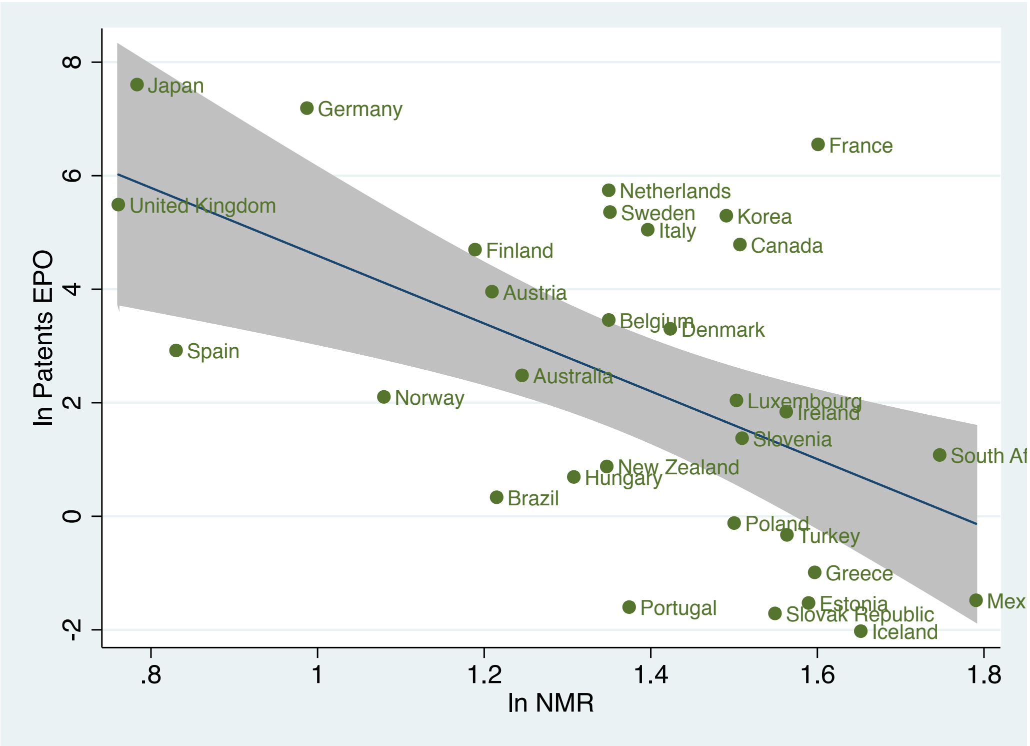
Source: OECD ETCR Data Regulation.

Figure 3: *Average patent grants at EPO and level of NMR index in the electricity sector by year*



Source: OECD ETCR Data Regulation and OECD Patent Grants (Priority date, IPC H – Electricity).

Figure 4: *Log-linear relationship between patent grants at EPO and NMR index in the electricity sector*



Source: OECD ETCR Data Regulation and OECD Patent Grants (Priority date, IPC H – Electricity).

Table 1: *Sample composition and policy reform*

ID	*Country*	*Observations*	*Period*	*Policy Change*	*Liberalization*	NMR			Patent Grants EPO		
						mean	*min*	*max*	*mean*	*min*	*max*
1	Australia	26	1985-2010	1995	Electricity Industry Act for Victoria (1994)	3.56	2.63	4.5	13.88	3.73	39.43
2	Austria	23	1988-2010	1999	Law of Electricity Supply (1998)	3.67	1.75	5.02	56.69	23.08	102.76
3	Belgium	26	1985-2010	2000	Law for the Organisation of the Electricity Market (1999)	4.00	1.84	4.68	34.67	11.82	59.63
4	Brazil	26	1985-2010	1994	Concession Law and IPP Law (1995)	3.82	1.79	6	2.80	0	9
5	Canada	26	1985-2010	1998	Energy Competition Act (1998)	4.73	2.63	6	160.99	27.19	333.70
6	Denmark	26	1985-2010	1996	Ammendment to Danish Supply Act (1996)	4.42	2.42	6	35.70	4.79	68.05
7	Estonia	17	1994-2010	1998	Energy Law (1997)	4.96	3.52	6	0.33	0	2
8	Finland	26	1985-2010	1995	Electricity Market Act (1995)	3.72	1.65	5.91	180.61	4.10	453.44
9	France	26	1985-2010	1999	Law No. 2000-108 (2000)	5.08	3.50	6	725.33	412.26	966.11
10	Germany	26	1985-2010	1998	Act on the Supply of Electricity and Gas (1998)	3.24	1.17	5	1377.48	822.12	2117.92
11	Greece	26	1985-2010	1999	Electricity Law (1999)	5.08	3.16	6	0.75	0	2.4
12	Hungary	26	1985-2010	1994	Electricity Act (1994)	4.13	1.60	6	2.40	0	5.43
13	Iceland	26	1985-2010	2003	Electricity Act (2003)	5.32	3.78	6	0.10	0	1
14	Ireland	26	1985-2010	2000	Electricity Regulation Act (1999)	4.97	2.19	6	13.17	0.2	39.77
15	Italy	26	1985-2010	1999	Bersani Decree (1999)	4.49	1.46	6	162.07	66.31	224.57
16	Japan	26	1985-2010	1995	Amendments to Electric Utility Law (1995)	2.31	1.40	3	2080.67	1040.95	2919.84
17	Korea, South	22	1989-2010	2001	Act on Promotion of Restructuring of the Electricity Power Industry (2000)	4.58	3.33	5.69	341.44	13.21	948.22
18	Luxembourg	26	1985-2010	2000	Law on the organization of the electricity market (2000)	4.76	2.36	6	11.86	1	26.93
19	Mexico	26	1985-2010	2010	Energy reform (2008)	5.99	5.81	6	0.40	0	4
20	Netherlands	26	1985-2010	1999	The Electricity Act (1998)	4.30	2.07	6	317.05	196.39	425.53
21	New Zealand	26	1985-2010	1993	Energy Act and Companies Act (1992)	4.15	2.06	6	2.89	0	7.69
22	Norway	26	1985-2010	1991	Energy Act (1990)	3.16	2.30	5.5	10.11	0.5	21.73
23	Poland	20	1991-2010	1999	Energy Act (1997)	4.67	2.69	6	2.37	0	10.17
24	Portugal	26	1985-2010	1994	Decree Laws 182/95, 183/95, 184/95,185/95 (1995)	4.33	1.98	6	0.26	0	1.5
25	Slovak Republic	24	1987-2010	2002	Amendment to the Law on Energy of 1998 (2001)	4.97	2.15	6	0.24	0	1.05
26	Slovenia	12	1999-2010	2005	Amendment to the Energy Act of 1999 (2004)	4.72	2.63	5.75	4.28	1.66	7.25
27	Spain	23	1988-2010	1994	Electricity Act (1994)	3.02	0.87	5.63	22.00	3.6	46.87
28	South Africa	26	1985-2010	2006	Electricity regulation act (2006)	5.76	4.75	6	3.70	0	7.19
29	Sweden	26	1985-2010	1991	Governmental Bill 1990/91:87 (1991)	4.11	2.30	6	294.97	33.50	659.30
30	Turkey	26	1985-2010	2001	Electricity Market Law (2001)	4.99	2.71	6	3.99	0	19
31	United Kingdom	26	1985-2010	1990	Electricity Act (1989)	2.60	1.17	5.66	247.13	164.65	342.29
	Total	765	1985-2010			4.30	0.87	6			

Source: OECD ETCR Data Regulation, Al-Sunaidy and Green, www.europex.org and authors' research.

Table 2: *Descriptive statistics*

	Obs	*Mean*	*SD*	*min*	*max*
Outcome variable					
patents	765	205.48	471.34	0	2919.84
Key policy variable and its components					
(Regulation intensity)					
NMR	765	4.30	1.64	0.87	6
$NMR \times PolicyChange$	765	1.59	1.73	0	5.91
(Entry regulation)				0	6
$NMR - entry$	765	3.55	2.60	0	6
$NMR - entry \times PolicyChange$	765	0.74	1.44	0	6
(Market structure)				0	6
$NMR - market\_str$	554	3.18	2.66	0	6
$NMR - market\_str \times PolicyChange$	554	1.10	1.87	0	6
(Public ownership)				0	6
$NMR - public\_own$	765	4.58	1.94	0	6
$NMR - public\_own \times PolicyChange$	765	2.06	2.47	0	6
(Vertical Integration)				0	6
$NMR - vert\_int$	765	5.31	0.87	3	6
$NMR - vert\_int \times PolicyChange$	765	2.47	2.41	0	6
Control variables					
GDP growth rate (% terms)	765	2.71	3.15	-14.57	11.74
import GDP ratio (% terms)	765	38.20	22.54	5.46	151.75
export GDP ratio (% terms)	765	39.50	25.77	6.57	181.78

Source: OECD ETCR Data Regulation and OECD Patent Grants (Priority date, IPC H – Electricity), and WDI (UN database).

Table 3: *Differences in patent grants between before- and after-policy change*

	before			*after*			*difference (before vs after)*		
Variable	*obs*	*mean*	*SD*	*obs*	*mean*	*SD*	*obs*	*t-test*	p-value
patent grants at EPO	362	143.27	19.43	403	261.36	26.96	765	-3.49	0.000
ln_patents_EPO	362	1.72	0.16	403	3.15	0.14	765	-6.75	0.000

Source: OECD ETCR Data Regulation and OECD Patent Grants (Priority date, IPC H – Electricity).

Table 4: *DID results – NMR index*

	ln_patents_EPO			
	(1)	*(2)*	*(3)*	*(4)*
ln_NMR	-10.44***	-1.95**	-1.47**	-1.40*
	(2.23)	(0.71)	(0.70)	(0.71)
PolicyChange	-14.05***	-2.04**	-2.80***	-2.72***
	(3.73)	(1.01)	(1.00)	(1.01)
$ln\_NMR \times PolicyChange$	7.87***	1.68**	1,81***	1.76***
	(2.15)	(0.63)	(0.61)	(0.61)
Country FE	No	Yes	Yes	Yes
Year FE	No	No	Yes	Yes
Other controls	No	No	No	Yes
Clusters	31	31	31	31
Observations	765	765	765	765
R-squared	0.22	0.92	0.93	0.93

Notes: Other controls include GDP growth, and export and import scaled to GDP. Standard errors are robust and clustered at the country level. *, **, and *** denote significance at the 10, 5, and 1 percentage level, respectively.

