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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 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). This impact appears to be mainly due to the degree of market contestability. Finally, we 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.

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†Corresponding author. SKEMA Business School - Université Côte d'Azur, Avenue Willy Brandt, 59777 Euralille, France. E-mail: marianna.marino@skema.edu

‡IÉSEG School of Management (LEM-CNRS 9221), 3 rue de la Digue, 59000 Lille, France; IZA, Institute for the Study of Labor; and NoCeT, Norwegian Centre for Taxation, Norwegian School of Economics. Email: p.parrotta@ieseg.fr

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

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1 Introduction

Economic and technological reasons lie behind the fact that network industries like electricity (and gas, telecommunication and transport) have typically been tightly regulated. Regulation would concern structural aspects of the industry (e.g., entry conditions, ownership, vertical integration) and the performance of the operators (tariffs and quality standards) hence having an impact on profits and possibly biasing the firms' willingness to innovate (Vogelsang [55]).

Our objective is to assess, at an empirical level, if the drastic changes in product market regulation, induced by the intense liberalization process of the electricity industries across many OECD countries, have affected the incentives to innovate of the firms operating in the sector.

The liberalization wave that has reshaped 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. There are some recurrent elements characterizing this reform process: 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 opened 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.

These are typically considered 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 [4], Jamasb and Pollit [34]). However, as first observed by Dooley [21], these positive effects may be offset, in the long term, by possibly lower rates of innovation, also associated with the liberalization process. This may be a critical issue in a sector facing the challenge of producing more electricity in a more sustainable way (International Energy Agency [32]) and where innovation is not only

related to the development of new generation technologies but also, for example, to the implementation of distribution infrastructures combining new electricity and ICT technologies and to the evolution of electricity storage technologies.

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 and Griffith [3]). Furthermore, the empirical literature specifically examining the relationship between deregulation and innovation in the electricity sector, in terms of patenting activity or of R&D expenditure, offers mixed conclusions (see for example, Jamasb and Pollitt [35], Sanyal and Gosh [51] and Cambini et al. [16]).

To solve this puzzle we use a panel of 31 OECD countries and we progressively compare countries that have deregulated their electricity sector, with countries that have not done so yet, in order to single out the impact of the reform process on innovation.

Innovation is measured by the number of patents granted within the electricity sector by the European Patent Office (EPO hereafter). 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 [19]). 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 the average of four low-level components, each providing, respectively, a measure of (i) entry regulation, (ii) vertical integration of the market, (iii) market concentration, (iv) presence of the state as a shareholder.

Our contribution is three-fold. First, we rely on a difference-in-difference analysis to determine if, and to what extent, the changes in the legal and regulatory framework, associated with substantial reforms aiming at relaxing or dismantling regulations restricting efficiency-enhancing competition, had an impact on the number of patents

in the electricity sector, separately from any pre-existing trend. The various sudden drops in regulation intensity, observed over time, allow us to identify non-overlapping pre- and post-treatment periods and hence to exploit the different evolution of the reforms (which have been far from homogeneous across OECD countries). Exploiting the differences in the timing and in the extent of the deregulatory process is a key feature of our design, which presents a non-static assignment to the treatment group, and controls for business cycle fluctuations in addition to heterogeneity across countries. Moreover, since our treatment is a continuous variable (i.e., the log of the NMR index observed in the post-treatment period in each country) we can quantify more precisely the effect of a percentage decrease in the NMR index on the number of patents. In our more general specification 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 %.

Second, the fact that our policy variable is made of different components (entry, vertical unbundling, concentration, privatization) allows us to investigate separately the impact of different policy measures on innovation. We find that the reduction of entry barriers associated with the regulatory framework seems to be the main driver of a decrease in patenting activities, hence a greater degree of market contestability sensibly decreases firms' incentives to innovate.

Third, we look at role played by the regulatory environment in which the reforms take place in shaping the relationship between deregulation and innovation. 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 liberalization process has already been more or less extensive. In support of this result we also find descriptive evidence of an inverted U-shaped relationship between deregulation and innovation. Assuming that a lower level of the NMR index can be associated with more competition, these last two findings are remarkably consistent with those concerning the relationship between competition and innovation described by Aghion et al. [1].

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

2 Historical background

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) and from features that uniquely pertain to this sector (for example, the non-storability of electricity implies that 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.[1]

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 [8]) 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. [13]).

During the 80's, primarily in western countries, technological (Joskow [39]) and

[1] A clear description of the specificity of the electricity industry and of its functioning can be found, among others, in Steiner [53].

political (Green [28]) 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.[2] 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, and creating well designed wholesale markets where price is determined by supply and demand. The liberalization process has also often involved the privatization of state owned utilities that in some cases have also been asked to divest a part of their assets.

The first OECD country passing a reform going in this direction was the United 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 [48]). Australia and New Zealand later followed with similar reforms.[3]

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 [30], Newbery and Pollitt [47] and Newbery [46]). Moreover, the Electricity Pool of England and 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

[2] A detailed overview of the reform process in OECD countries is provided by Al-Sunaidy and Green [4].

[3] Reforms 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 [10]).

(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) 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, 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.[4]

Competitive electricity markets face now a considerable challenge: there is a growing consensus about the fact that "environmentally beneficial electrification" (i.e., a progressive electrification of energy end uses such as space heating, water heating, and transportation) is needed to reach substantial emission reduction goals for carbon dioxide (Dennis et al., [20]).[5]

This implies a significant increase in the demand for electricity and a greater generation capacity coming from renewable sources. Utilities have typically managed to provide a reliable electricity grid system by operating supply-side resources (e.g., coal, nuclear, and natural gas) that would allow them to meet, at any moment, the energy demand consumers placed on the system. However, grid operators can exercise only a limited control over renewable energy resources: windmills and PV panels work in particular periods when the weather is favorable, not necessarily when the demand is at its peak. This fact not only hinders the profitability of renewable resources but also the feasibility of a further increase of their generation capacity.

As also stressed by the European Commission [25] innovation is the key for a further electrification of the economy. Apart from technologies directly meant to further develop the generation capacity and efficiency of renewable sources, the two technologies

[4]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 [22] and 2003 [24] were putting forward an institutional setting aimed at the creation of a European competitive electricity market. 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 [23]).

[5]According to projections of the International Energy Agency [33] for OECD countries, the average CO2 intensity of electricity needs to fall from 411 grams per kilowatt hour (g/kWh) in 2015 to 15 g/kWh by 2050 to achieve the goal of limiting the global increase in temperatures to 2°C.

that could profoundly change the energy market (Green [29]) are electricity storage at a grid scale (that could have a crucial role of balancing variability of wind and solar power) and the implementation of a *smart* grid, capable to better control the load side of the equation. In particular, a smart grid would yield an improved network efficiency, by affecting demand responses, relying more and more on ICT and by optimally managing devices that possess energy storage capabilities (e.g., electric water heaters, electric vehicles).

Our objective is to assess whether, and to what extent, the liberalization process of the electricity sector has created an environment that can support the industry in facing the challenges we have just mentioned.

3 Empirical and theoretical background

The greater availability of data (across countries) has led to an increasing interest towards the economic effects of regulation in general. For example, it has been shown that regulatory restrictions might have detrimental effects on infrastructural investment (Alesina et al. [5]) and employment (Bertrand and Kramartz [12]) while increasing prices (Martin et al. [42]) in the regulated sectors.[6] Bassanini and Ernst [9] find a negative correlation between the intensity of product market regulation and the intensity of R&D expenditure in 18 OECD countries.

Studies aiming at assessing the impact of liberalization in the electricity industry have initially focused on prices and cost efficiency often attaining mixed conclusions (Steiner [53], Hattori and Tsutsui [31], Fiorio, Florio and Doronzo [27], Fiorio and Florio [26]).

One of the first attempts to provide some evidence of the relationship between the liberalization process and innovation, specifically for the electricity industry, is the paper by Dooley [21] that describes reductions in energy R&D investments occurring in several advanced countries following the deregulation of their respective energy sec-

[6]Barone and Cingano [11] also look at the effects of regulation on downstream manufacturing activities. Lower service regulation is associated with faster value added, productivity and export growth in manufacturing industries using services more intensively.

tors. 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 a long-term negative impact on national energy sectors, the whole economies, and environmental well-being. This view is reinforced by Jasmab and Pollit [35] and Sterlacchini [54]: 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.[7] These papers just provide descriptive evidence of a trend so that it is not possible to infer the actual impact of the reforms on innovation in the electricity industry.

To the best of our knowledge very few studies attempt to identify a more precise empirical relationship between innovation and intensity of regulation. A recent example is given by Cambini et al. [16]. This study matches industry-level data (for the electricity sector) on R&D budgets and EPO applications with the NMR index (or its components) to evaluate the link between liberalization and the propensity to innovate. Deploying a fixed-effects panel analysis, the study provides evidence of an increase in the aggregated electricity R&D and patenting activities following market deregulation. In particular, policies aimed at a reduction of vertical integration are positively related to 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 seem to mostly affect R&D expenditures.[8] Kim et al. [41] also use the components of the NMR index as policy variables (at a lower level of aggregation than Cambini et al. [16]), and examine their association with R&D expenditure (excluding firms not dedicated to electric power production) finding opposite results. Sanyal and Ghosh [51] examine the role of deregulation in affecting the trends of quantity and quality of innovation, in

[7] Jasmab and Pollit [36] also describe a decrease of the patenting activity in the UK electricity sector.

[8] Relying on data from the telecommunication industry, Prieger [50] finds a similar relationship between regulation intensity and service innovations introduced by telecommunication providers in US.

the electric equipment manufacturing sector, in the Unites States. Using patents as a metric for innovation, they find that the 1992 Energy Policy Act had a specific role in the decline of patents granted to electricity equipment manufacturers. 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.

At a theoretical level, the debate on the relationship between innovation and competition goes back to Schumpeter who famously argued that the prospect of an increased market power, and large scale, foster innovation (Schumpeter [52]). By contrast, Arrow [7] 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 suggested by Motta, [43] 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".

An important stream of the theoretical and empirical literature on competition and innovation (nicely summarized by Aghion and Griffith [3]) suggests indeed that there is a non-monotonic relationship between innovation and product market competition. Some of these insights can also be used to better understand the forces at stake within the electricity industry.

The reform process has most likely increased the overall level of competition in the electricity markets. The higher is the level of competition, the lower may be the profit margins, both at the generation and at the distribution level, where former incumbents would potentially face new competitors. In a Schumpeterian perspective, this "pure competition effect" might directly decrease the incumbents' willingness to innovate. Moreover, the profits and the willingness to innovate of the upstream equipment producers, who were selling their innovation to downstream utilities, may be negatively impacted by a lower demand coming from the incumbent utilities.

An increased product market competition might also foster innovation because of the so called "escaping competition" effect (Aghion et al. [1], [2]). In scarcely competitive environments, an increase in competition might increase a firm's post-innovation

rent by more than it decreases its pre-innovation rent. To put it differently, a greater competition might encourage innovation because it could help a firm to increase the competitive gap with its competitors. Following this logic, both the incumbent electricity suppliers, and the equipment manufacturers, might be pushed to innovate more in order to become a technological leader when faced with more competitive market conditions.

The prediction of Aghion et al. [1] is that the the latter effect tends to dominate the former one for low initial levels of competition, the opposite happens the more competition becomes intense, so that the relationship between competition and innovation is an inverted U-shape.

Moreover, Sanyal and Gosh [51] suggest that a third force, the "appropriation effect", should also be considered for the electricity industry, where a relevant part of innovation is produced by equipment manufacturers. The entry of new firms in the sector, at the generation and distribution level, provides the equipment manufacturers with an increased demand for their products but also with a higher bargaining power vis-a-vis the incumbent firms. This should boost their profits and their willingness to innovate up to the point where both demand from new entrants and bargaining power are eroded by an excessive level of competition in the industry.

To sum up, three countervailing forces are at stake so it is not clear, from a theoretical point of view, what would be the net effect of a decrease in product market regulation on innovation in the electricity industry. In what follows we are able to quantify such a net effect in terms of the variation of patent grants due to a change in the NMR index following a reform.

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, 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.[9] We retrieve our policy variable, the NMR index for 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[10] for the 1985-2010 period, yielding 765 observations (see *Table 1*). Selection of time period and 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.

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.[11] 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

[9] 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.

[10] 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.

[11] 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).

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 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 [34], 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.

Our policy variable, the NMR index, is part of a set of time-varying indicators that has been built by the OECD to provide a measure of industrial regulations that restrain efficiency-enhancing competition in several regulated sectors.[12] 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. As such, the NMR index is well suited to describe the speed and intensity of liberalization. Any other policy goal, like environmental sustainability, is not taken into account. We use the NMR index for the electricity sector. The construction of the index involves three steps.[13]

First, the information gathered, coming from the answers to questionnaires sent by the OECD to experts on a yearly basis in each country,[14] is coded into separate

[12]More details on the NMR indices can be found in Conway and Nicoletti [19], 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. [18]).

[13]The NMR indices of the other sectors are built in a similar way.

[14]The information is objective (as opposed to survey-based) since it is based on specific measurement criteria related to regulations and markets

quantitative scores, concerning different aspects of regulation, that are increasing in restrictions to competition.

Second, for each country, these scores are aggregated into four sub-indicators that cover specific areas of regulation. The four different components measure 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). Hence, each component provides a measure of a different kind of restriction to competition within the sector.

Third, for each country, these components are aggregated at the industry level taking simple averages, hence also the aggregate index can take value between 0 and 6.[15] To sum up, 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 for potential entrants to access the industry and the possibility of supplier choice 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 in the electricity sector for most OECD countries. The Entry Regulation component hence provides, as far as regulation is concerned, an indirect measure of market contestability.

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.

[15] As mentioned also in Conway and Nicoletti [19] 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. 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.

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. An important element of many reforms has been the separation of 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.[16]

The fourth component, *Market Structure* (NMR-market_str), provides a measure of the degree of concentration (and hence, indirectly, of competitiveness) in the various segments of the whole market by measuring the 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 (Bourls et al., [15]). Bourls et al. [14] 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 in affecting competition.

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 that can be associated with a reform, 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 typically more intense regulatory regime

[16] 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 [40]; Newbery [45]), 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 [34]).

(controls or untreated), before and after the treatment occurs. The empirical model, estimated by OLS, takes the following form:

$$ln_patents_{it} = \alpha + \beta ln_NMR_{it} + \gamma PolicyChange_{it} + \tag{1}$$
$$\delta ln_NMR_{it} \times PolicyChange_{it} + \eta_i + \theta_t + X'_{it}\omega + \varepsilon_{it},$$

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 a drop in regulation (i.e., a reform) occurred or not in a given country. More precisely, 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.[17] 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,

[17] 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%.

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 [6], and Cameron and Trivedi [17]). 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

Information on sample composition and policy reforms are reported in *Table 1*, which shows, for each country, the related number of observations, time horizon and year when the policy change occurs (i.e., when we observe a sudden drop in the NMR index). We are able to associate a change in the legal framework (sixth column in *Table 1*) with each of the policy changes we consider. *Table 1* also includes the average, the minimum and the maximum value of both NMR index and number of patent grants at the EPO over the observational period. *Table 1*, combined with *Figure 1* and the graphs collected in the Appendix A, provide detailed information on the structure of the sample, the evolution of the NMR index over time in each country, 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 evolution over time 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. Thus, examining separately the change over time of each

component gives an interesting account of how, and to what extent, national markets have changed as compared to when they were fully regulated.

[*Table 1 and Figure 1 about here*]

Figure 2 shows 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.

We find descriptive evidence of an inverted U-shaped relationship between the number of patents and the NMR index by collapsing our sample by observational year, as shown in *Figure 3*. On the one hand, a decrease in the NMR index can be associated with an increase in patents, roughly before the median policy change year (i.e., 1999, the average policy change is 1998) and for values of the NMR index above 4 (fairly close to the average value 4,3). This pattern is inverted in the following years or for lower values of the NMR index. Quite interestingly, this is true in spite of the spike in environmental patent 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 [49]).

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 and 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 NMR index (*Figures B4*). This is in line with the findings of Cambini et al. [16].

[*Figure 4 about here*]

Table 2 reports observations (obs), mean and standard deviation (SD) for *patents*, *GDP growth rate*, *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 vertical integration (NMR-vert_int) and public ownership (NMR-public_own) 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 %.

[*Tables 2 about here*]

5 Results

Table 3 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 a further decrease in the NMR index, following a sharp reduction in the intensity of regulation (i.e., a reform), 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 %.

It is worth stressing that the parameter of interest can be estimated as an elasticity because of the non-standard specification of our DID approach. Indeed, the treatment variable is defined here as the logarithm of the NMR index observed in the post-treatment period rather than a simple interaction between two dichotomous variables (i.e., treatment and post-treatment dummies). This allows us to quantify more precisely the expected change in the number of patent grants due to a further change in the NMR index after a reform. The number so obtained may be interpreted as the net effect of the three countervailing forces discussed above (section 3), i.e., the pure competition effect, the escaping competition effect, and appropriation effect. An alternative way to quantify our main finding is that, for a country with an average regulation intensity, a 10 % reduction in NMR (i.e., a reduction of about 0.43) decreases patent grants at EPO by about 36 units.

We have also evaluated 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 but rather to targeted policies

as shown by Johnstone et al. [38].

[*Table 3 about here*]

We also try to disentangle the role specifically played by changes occurring in each of the 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 4* 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 in the firms' incentive to innovate after a drastic reform has occurred. Indeed, when we consider the treatment variable, $ln_NMR - entry \times PolicyChange$ we find that a 1% drop in the variable NMR-Entry, in the post-reform period, decreases patent grants considerably: the associated elasticity is 3.48. Examining the results for the Market Structure and Public Ownership components, we observe that the corresponding treatment variables ($ln_NMR - market_str \times PolicyChange$ and $ln_NMR - public_own \times PolicyChange$) both carry a similar and significant coefficient of about 0.25. This elasticity is still positive but considerably smaller (about 14 times) than the one associated with Entry Regulation. This shows the different relevance of distinct 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 4 about here*]

Furthermore, we provide 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. We divide the sample in two complementary subsets, countries whose average NMR index is respectively below or above the threshold value of 4, then we implement our DID model on each sub-sample, separately. Although the choice of

this threshold value is somehow arbitrary, it appears to be fairly close to the sample average of the NMR index and to the turning point of the regulation-innovation pattern described in *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 5*, 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 in *Table 3*). However, quite interestingly, the estimates for the "above threshold" sub-sample show opposite signs.