Table 5: *DID results – by regulatory component*

	ln_patents_EPO			
	(1)	*(2)*	*(3)*	*(4)*
Component	*Entry regulation*	*Market Structure*	*Public Ownership*	*Vertical integration*
$ln\_NMR - entry$	-3.38***			
	(1.13)			
PolicyChange	-5.06***			
	(1.93)			
$ln\_NMR - entry \times PolicyChange$	3.48***			
	(1.12)			
$ln\_NMR - mark\_str$		-0.39**		
		(0.14)		
PolicyChange		-0.05		
		(0.12)		
$ln\_NMR - mark\_str \times PolicyChange$		0.25**		
		(0.07)		
$ln\_NMR - public$			-0.03	
			(0.09)	
PolicyChange			-0.16	
			(0.09)	
$ln\_NMR - public \times PolicyChange$			0.25***	
			(0.08)	
$ln\_NMR - vert\_int$				-0.76
				(0.51)
PolicyChange				0.00
				(0.00)
$ln\_NMR - vert\_int \times PolicyChange$				-0.07
				(0.08)
Clusters	31	31	31	31
Observations	765	554	765	765
R-squared	0.93	0.95	0.93	0.93

Notes: All specifications include the full set of controls. Standard errors are robust and clustered at the country level. *, **, and *** denote significance at the 10, 5, and 1 percentage level, respectively.

Table 6: *DID results – testing the inverted U-shaped relationship*

	ln_patents_EPO	
	(1)	*(2)*
	below threshold	*above threshold*
ln_NMR	-2.24*	7.70**
	(1.05)	(3.00)
$PolicyChange$	-3.80*	12.48**
	(1.72)	(5.21)
$ln\_NMR \times PolicyChange$	2.37*	-6.79**
	(1.05)	(2.92)
Clusters	10	21
Observations	254	511
R-squared	0.95	0.92

Notes: All specifications include the full set of controls. The 'below threshold' subsample includes countries associated with an average regulation index lower than 4 (i.e. Australia, Austria, Belgium, Brazil, Finland, Germany, Japan, Norway, Spain, and United Kingdom). The 'above threshold' is the complementary set of the 'below threshold'. Standard errors are robust and clustered at the country level. *, **, and *** denote significance at the 10, 5, and 1 percentage level, respectively.

Table 7: *Robustness checks*

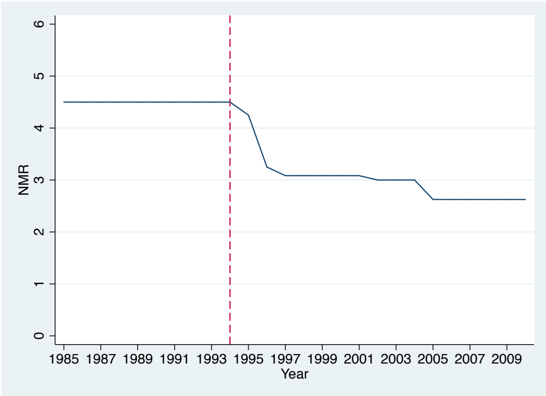
	ln_patents_EPO			
	(1)	*(2)*	*(3)*	*(4)*
	European countries	*Historical EU countries*	*Balanced panel*	*Different imputation*
ln_NMR	-1.81	-2.36*	-1.24	-0.89*
	(1.15)	(1.12)	(0.76)	(0.45)
PolicyChange	-3.98**	-4.58**	-2.60**	-1.45**
	(1.79)	(1.90)	(1.02)	(0.61)
ln_NMR × PolicyChange	2.39**	2.73**	1.70**	0.98**
	(1.06)	(1.13)	(0.63)	(0.38)
Clusters	21	17	24	31
Observations	509	434	624	765
R-squared	0.95	0.96	0.94	0.96

		ln_patents_EPO		*ln_patents_USPTO*
	(5)	*(6)*	*(7)*	*(8)*
	Lead value PolicyChange	*Above median PolicyChange*	*Above mean PolicyChange*	*Patent grants at USPTO*
ln_NMR	-1.40*	-0.31	-0.01	-0.53
	(0.71)	(0.31)	(0.33)	(0.40)
PolicyChange	-2.63**	-1.53***	-0.87	-1.21**
	(0.99)	(0.55)	(0.56)	(0.57)
ln_NMR × PolicyChange	1.71***	1.21***	1.01***	0.81**
	(0.59)	(0.30)	(0.31)	(0.38)
Clusters	31	31	31	31
Observations	734	734	734	641
R-squared	0.94	0.94	0.93	0.95

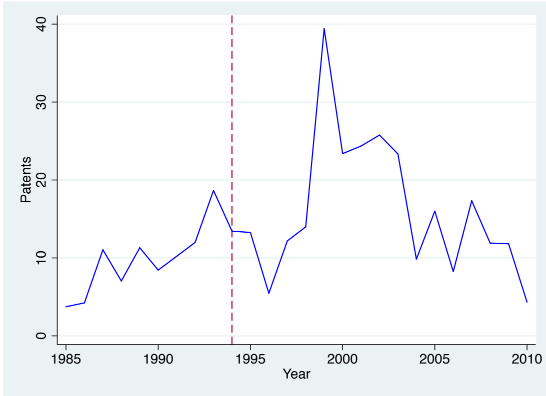
Notes: All specifications include the full set of controls. Standard errors are robust and clustered at the country level. *, **, and *** denote significance at the 10, 5, and 1 percentage level, respectively. The sub-sample 'European countries' includes Austria, Belgium, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, United Kingdom. The sub-sample 'Historical EU countries' includes all European countries except for Estonia, Hungary, Poland, Slovak Republic and Slovenia. The sub-sample 'Balanced panel' includes solely countries observed for the whole sample period (1985-2010 for EPO).

Appendix A

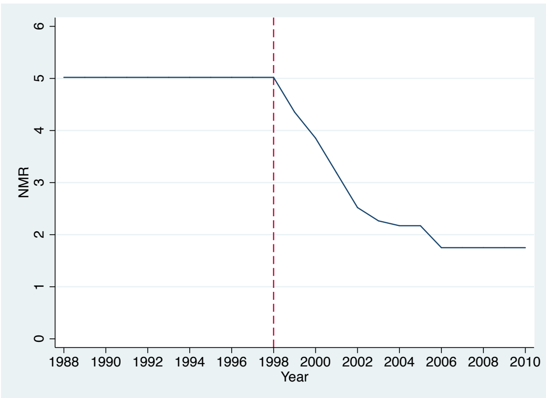
Australia: NMR



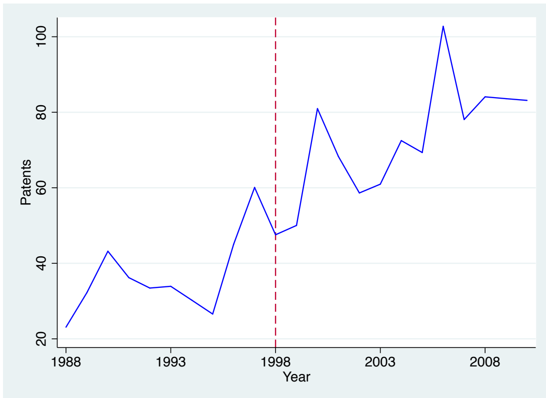
Australia: Patent grants (EPO)



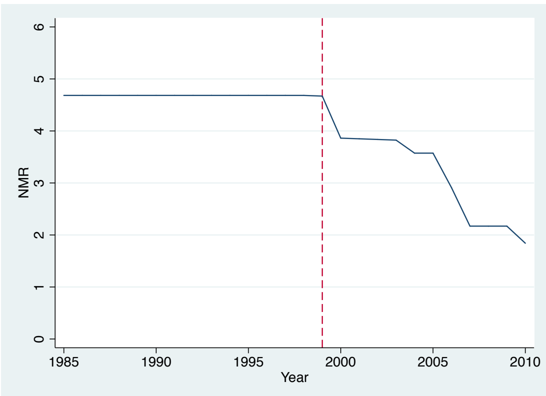
Austria: NMR



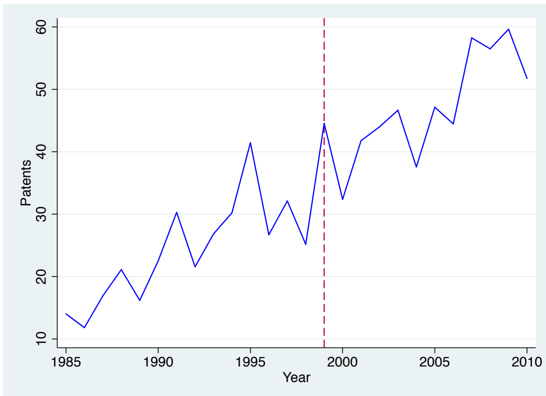
Austria: Patent grants (EPO)



Belgium: NMR

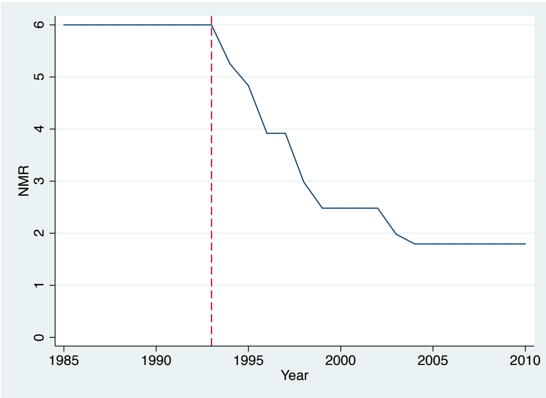


Belgium: Patent grants (EPO)

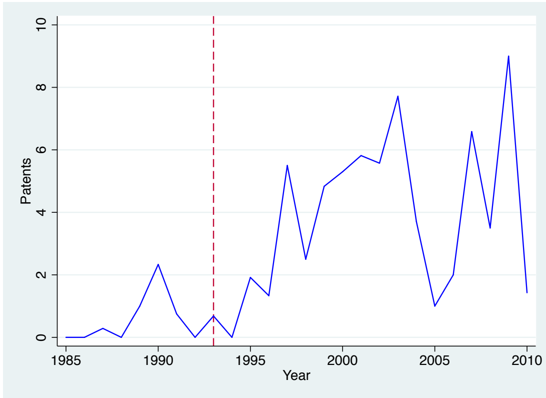


Source: OECD ETCR Data Regulation and OECD Patent Grants (Priority date, IPC H – Electricity).