In particular, the fact that the coefficient associated with our treatment variable is positive for the "below-threshold" sub-sample and negative for the "above threshold" sub-sample seems to point out that a further decrease in product market regulation, after a reform, may have opposite effects on patenting activity depending on whether one considers countries that have experienced a relatively more intense liberalization process ("below-threshold" sub-sample) or a relatively less intense one ("above threshold" sub-sample). Specifically, we find that a 1 % reduction in the NMR index, in the post-reform period, decreases the number of patents by 2.37 % for countries belonging to the 'below- threshold' sub-sample, whereas a similar reduction in the treatment variable increases the number of patents by 6.79 % for the complementary sub-sample. To put it differently, a further decrease in the NMR index, in the post-reform period, hinders the patenting activity in countries where the liberalization process has been on average more substantial. On the contrary, in countries where the liberalization process has been on average more modest, a further decrease in the NMR index, in the post-reform period, may have a positive impact on patenting, consistently with the pattern observed in *Figure 3*.

Our results appear to shed some light on the seemingly conflicting findings concerning the relationship between deregulation and innovation in the electricity sector. Indeed, among multi-country studies like ours, while the evidence provided by Cambini et al. [16] supports the hypothesis that market deregulation enhances innovation, Kim

et al. [41] show opposite results. Sanyal and Ghosh [51], focusing on the electricity market in a single country (the United States), find that stronger downstream competition hinders innovation in the upstream sector. Our results, based on a design that (a) compares deregulatory processes across several countries and (b) exploits differences in the timing of national reforms, appear to solve this 'puzzle' because they suggest under which conditions (i.e., regulatory environment and regulatory component), and to what extent, deregulation may hamper innovation. Overall, we find that, ceteris paribus, pushing deregulation too far and especially lightening entry conditions, may significantly reduce the incentives of firms to invest in innovation activities. Yet, countries extremely reluctant to engage in an even moderate liberalization of the electricity sector may not benefit from potentially large gains in terms of productivity and knowledge diffusion associated with higher number of patent grants.

[*Table 5 about here*]

5.1 Robustness checks

Table 6 reports several robustness checks that corroborate our main results (*Table 3*). First, the focus on relatively homogeneous country groups, columns (1)-(2), allows us to remove potential bias arising from differences in patent legislation across countries. It turns out that the treatment effects estimated for European and historical EU members are even larger than the one found for the full sample. The check reported in column (3) tests whether the observations related to country entering the sample later than 1985 (i.e., the unbalanced nature of the sample) influence our parameter of interest. We find the treatment effect for this check very much in line with our main finding. A similar conclusion can be drawn for the sensitivity analysis performed to evaluate potential anticipation effects by taking the first lead of the treatment variable and treatment period (i.e., the lead values of $PolicyChange$ and $NMR \times PolicyChange$), shown in column (4). A substantial different imputation of the dependent variable,[18] see column (5), lowers the size of our key estimate but still confirms its policy implications.

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

In columns (6) and (7), we re-define both treatment variable and treatment period depending on whether the reduction in the NMR index is larger than 16 % or 23 %, i.e., we assign 0 to *PolicyChange* when the latter is below its median or mean value, respectively. This is to test whether and how sensitive the treatment effect is to a much stricter definition of sudden drops in regulation. Again, we find that such a re-definition of both treatment variable and treatment period does not substantially affect our results. Lastly, we perform a sensitivity analysis on an alternative and relevant measure of innovation in the electricity sector, in order to test the external validity of our analysis. As reported in column (8), our main policy implications do not change if we use patents granted by USPTO (US Patent and Trademark Office) as a dependent variable.

[*Table 6 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) and innovation (measured by patent grants at EPO) by relying on a DID analysis and taking into account the heterogeneity of the reform process across 31 OECD countries, both in terms of timing and intensity.

We find that in general, a further decrease in regulation intensity, after a drastic reform has occurred, has a negative 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 the regulatory environment may have a role in shaping the relationship between deregulation and innovation. In particular, this effect is positive in countries that, on average, have experienced a relatively weak reform process and negative in countries who have experienced a more drastic liberalization process. (in line with Aghion et al. [1]).

Our results may have interesting implications for policy. On the one hand, countries who lag far behind in the liberalization process might not only miss the opportunity to have a more efficient electricity market but also lose the chance to benefit from non-negligible gains in innovation. On the other hand, 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 the demand for electricity, and the use of sustainable ways to produce it, are set to grow considerably in the next few years (International Energy Agency [32]). 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 the firms operating in the sector with sufficient incentives to innovate. This issue may be particularly relevant for countries that have implemented major reforms of the industry, calling eventually for policies that complement the liberalization process. For example, as far as the decarbonization of electricity production is concerned, an appropriate mix of liberalization and policies supporting renewable energy is needed, as pointed by Nesta et al. [44]. Indeed they find that such policies have an important role in creating demand for renewable energy and to make market entry attractive for new players that rely on more innovative technologies. Moreover, renewable energy policies are more effective in generating green patents in

countries with deregulated energy markets. Their results, in line with ours, point out that product market regulation and policies supporting renewable energy are distinct but complementary instruments that are available to policy makers. This seems to be consistent, for example, with the UK experience. As described by Jasmab and Pollit [37], the British electricity industry has been characterized by an intense liberalization process that has been followed by a decline in innovation efforts in the sector. However, the implementation of a specific energy technology and innovation policy has accompanied the recent partial recovery of R&D expenditure and patenting activity.

References

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

[2] Aghion P., Harris C., Howitt P. Vickers J., 2001. Competition, Imitation and Growth with Step-by-Step Innovation, Review of Economic Studies 68:467492.

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

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

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

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

[7] 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.

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

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

[10] Bacon R. W., 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.

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

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

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

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

[15] Bourls R., Cette G., Lopez J., Mairesse J., 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.

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

[17] Cameron, A. C., Trivedi, P. K., 2005. Microeconometrics: methods and applications. Cambridge university press.

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

[19] 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.

[20] Dennis K., Lazar J., Colburn K., 2016. Environmentally beneficial electrification: The dawn of emissions efficiency'. The Electricity Journal 29:52-58.

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

[22] European Commission, 1996. 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.

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

[24] European Commission, 2003. 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.

[25] European Commission, 2015. Energy Union Package: A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy.

[26] 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.

[27] Fiorio C.V., Florio M., 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.

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

[29] Green R., 2017. Evidence, and Supplementary Evidence, submitted to the House of Lords Economic Affairs Committee inquiry on The Economics of UK Energy Policy.

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

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

[32] International Energy Agency, 2017. World Energy Outlook.

[33] International Energy Agency, 2016. Re-powering markets. Electricity markets series.

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

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

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

[37] Jamasb T., Pollitt M., 2015. Why and how to subsidise energy R+D: Lessons from the collapse and recovery of electricity innovation in the UK. Energy Policy, 83:197-205.

[38] Johnstone N., Hai I., Popp D., 2010. Renewable energy policies and technological innovation: Evidence based on patent counts. Environmental and Resource Economics 45:133-155.

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

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

[41] Kim J., Kim Y., Flacher D., 2012. Energy Policy, 48:103-117

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

[43] Motta M., 2004. Competition Policy: Theory and Practice. Cambridge: Cambridge University Press

[44] Nesta L., Vona F., Nicolli F., 2014. Environmental Policies, Competition and Innovation in Renewable Energy, Journal of Environmental Economics and Management 67:396-411.

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

[46] 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.

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

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

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

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

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

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

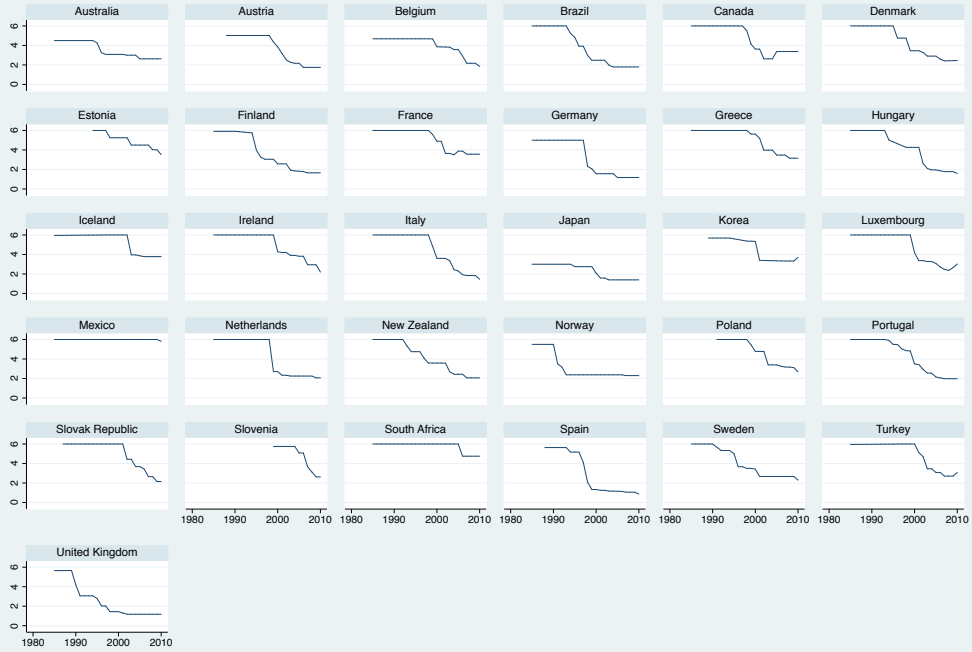
[53] Steiner F., 2001. Regulation, Industry Structure and Performance in the Electricity Supply Industry. OECD Economic Studies, No. 32.