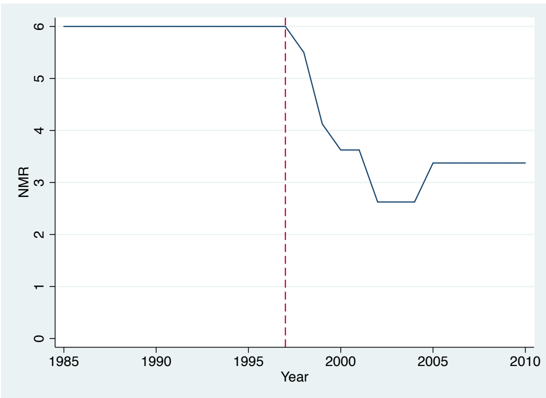
Brazil: NMR



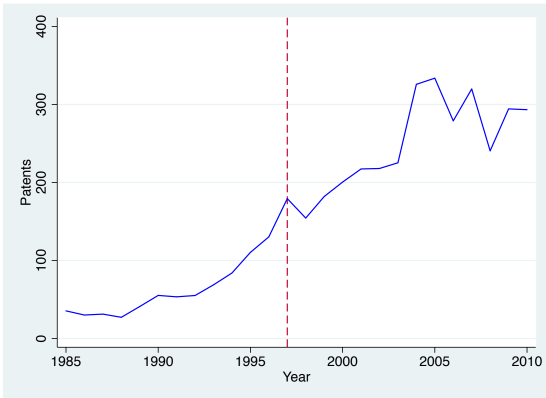
Brazil: Patent grants (EPO)



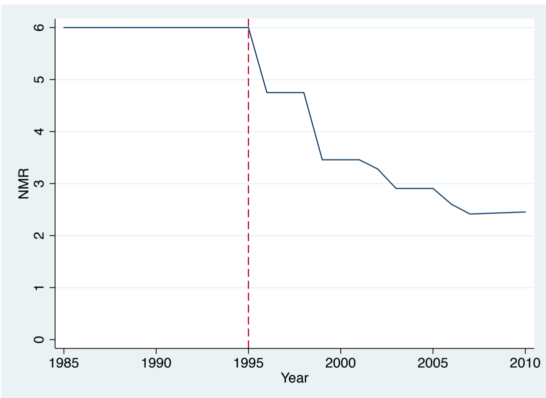
Canada: NMR



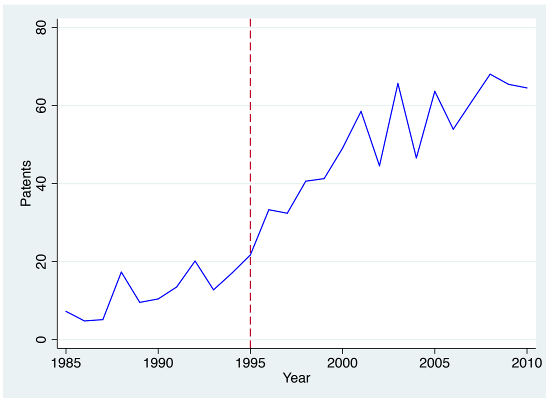
Canada: Patent grants (EPO)



Denmark: NMR

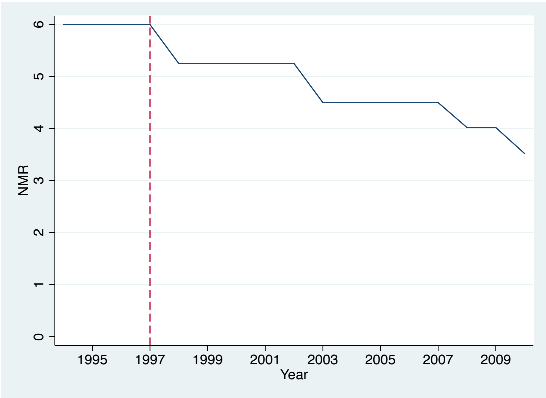


Denmark: Patent grants (EPO)

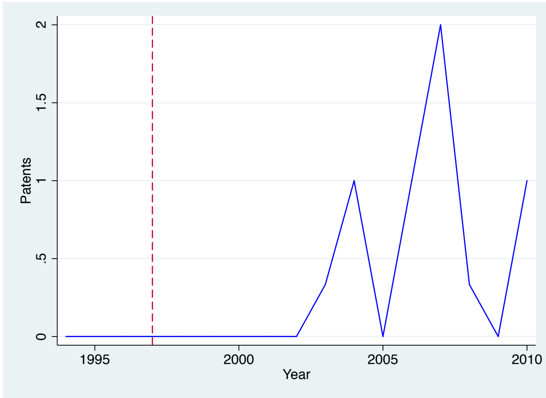


Source: OECD ETCR Data Regulation and OECD Patent Grants (Priority date, IPC H – Electricity).

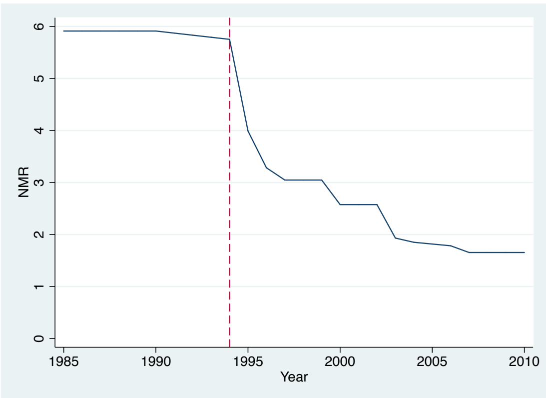
Estonia: NMR



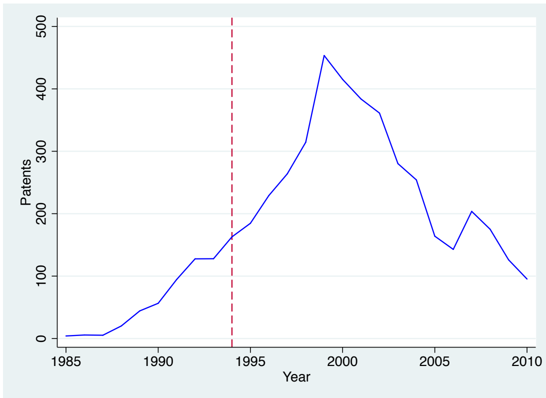
Estonia: Patent grants (EPO)



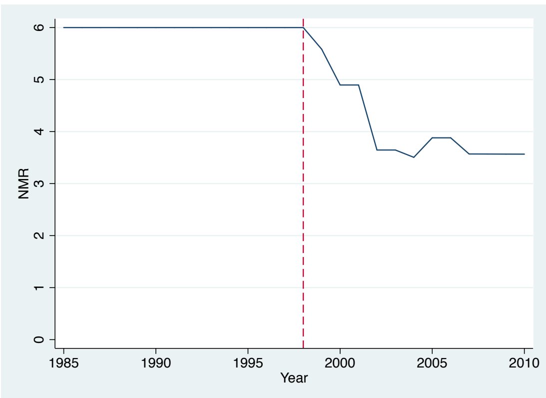
Finland: NMR



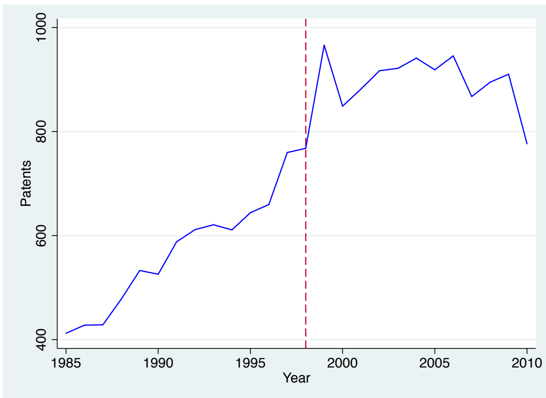
Finland: Patent grants (EPO)



France: NMR

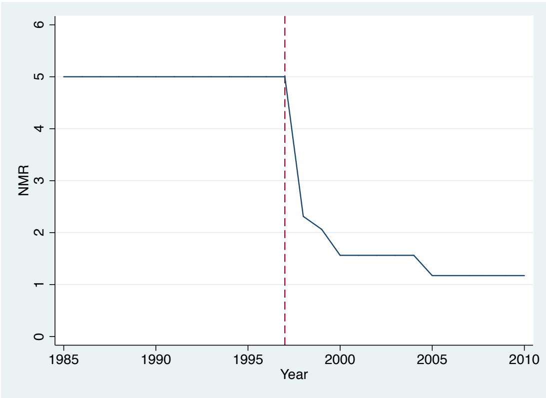


France: Patent grants (EPO)

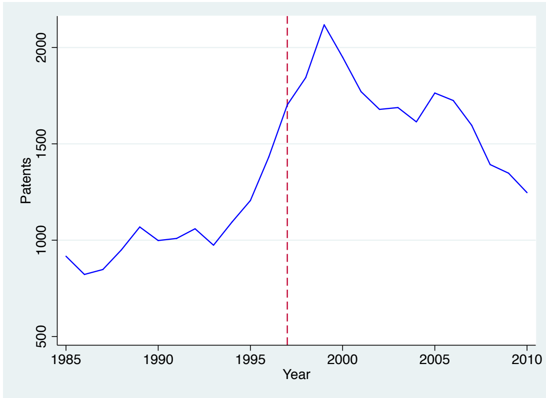


Source: OECD ETCR Data Regulation and OECD Patent Grants (Priority date, IPC H – Electricity).

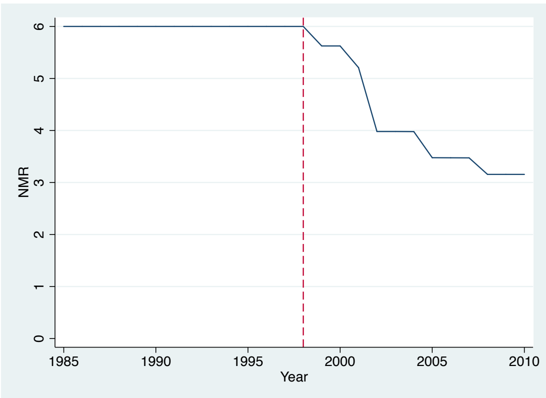
Germany: NMR



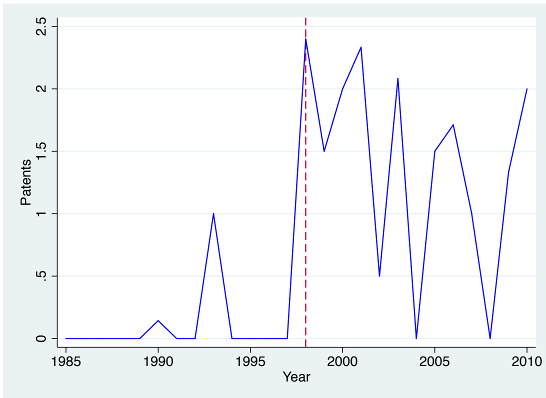
Germany: Patent grants (EPO)



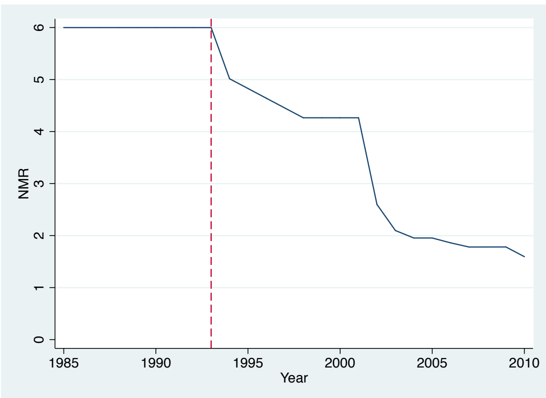
Greece: NMR



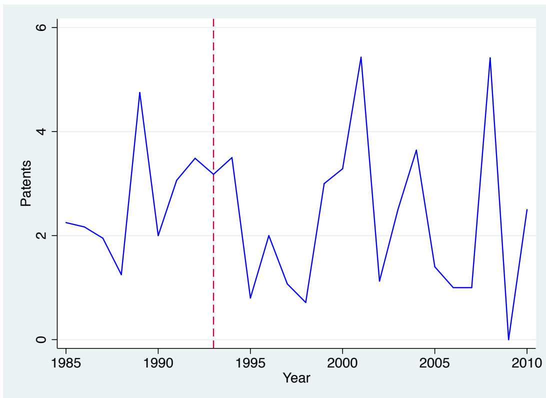
Greece: Patent grants (EPO)



Hungary: NMR

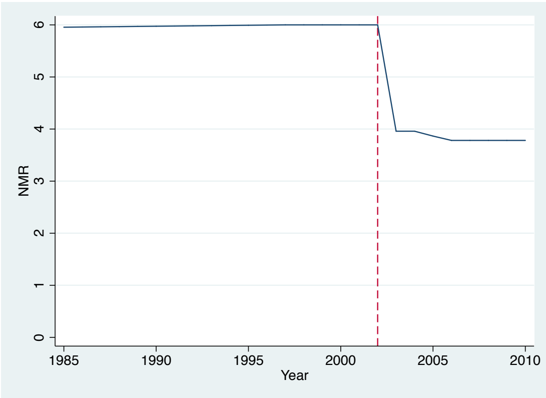


Hungary: Patent grants (EPO)

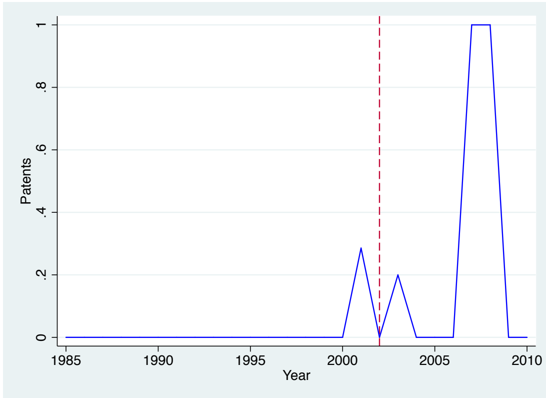


Source: OECD ETCR Data Regulation and OECD Patent Grants (Priority date, IPC H – Electricity).

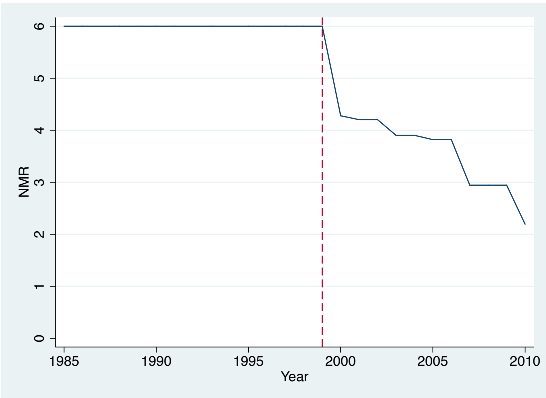
Iceland: NMR



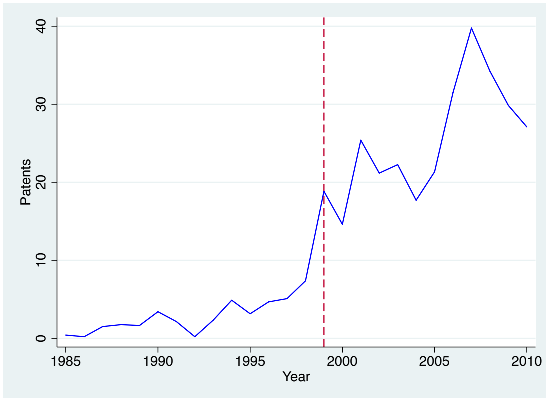
Iceland: Patent grants (EPO)



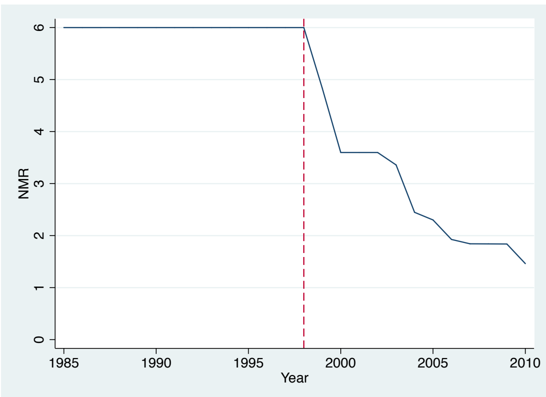
Ireland: NMR



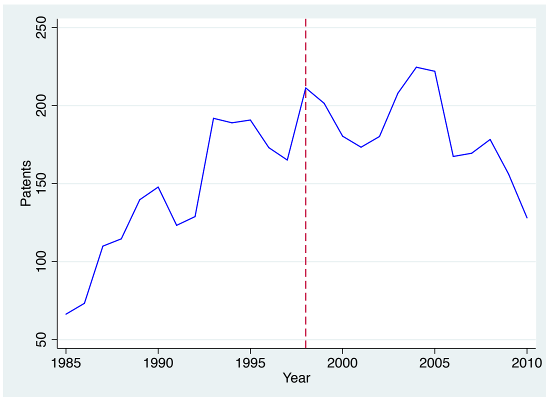
Ireland: Patent grants (EPO)



Italy: NMR

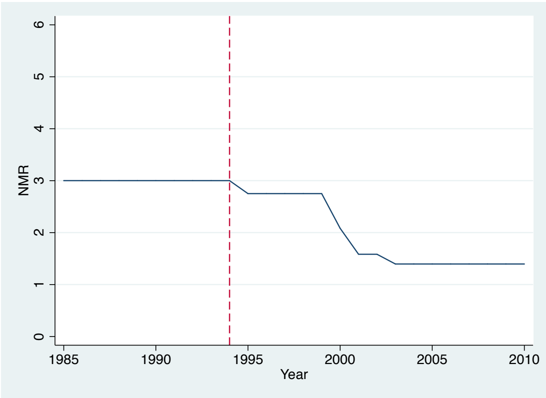


Italy: Patent grants (EPO)

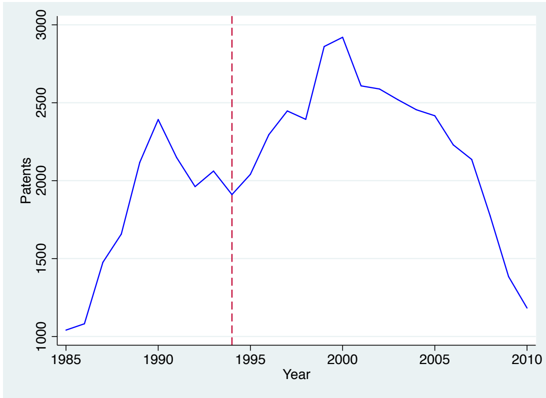


Source: OECD ETCR Data Regulation and OECD Patent Grants (Priority date, IPC H – Electricity).

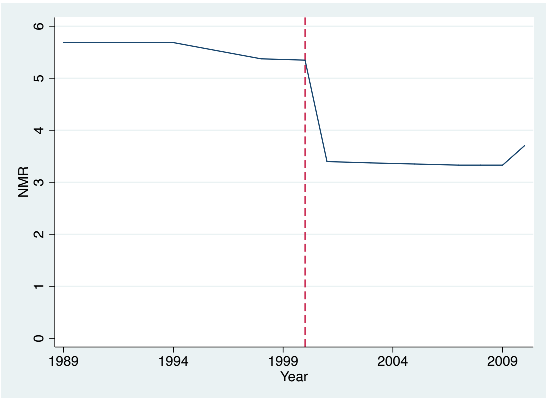
Japan: NMR



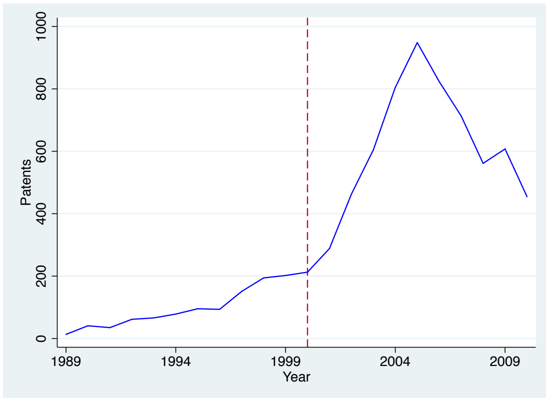
Japan: Patent grants (EPO)



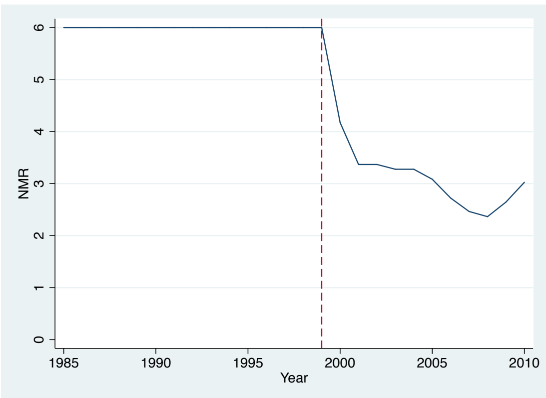
Korea, South: NMR



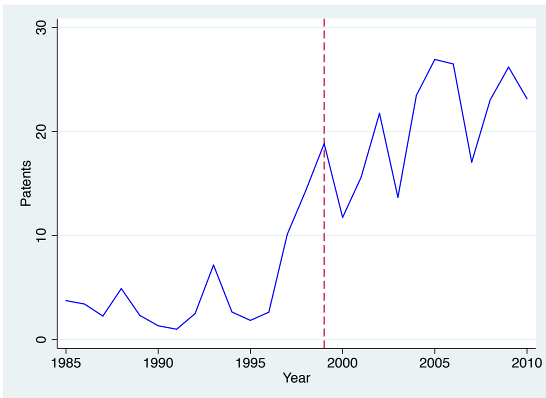
Korea, South: Patent grants (EPO)



Luxembourg: NMR

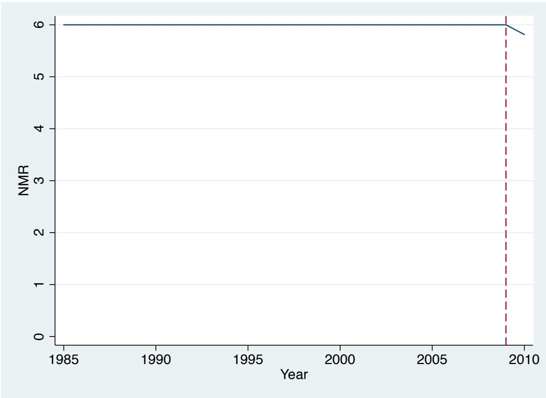


Luxembourg: Patent grants (EPO)

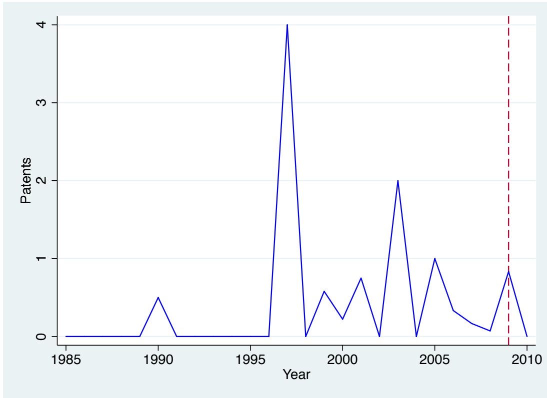


Source: OECD ETCR Data Regulation and OECD Patent Grants (Priority date, IPC H – Electricity).