[54] 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.

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

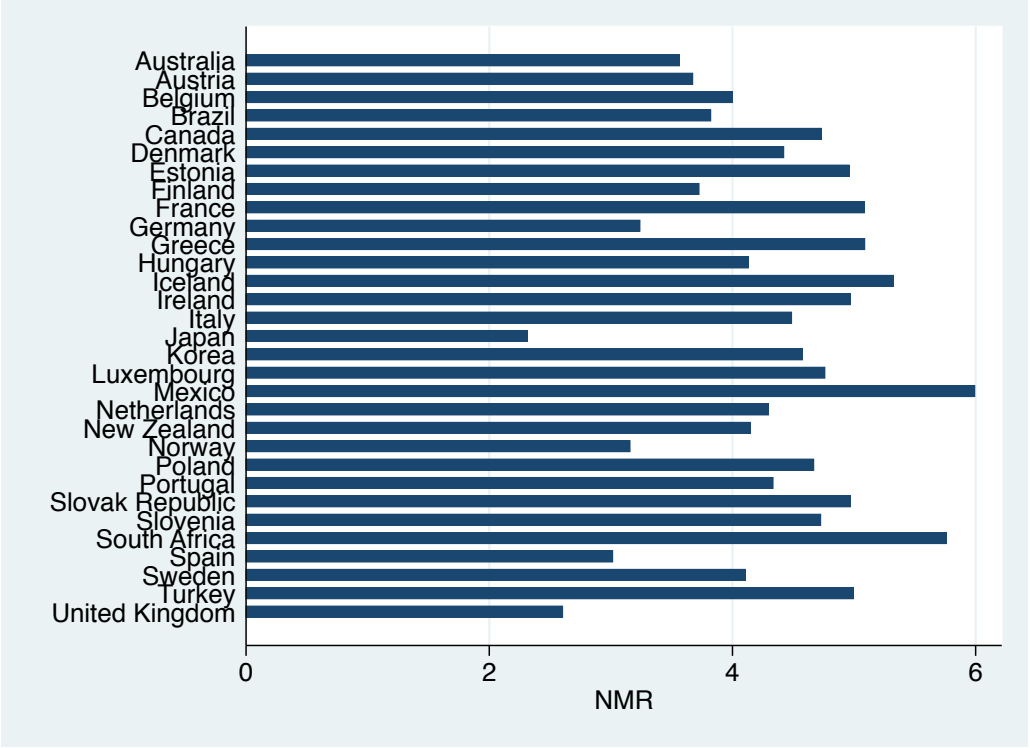
Figures and Tables

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



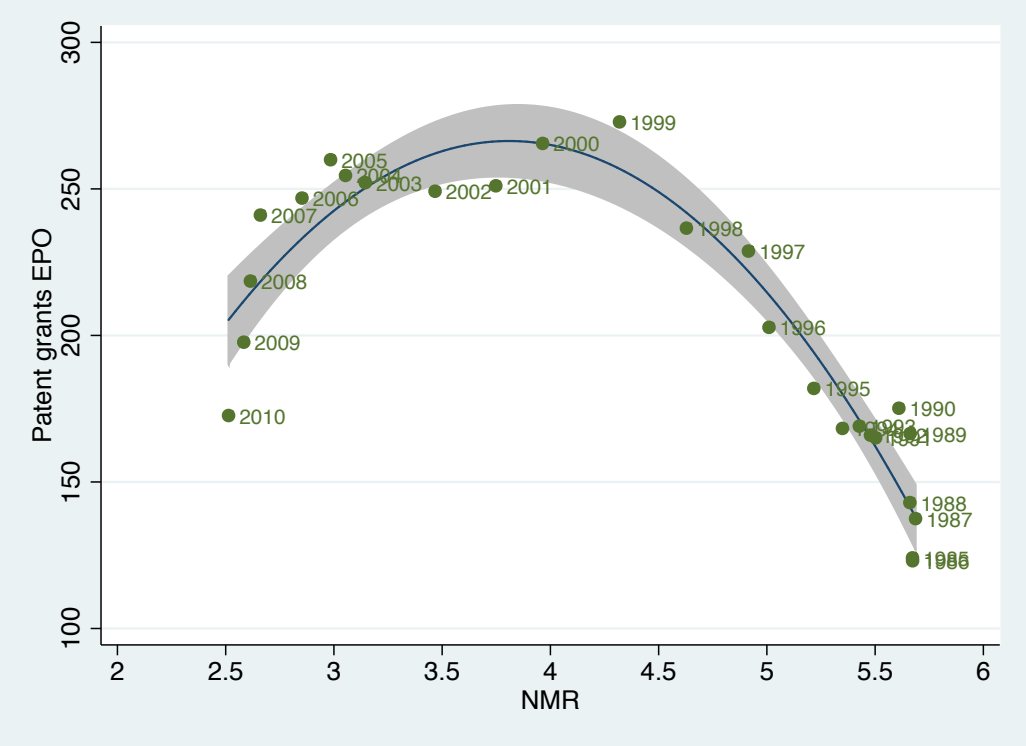
Source: OECD ETCR Data Regulation.

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



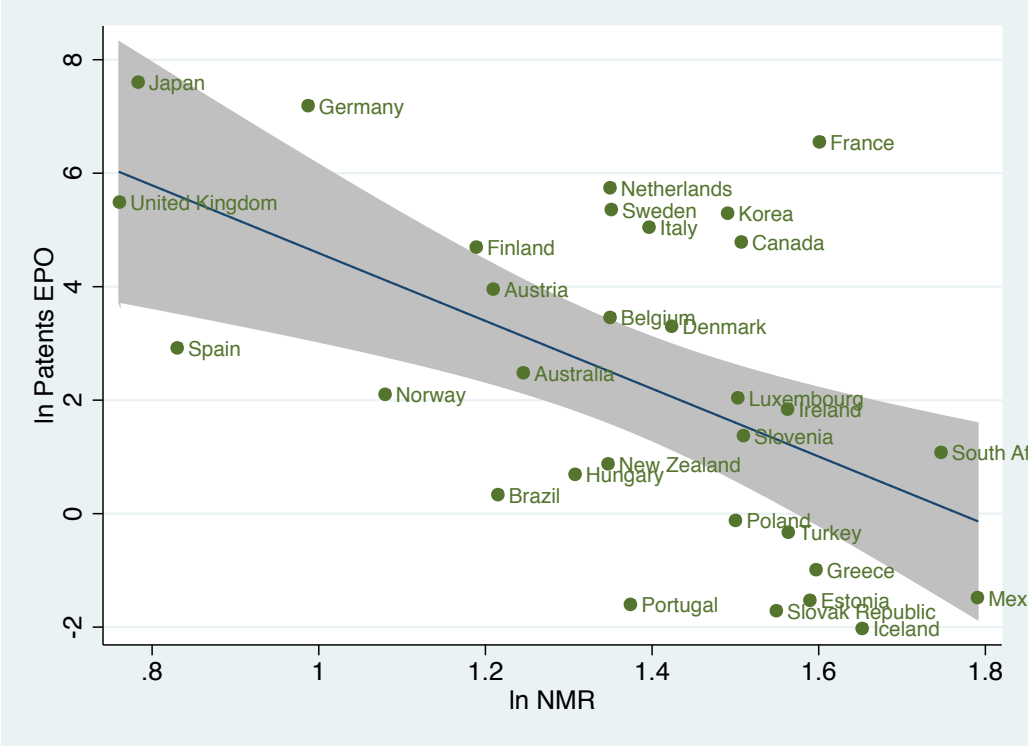
Source: OECD ETCR Data Regulation.

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 by country*



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	205.48	0	2919.84

Source: OECD ETCR Data Regulation, Al-Sunaidy and Green [4], 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: *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 4: *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 5: *DID results – by regulatory environment*

	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.

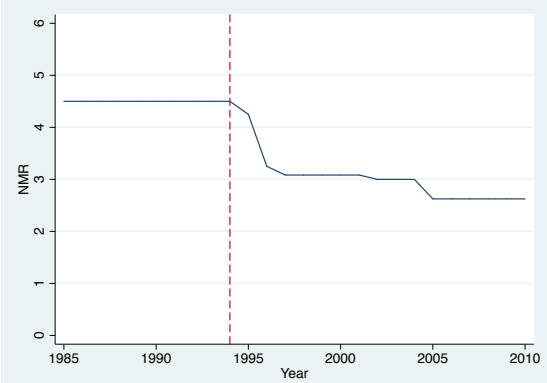
Table 6: *Robustness checks*

	ln_patents_EPO			
	(1)	*(2)*	*(3)*	*(4)*
	European countries	*Historical EU countries*	*Balanced panel*	*Lead value PolicyChange*
ln_NMR	-1.81	-2.36*	-1.24	-1.40*
	(1.15)	(1.12)	(0.76)	(0.71)
$PolicyChange$	-3.98**	-4.58**	-2.60**	-2.63**
	(1.79)	(1.90)	(1.02)	(0.99)
$ln_NMR \times PolicyChange$	2.39**	2.73**	1.70**	1.71***
	(1.06)	(1.13)	(0.63)	(0.59)
Clusters	21	17	24	31
Observations	509	434	624	734
R-squared	0.95	0.96	0.94	0.94
	ln_patents_EPO			*ln_patents_USPTO*
	(5)	*(6)*	*(7)*	*(8)*
	Different imputation	*Above median PolicyChange*	*Above mean PolicyChange*	*Patent grants at USPTO*
ln_NMR	-0.89*	-0.31	-0.01	-0.53
	(0.45)	(0.31)	(0.33)	(0.40)
$PolicyChange$	-1.45**	-1.53***	-0.87	-1.21**
	(0.61)	(0.55)	(0.56)	(0.57)
$ln_NMR \times PolicyChange$	0.98**	1.21***	1.01***	0.81**
	(0.38)	(0.30)	(0.31)	(0.38)
Clusters	31	31	31	31
Observations	765	765	765	641
R-squared	0.96	0.94	0.93	0.95

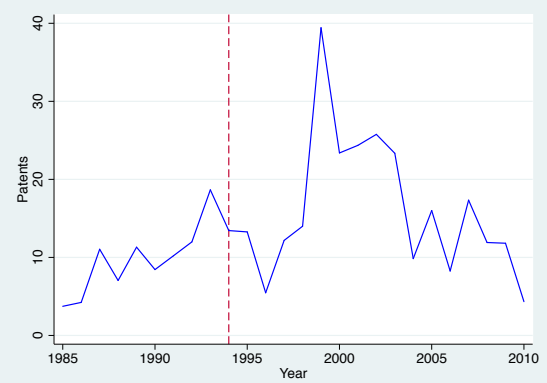
Notes: All specifications include the full set of controls. Standard errors are robust and clustered at the country level. *, **, and *** denote significance at the 10, 5, and 1 percentage level, respectively. The sub-sample 'European countries' includes Austria, Belgium, Denmark, Estonia, Finland, France, 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



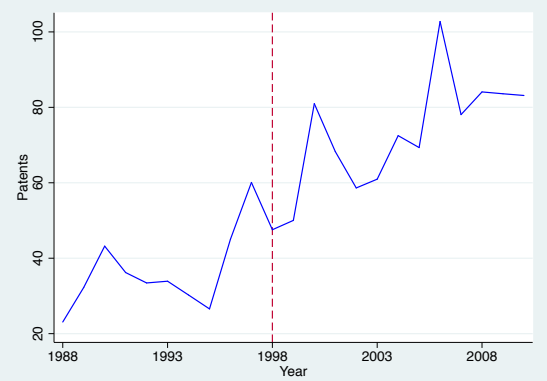
Australia: Patent grants (EPO)



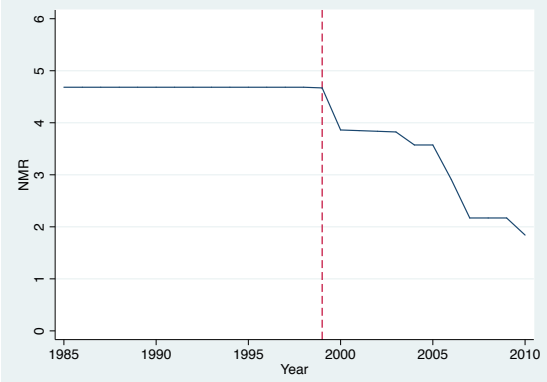
Austria: NMR



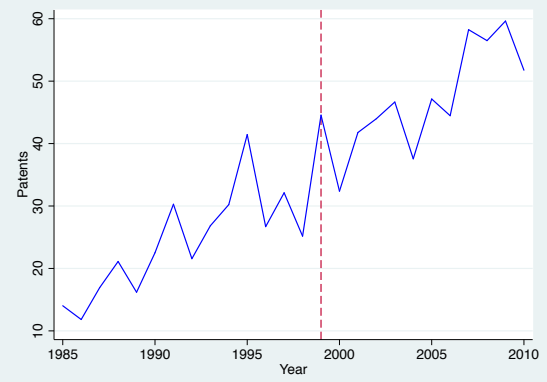
Austria: Patent grants (EPO)



Belgium: NMR

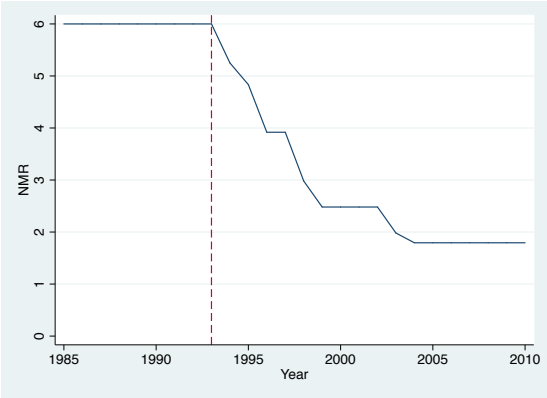


Belgium: Patent grants (EPO)

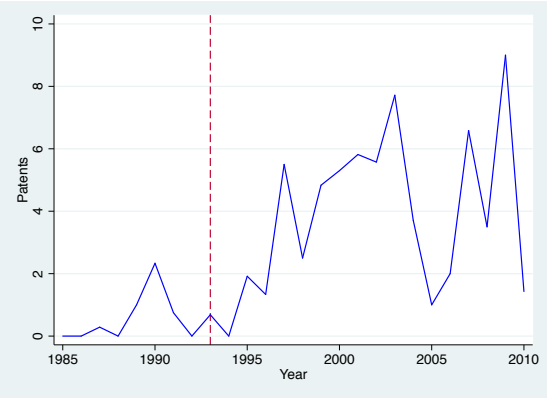


Source: OECD ETCR Data Regulation and OECD Patent Grants (Priority date, IPC H – Electricity).

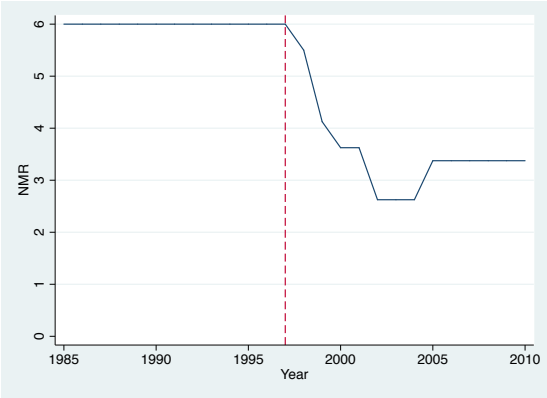
Brazil: NMR



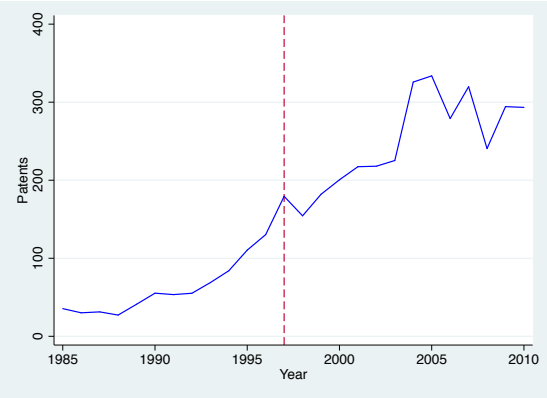
Brazil: Patent grants (EPO)



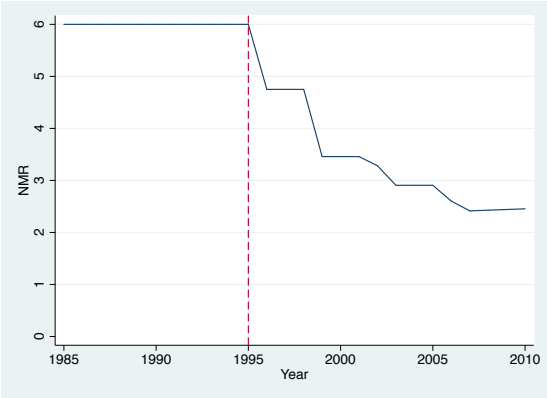
Canada: NMR



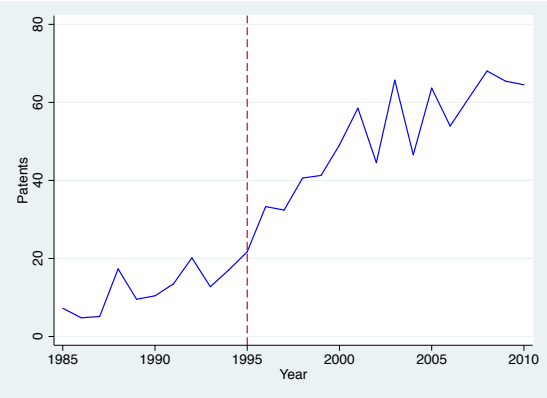
Canada: Patent grants (EPO)



Denmark: NMR

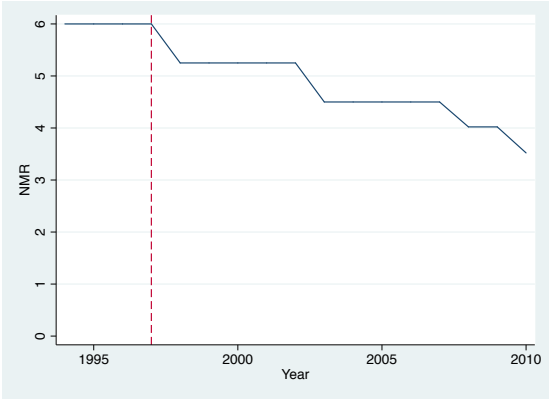


Denmark: Patent grants (EPO)