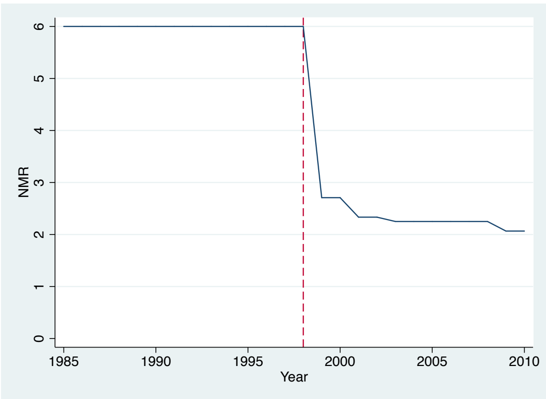
Mexico: NMR



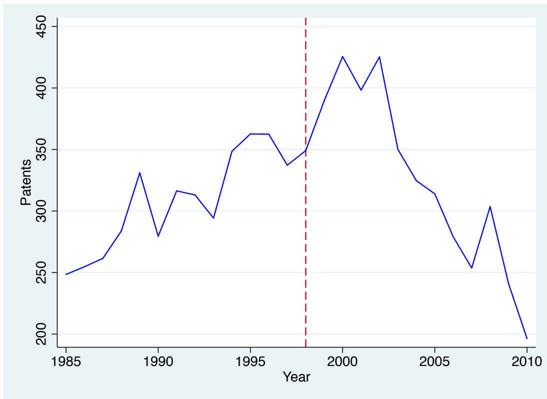
Mexico: Patent grants (EPO)



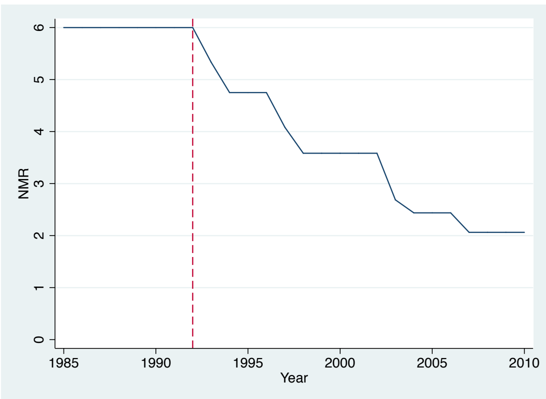
Netherlands: NMR



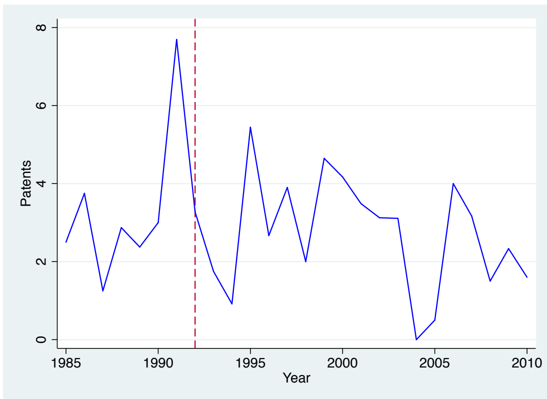
Netherlands: Patent grants (EPO)



New Zealand: NMR

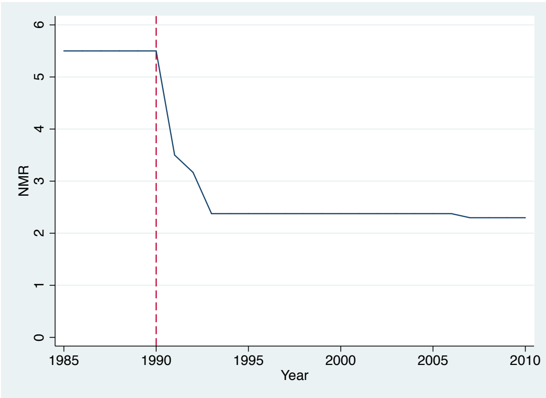


New Zealand: Patent grants (EPO)

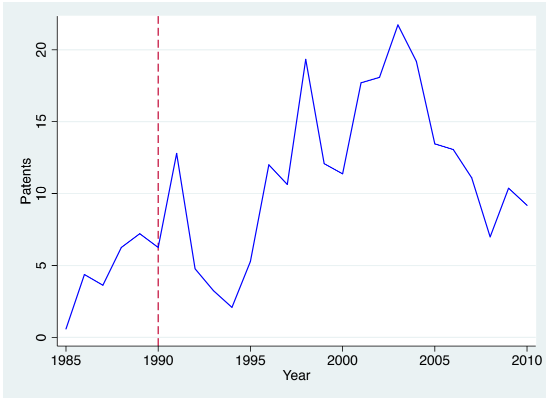


Source: OECD ETCR Data Regulation and OECD Patent Grants (Priority date, IPC H – Electricity).

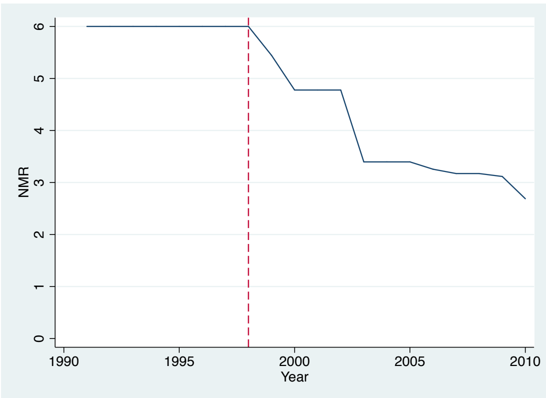
Norway: NMR



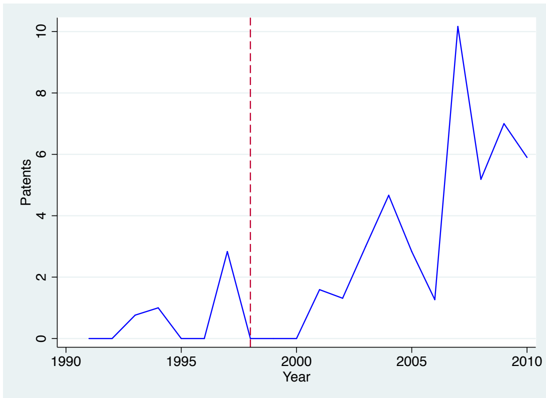
Norway: Patent grants (EPO)



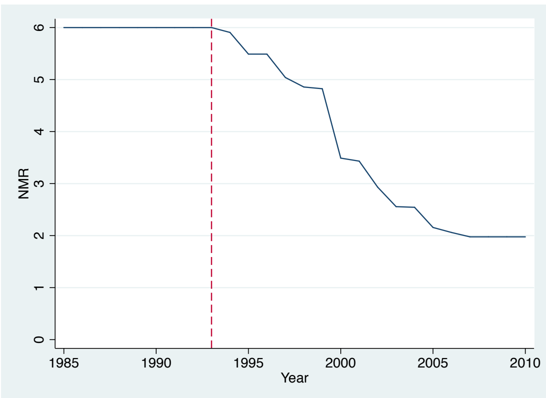
Poland: NMR



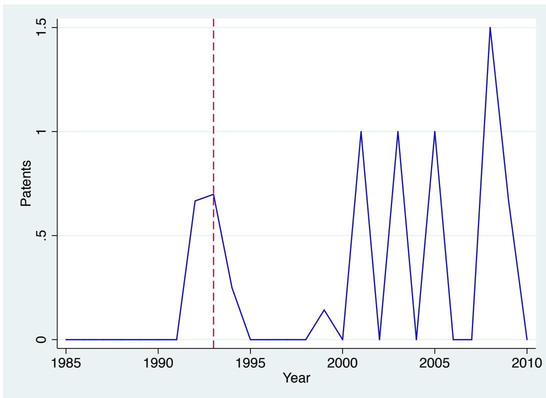
Poland: Patent grants (EPO)



Portugal: NMR

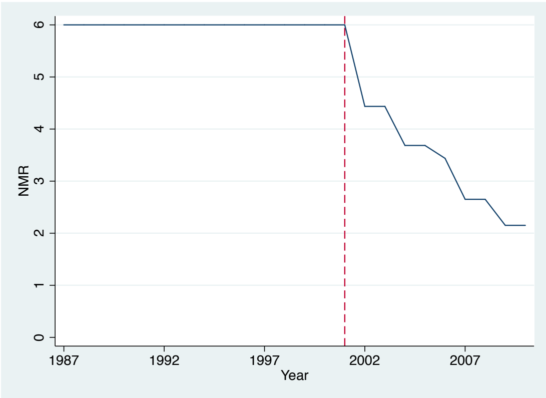


Portugal: Patent grants (EPO)

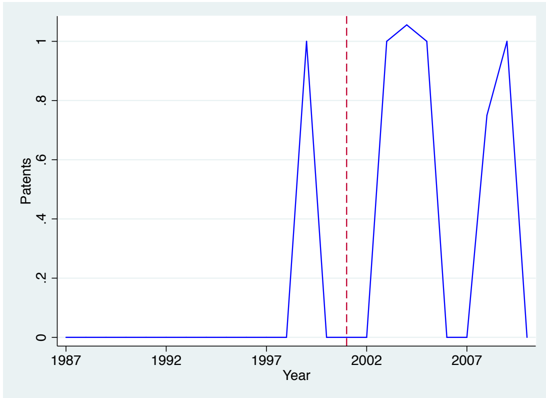


Source: OECD ETCR Data Regulation and OECD Patent Grants (Priority date, IPC H – Electricity).