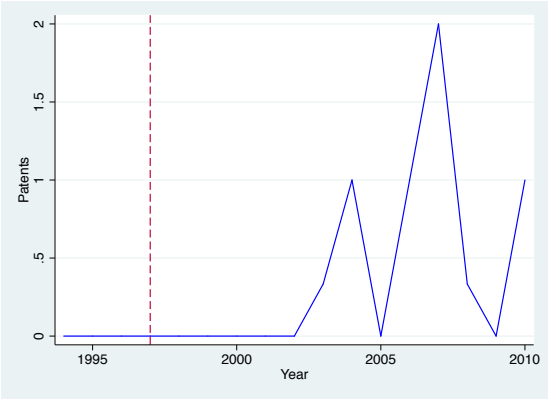


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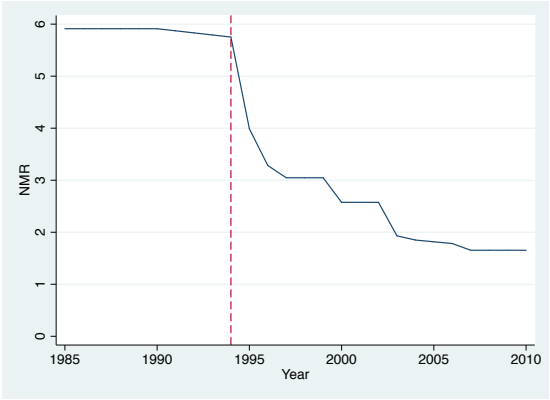
Estonia: NMR



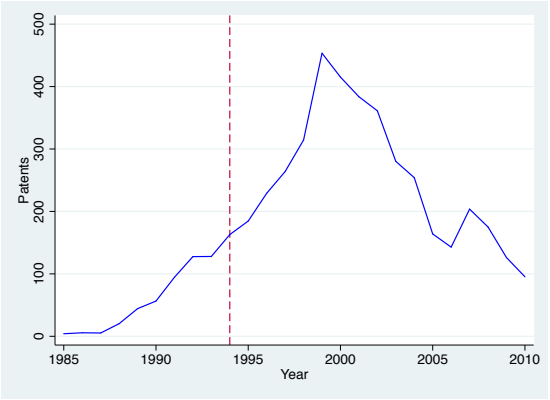
Estonia: Patent grants (EPO)



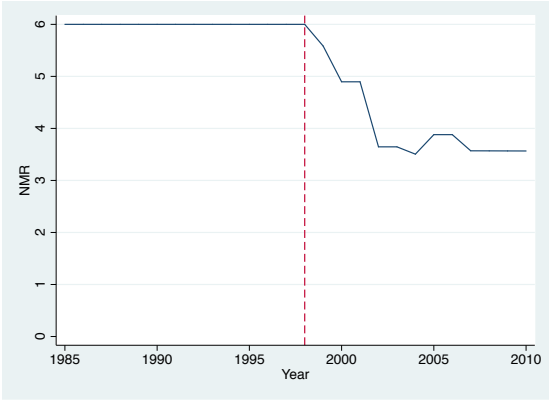
Finland: NMR



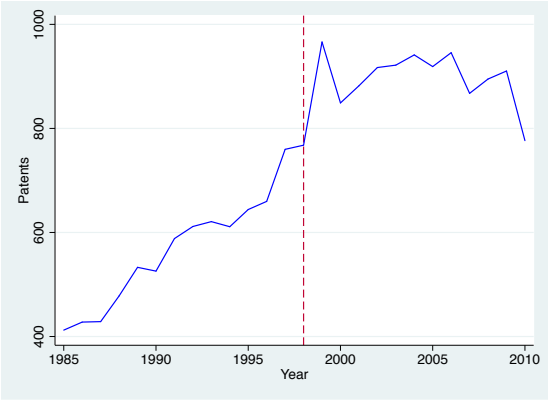
Finland: Patent grants (EPO)



France: NMR

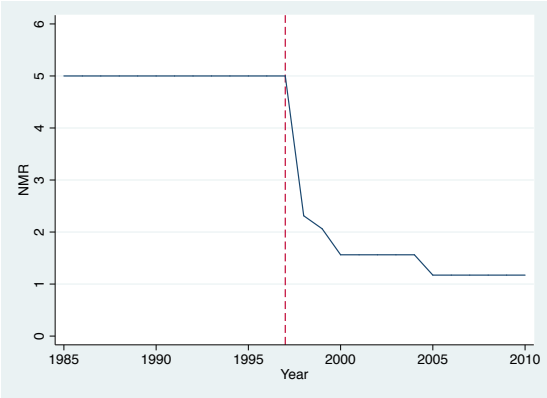


France: Patent grants (EPO)

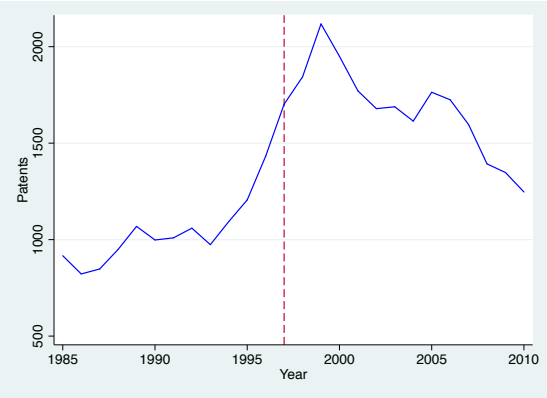


Source: OECD ETCR Data Regulation and OECD Patent Grants (Priority date, IPC H – Electricity).

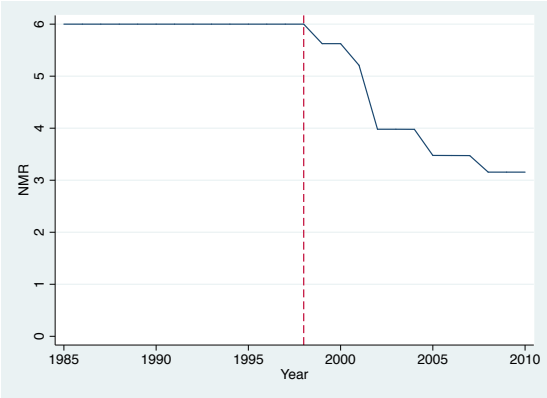
Germany: NMR



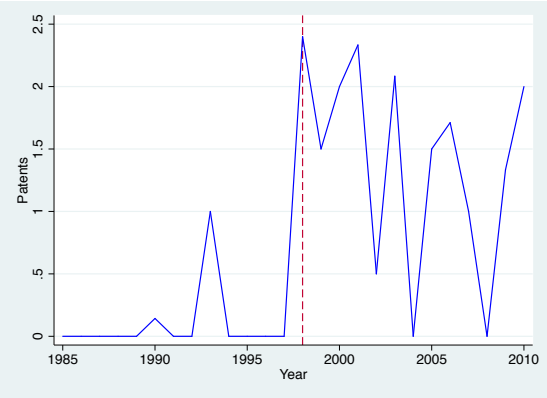
Germany: Patent grants (EPO)



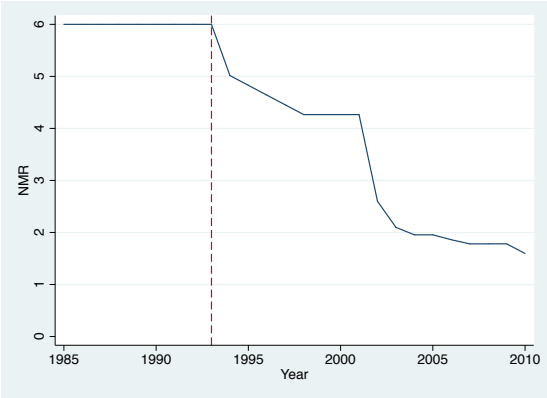
Greece: NMR



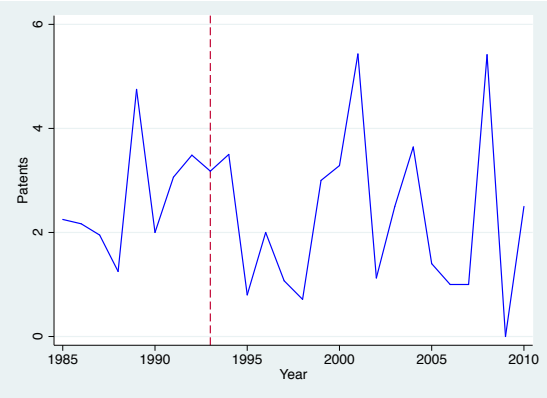
Greece: Patent grants (EPO)



Hungary: NMR

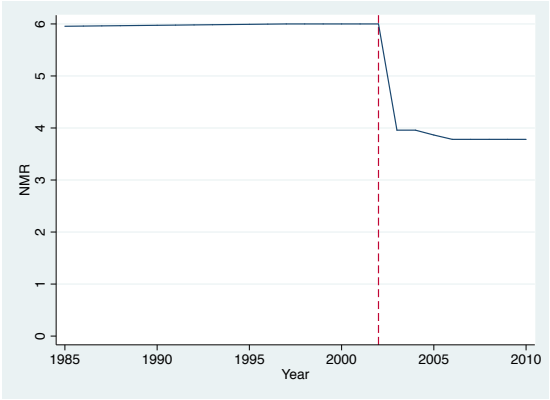


Hungary: Patent grants (EPO)

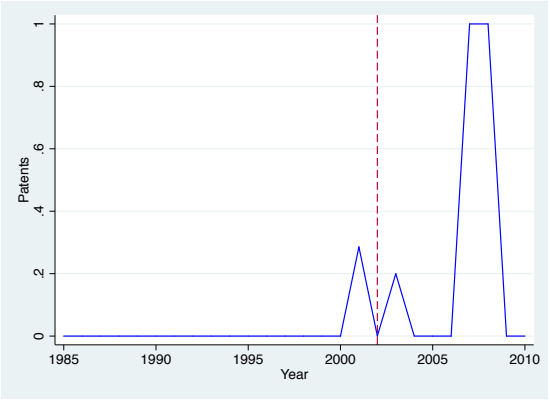


Source: OECD ETCR Data Regulation and OECD Patent Grants (Priority date, IPC H – Electricity).

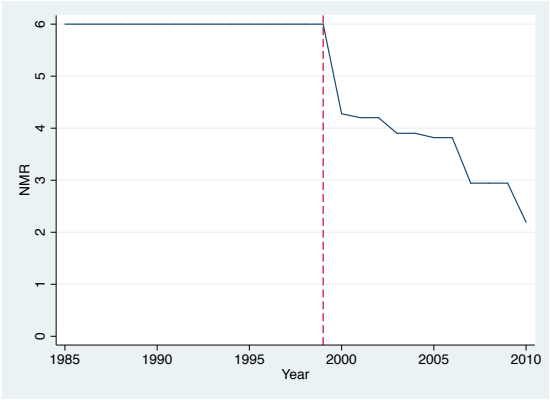
Iceland: NMR



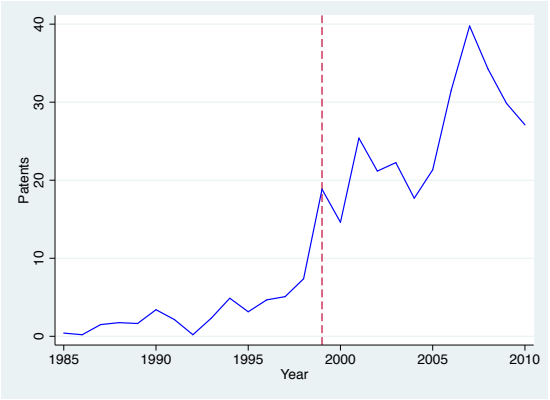
Iceland: Patent grants (EPO)



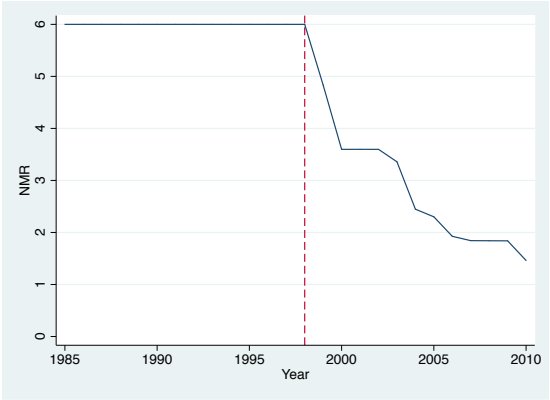
Ireland: NMR



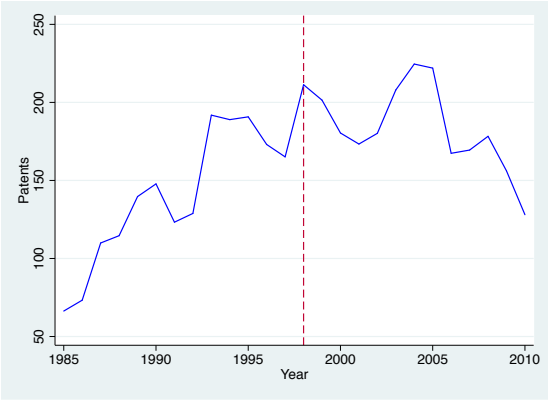
Ireland: Patent grants (EPO)



Italy: NMR

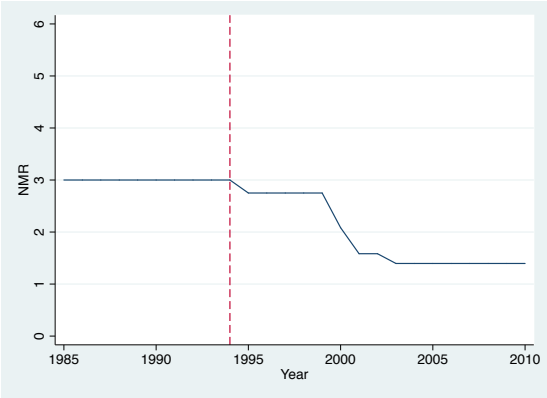


Italy: Patent grants (EPO)

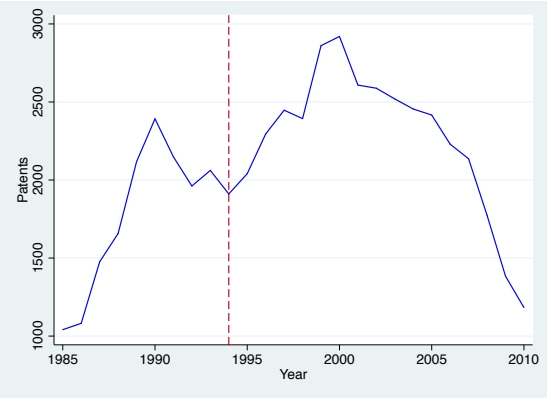


Source: OECD ETCR Data Regulation and OECD Patent Grants (Priority date, IPC H – Electricity).

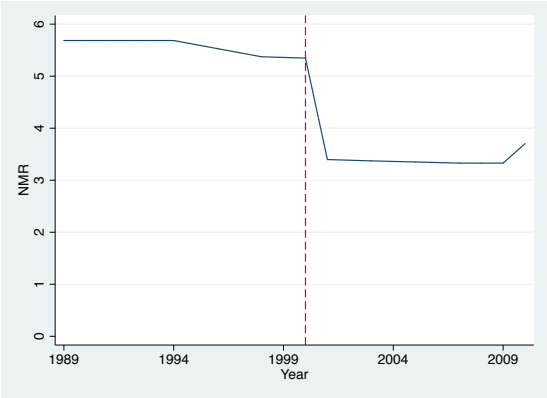
Japan: NMR



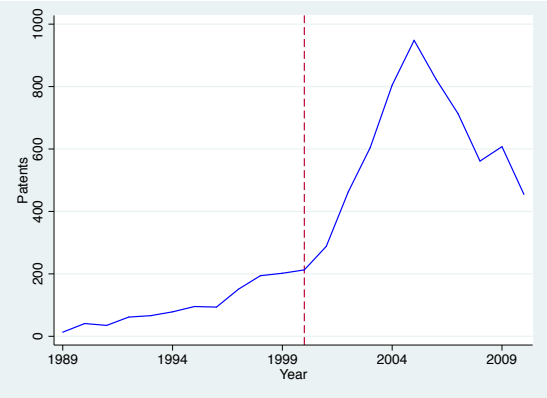
Japan: Patent grants (EPO)



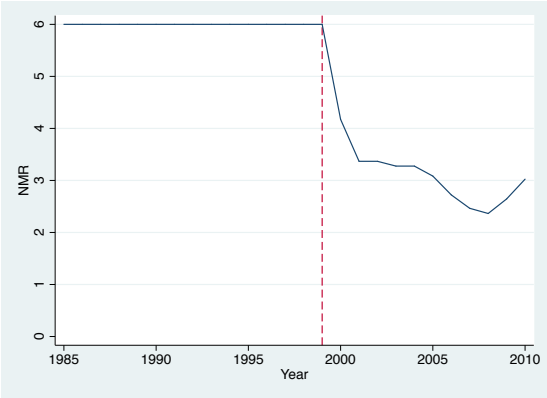
Korea, South: NMR



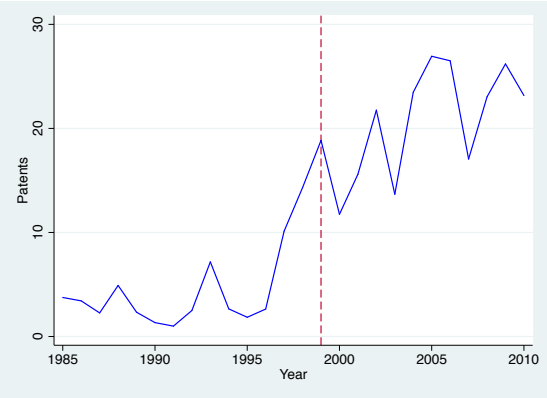
Korea, South: Patent grants (EPO)



Luxembourg: NMR

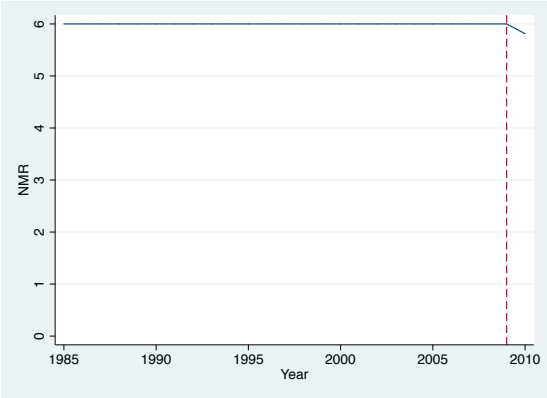


Luxembourg: Patent grants (EPO)

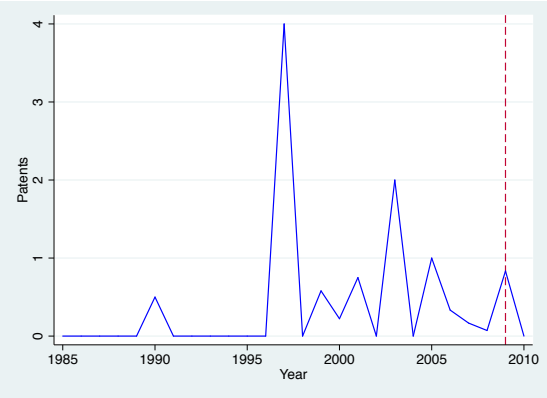


Source: OECD ETCR Data Regulation and OECD Patent Grants (Priority date, IPC H – Electricity).