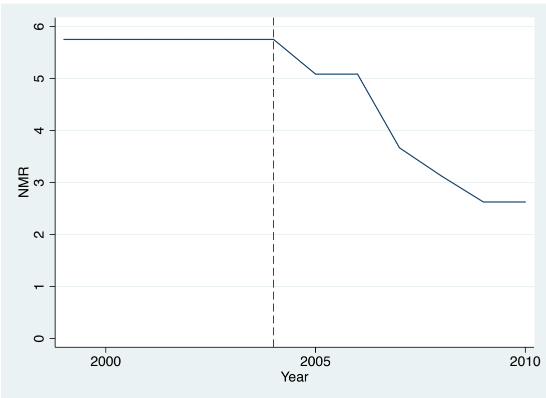
Slovak Republic: NMR



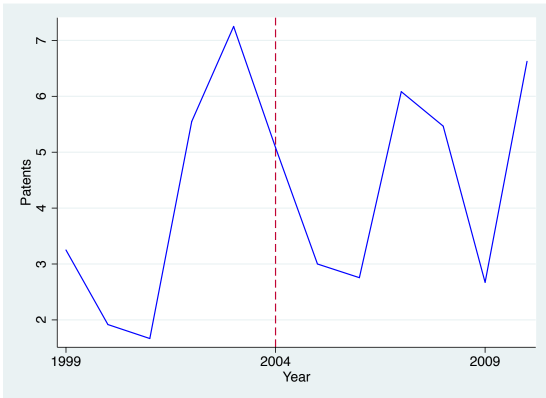
Slovak Republic: Patent grants (EPO)



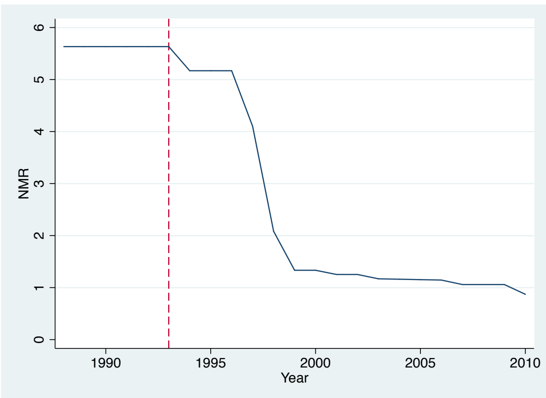
Slovenia: NMR



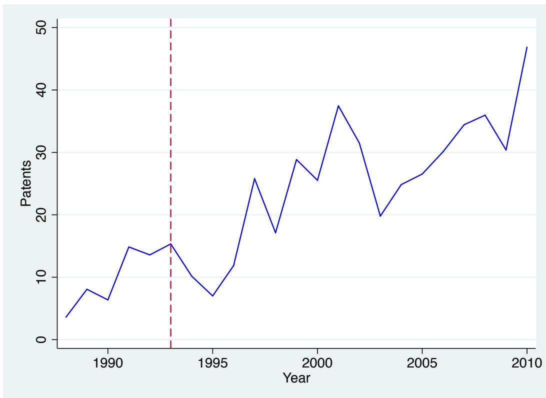
Slovenia: Patent grants (EPO)



Spain: NMR

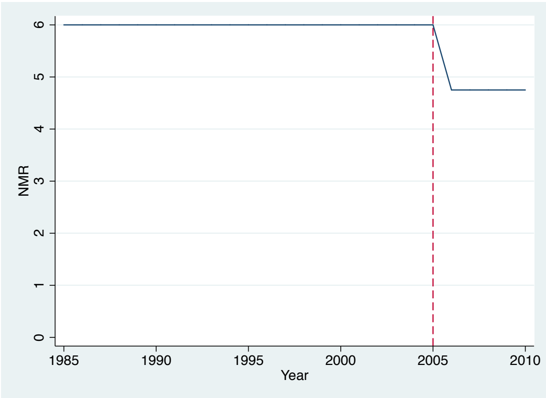


Spain: Patent grants (EPO)

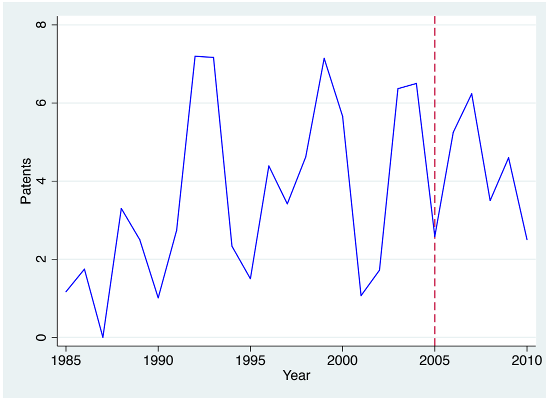


Source: OECD ETCR Data Regulation and OECD Patent Grants (Priority date, IPC H – Electricity).

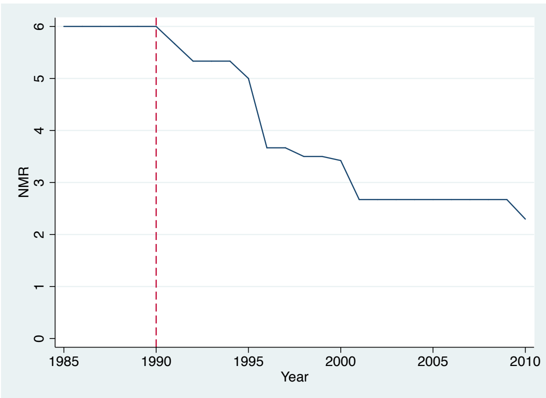
South Africa: NMR



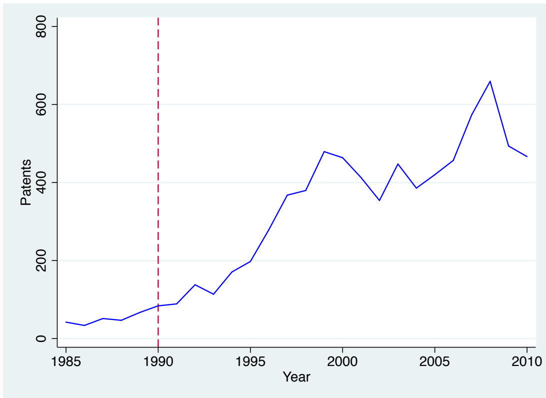
South Africa: Patent grants (EPO)



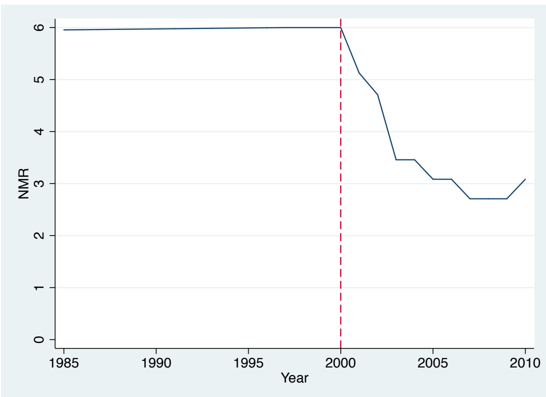
Sweden: NMR



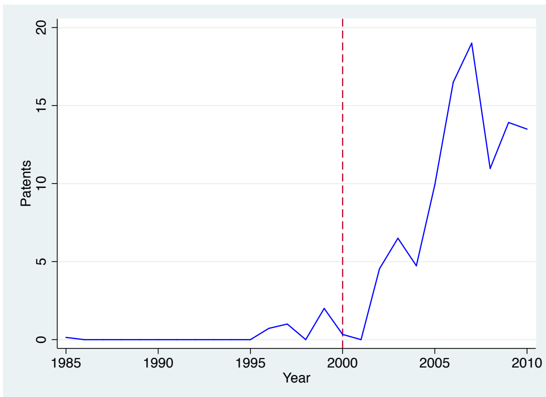
Sweden: Patent grants (EPO)



Turkey: NMR

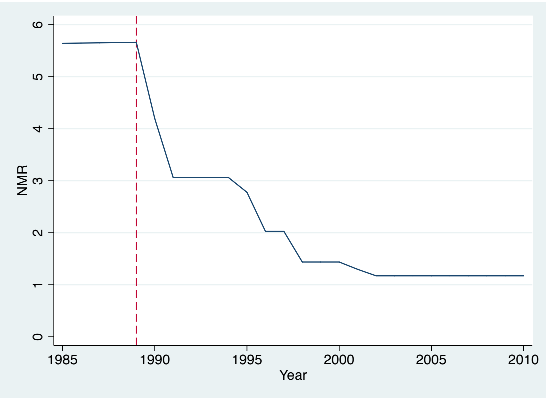


Turkey: Patent grants (EPO)

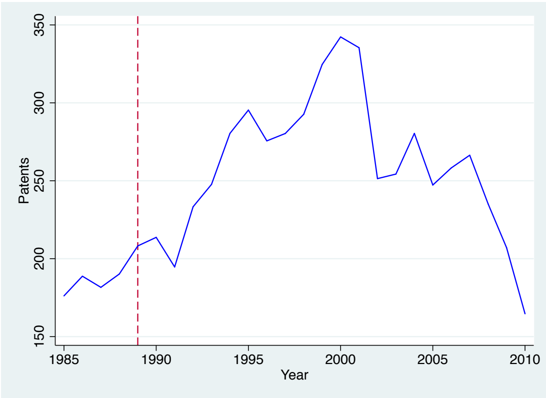


Source: OECD ETCR Data Regulation and OECD Patent Grants (Priority date, IPC H – Electricity).

United Kingdom: NMR

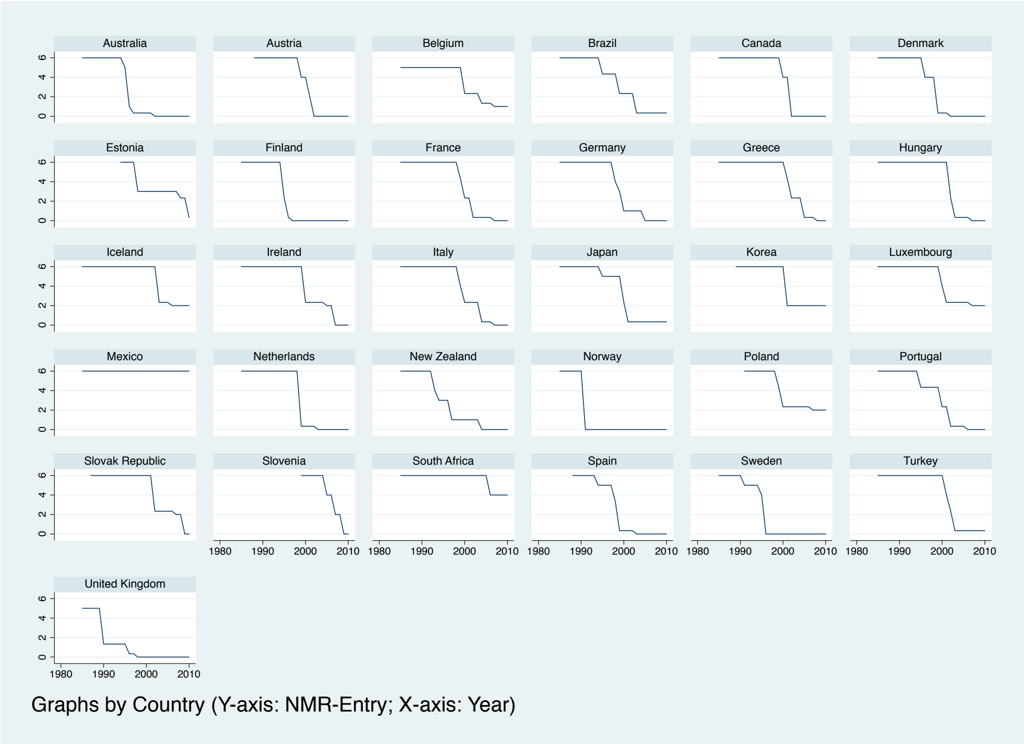


United Kingdom: Patent grants (EPO)



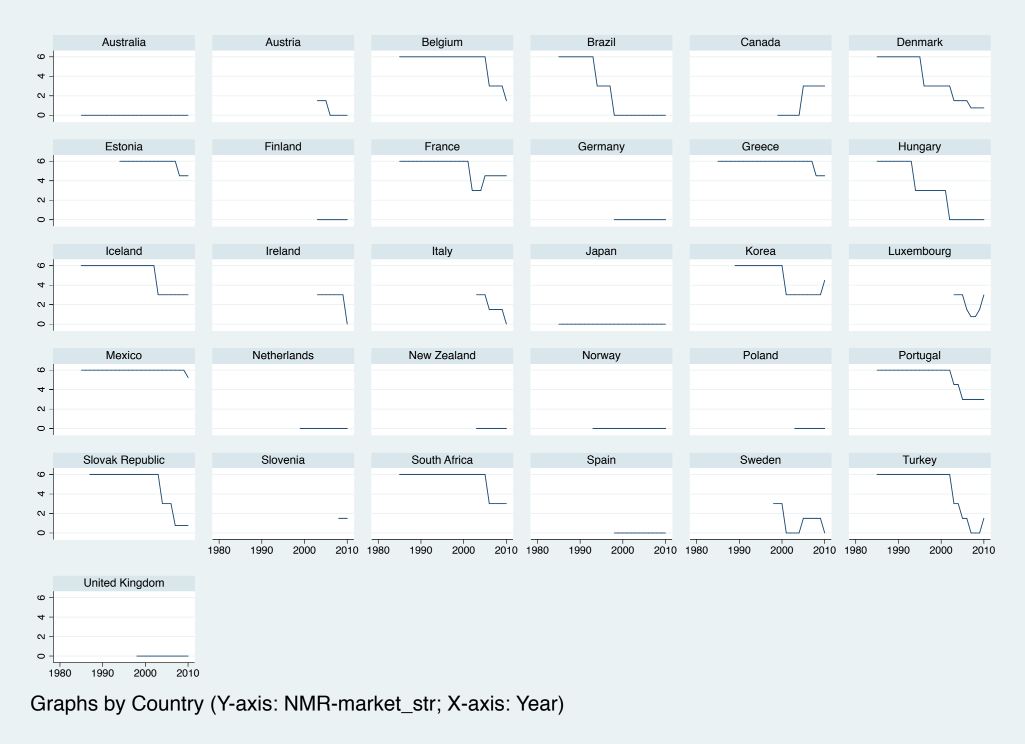
Source: OECD ETCR Data Regulation and OECD Patent Grants (Priority date, IPC H – Electricity).

Figure A1: *NMR-entry index in the electricity sector (vertical axis) over time (horizontal axis) by country*



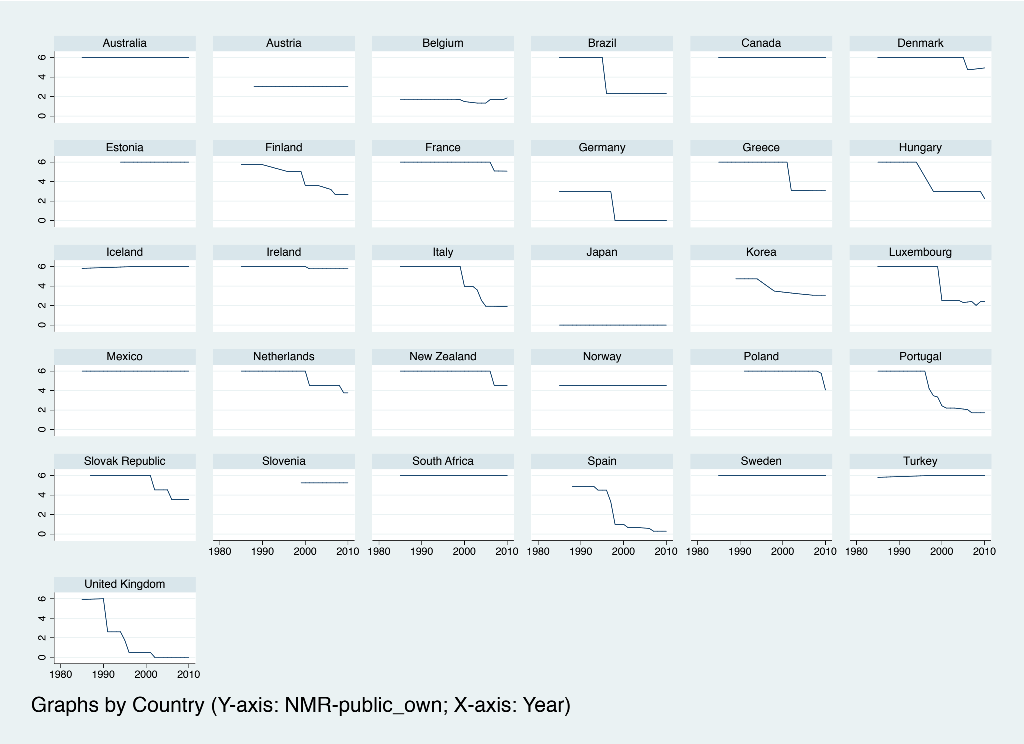
Source: OECD ETCR Data Regulation.

Figure A2: *NMR-market_str index in the electricity sector (vertical axis) over time (horizontal axis) by country*



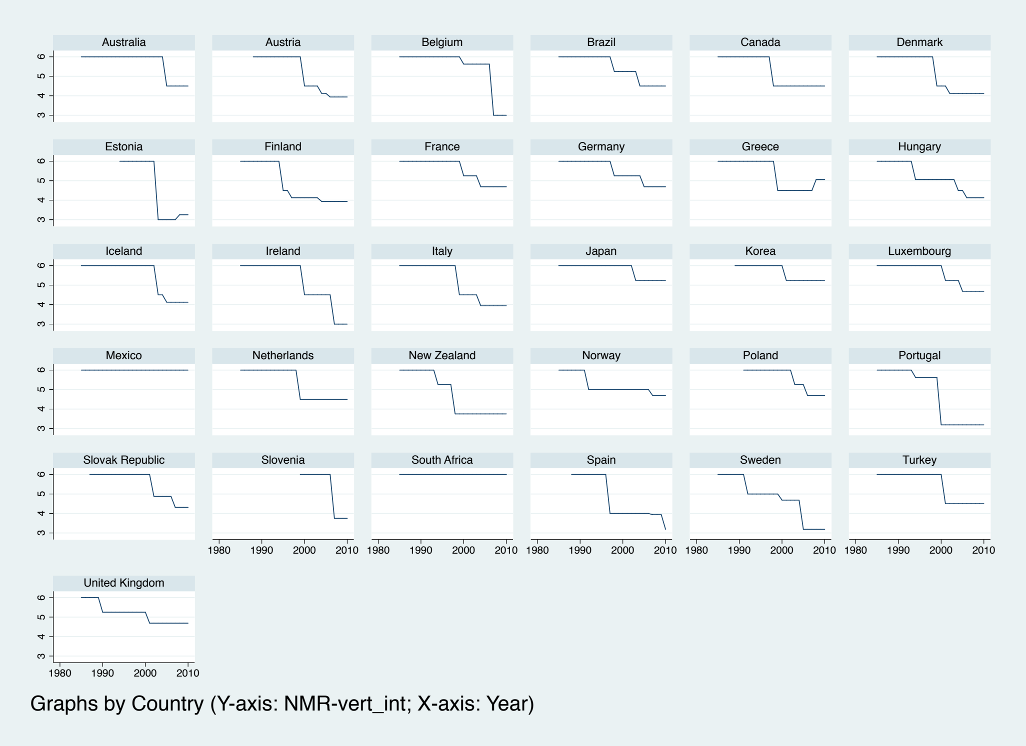
Source: OECD ETCR Data Regulation.

Figure A3: *NMR-public_own index in the electricity sector (vertical axis) over time (horizontal axis) by country*



Source: OECD ETCR Data Regulation.

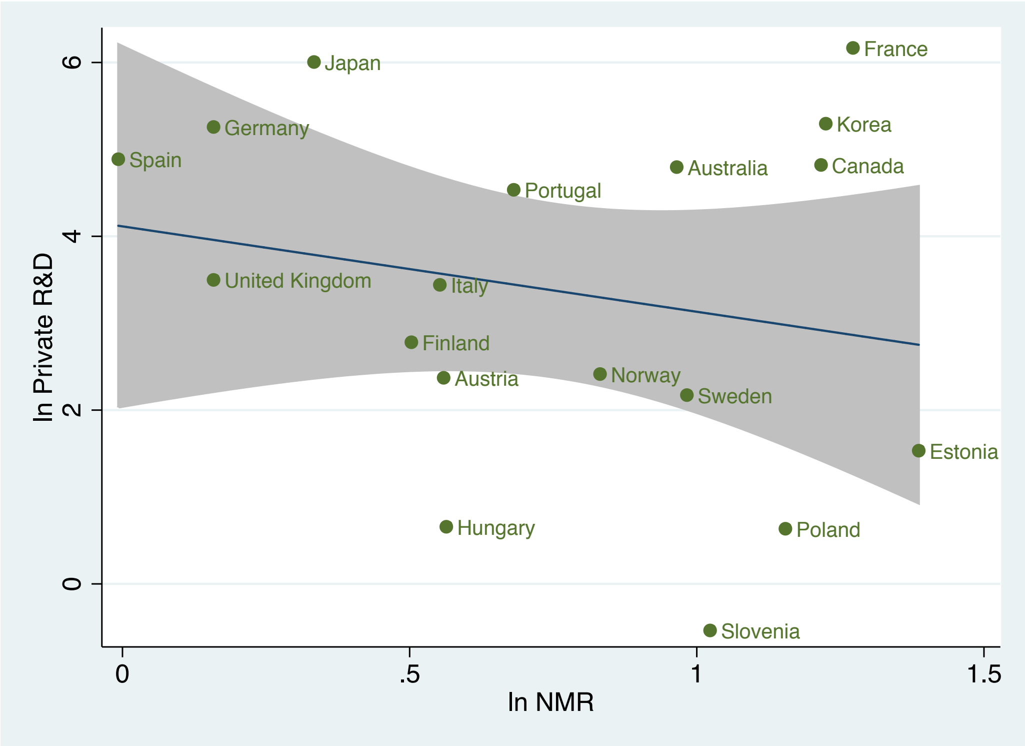
Figure A4: *NMR-vert_int index in the electricity sector (vertical axis) over time (horizontal axis) by country*



Source: OECD ETCR Data Regulation.

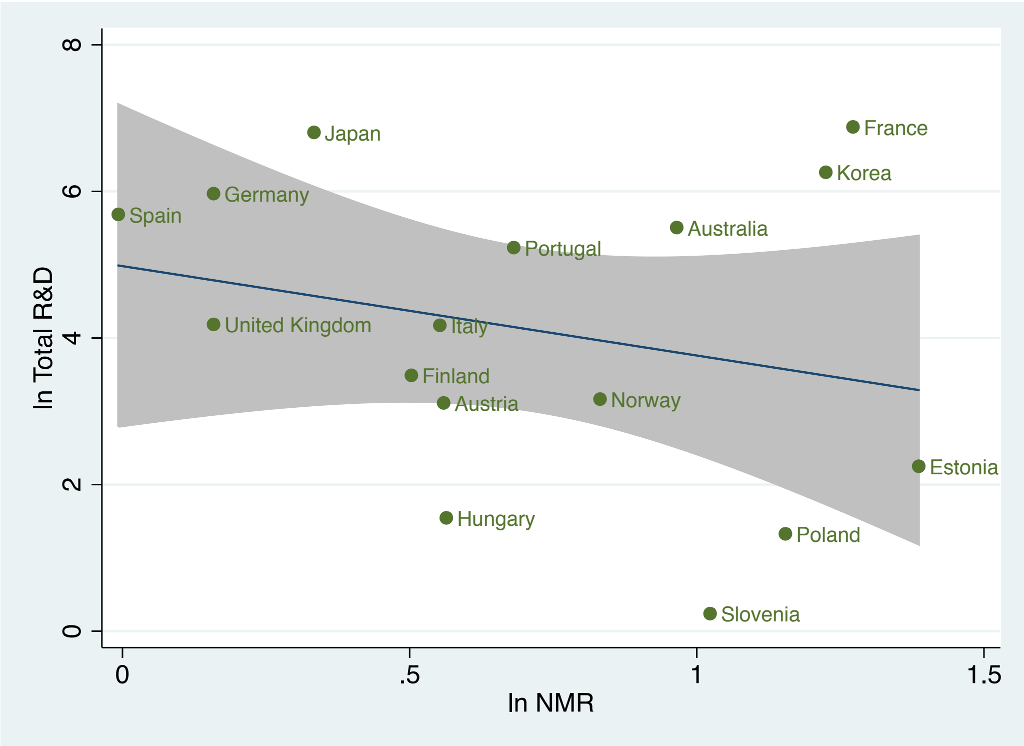
Appendix B

Figure B1: *Log-linear relationship between private R&D expenditure and NMR index in the electricity sector by country*



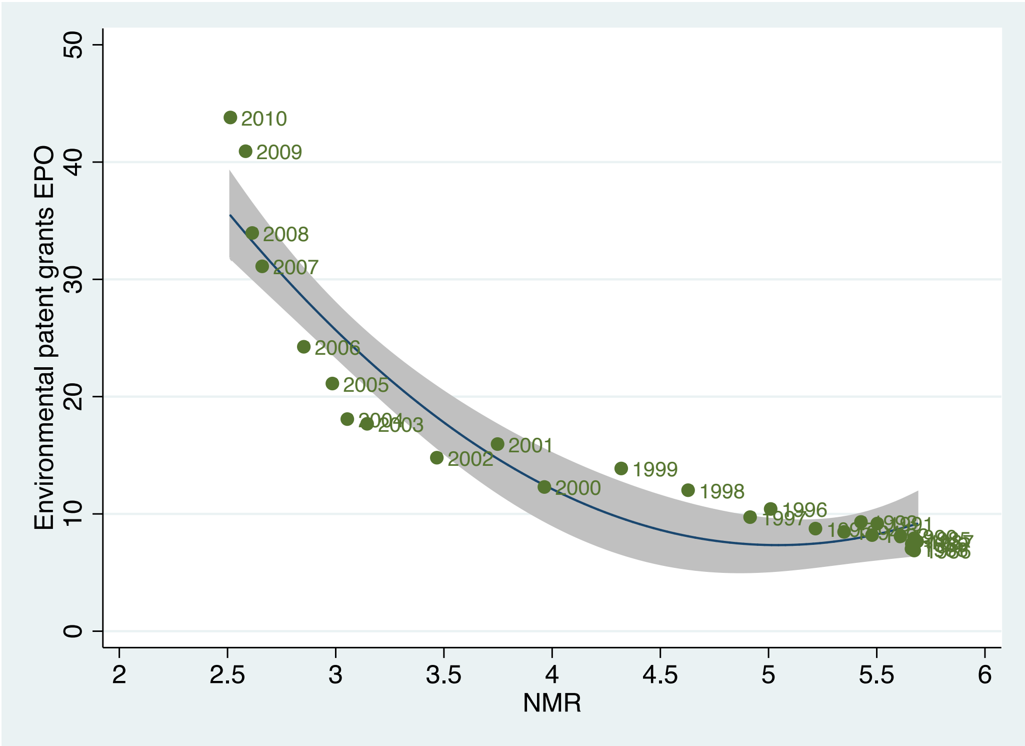
Source: OECD ETCR Data Regulation and OECD R&D data (Electricity, gas, steam and air conditioning supply; water collection, treatment and supply).

Figure B2: *Log-linear relationship between total R&D expenditure and NMR index in the electricity sector by country*



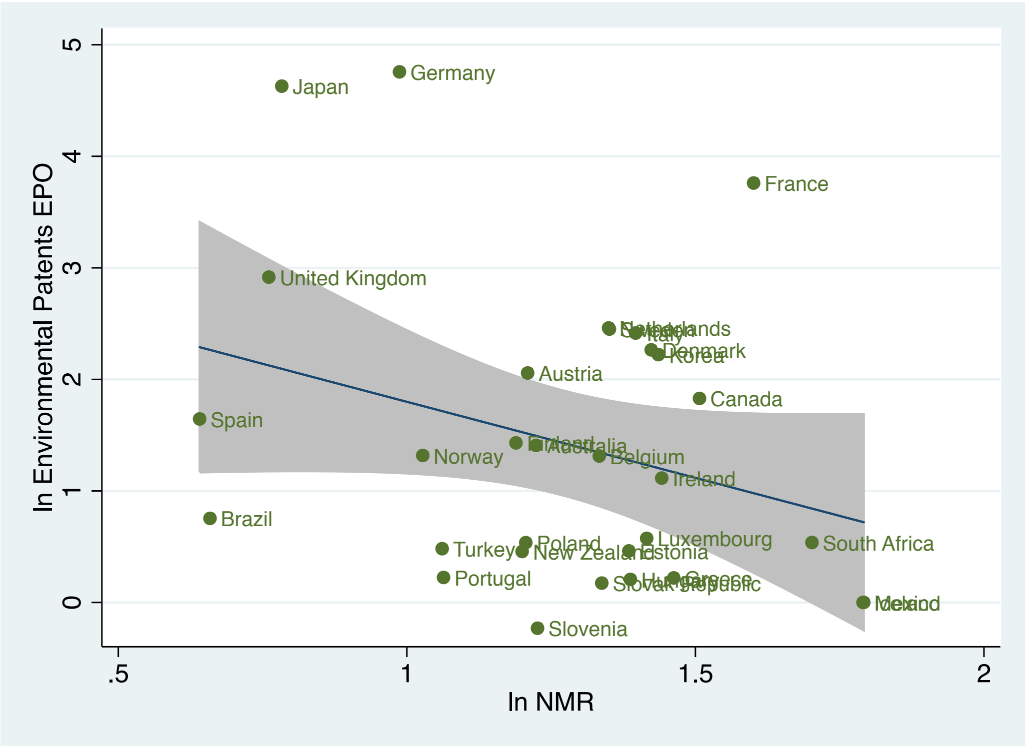
Source: OECD ETCR Data Regulation and OECD R&D data (Electricity, gas, steam and air conditioning supply; water collection, treatment and supply).

Figure B3: *Average environmental patent grants at EPO and level of NMR index in the electricity sector by year*



Source: OECD ETCR Data Regulation and OECD Patent Grants (Priority date, ENE – Climate change mitigation technologies related to energy generation, transmission or distribution).

Figure B4: *Log-linear relationship between environmental patent grants at EPO and NMR index in the electricity sector by country*



Source: OECD ETCR Data Regulation and OECD Patent Grants (Priority date, ENE – Climate change mitigation technologies related to energy generation, transmission or distribution).

Table B1: *Descriptive statistics on Environmental patents and R&D expenditure*

Variable	*obs*	*mean*	*SD*	*min*	*max*
env_patent grants at EPO	765	16.14	42.18	0	420.33
ln_env_patent grants at EPO	765	0.64	2.34	-2.30	6.04
private_RD	60	109.61	146.29	0	523.97
ln_private_RD	56	3.53	2.00	-2.26	6.26
total_RD	57	241.09	320.72	0	1081.88
ln_total_RD	53	4.27	2.03	-1.43	6.99

Source: OECD R&D data (Electricity, gas, steam and air conditioning supply; water collection, treatment and supply) and OECD Patent Grants (Priority date, ENE – Climate change mitigation technologies related to energy generation, transmission or distribution).

Table B2: *DID results – main estimates and by regulatory component*

	ln_env_patents_EPO				
	(1)	*(2)*	*(3)*	*(4)*	*(5)*
ln_NMR	-0.42				
	(0.75)				
PolicyChange	-0.25	3.58	-0.03	0.07	0.00
	(1.08)	(3.61)	(0.21)	(0.22)	(.)
$ln\_NMR \times PolicyChange$	0.20				
	(0.62)				
$ln\_NMR - entry$		1.92			
		(2.02)			
$ln\_NMR - entry \times PolicyChange$		-1.91			
		(2.03)			
$ln\_NMR - mark\_str$			-0.18*		
			(0.10)		
$ln\_NMR - mark\_str \times PolicyChange$			0.09		
			(0.08)		
$ln\_NMR - public$				-0.09	
				(0.17)	
$ln\_NMR - public \times PolicyChange$				0.04	
				(0.10)	
$ln\_NMR - vert\_int$					0.26
					(0.60)
$ln\_NMR - vert\_int \times PolicyChange$					0.10
					(0.10)
Clusters	31	31	31	31	31
Observations	765	765	547	765	765
R-squared	0.85	0.85	0.87	0.85	0.85

Notes: All specifications include the full set of controls. Standard errors are robust and clustered at the country level. *, **, and *** denote significance at the 10, 5, and 1 percentage level, respectively.