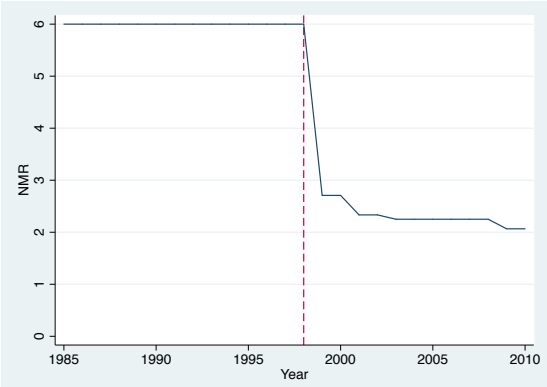
Mexico: NMR



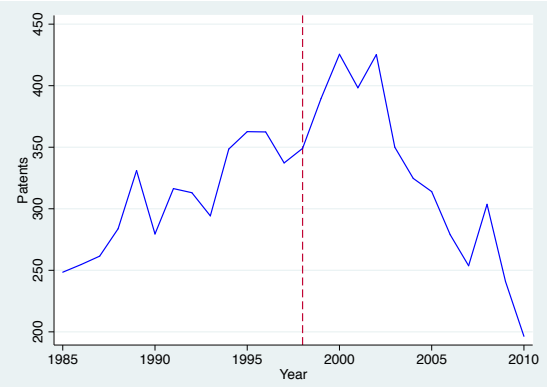
Mexico: Patent grants (EPO)



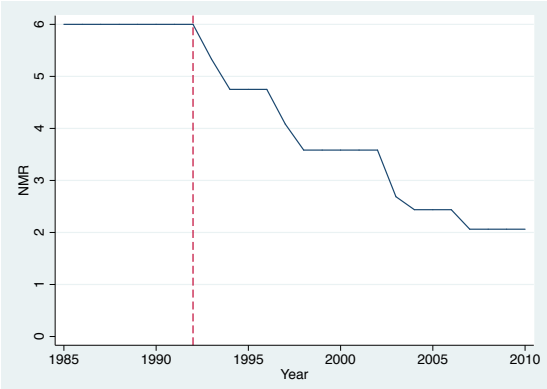
Netherlands: NMR



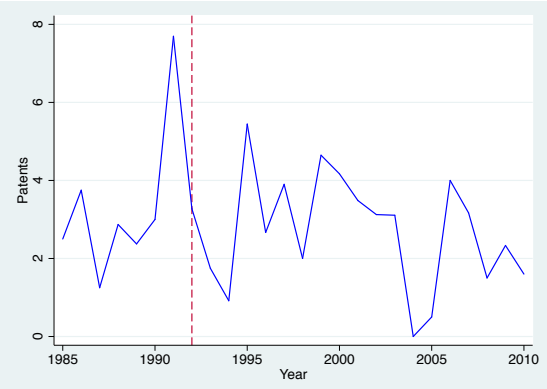
Netherlands: Patent grants (EPO)



New Zealand: NMR

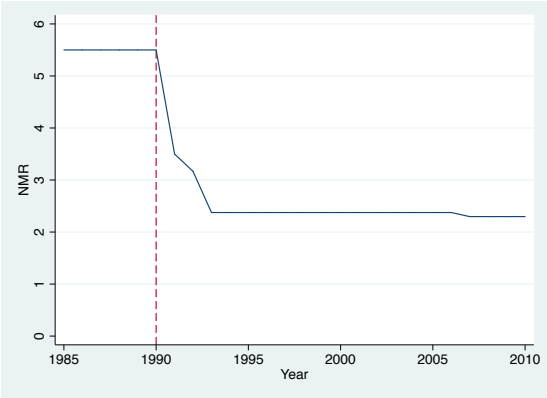


New Zealand: Patent grants (EPO)

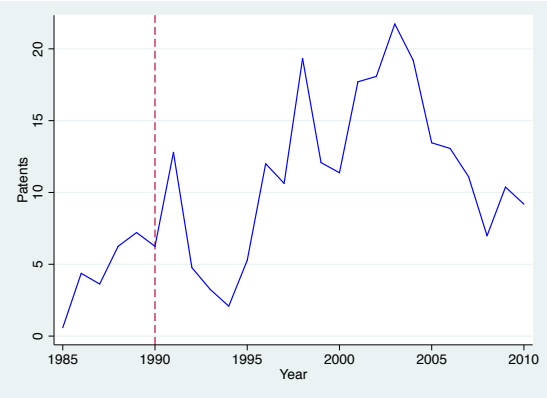


Source: OECD ETCR Data Regulation and OECD Patent Grants (Priority date, IPC H – Electricity).

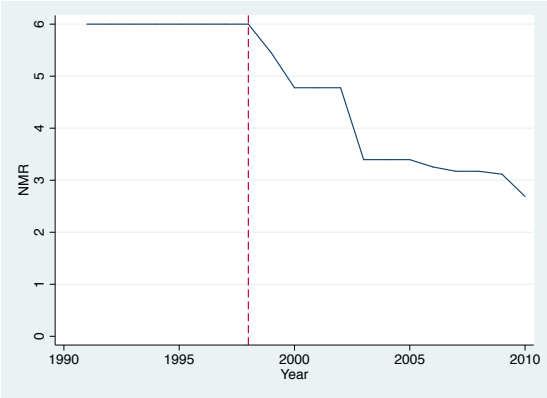
Norway: NMR



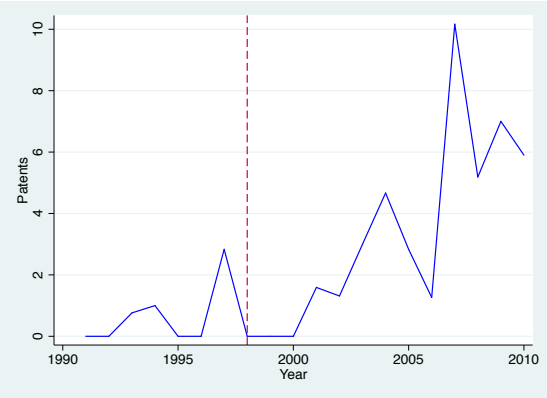
Norway: Patent grants (EPO)



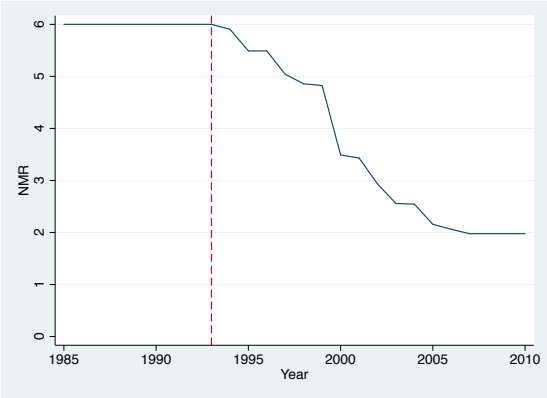
Poland: NMR



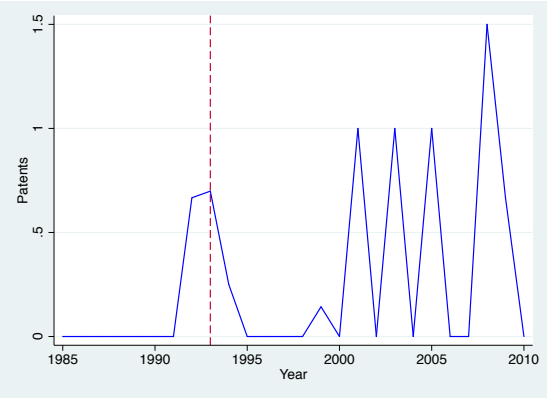
Poland: Patent grants (EPO)



Portugal: NMR

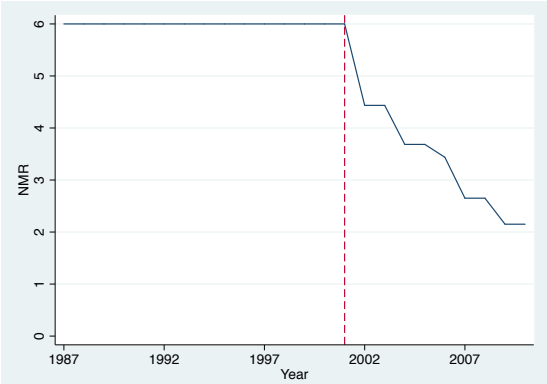


Portugal: Patent grants (EPO)

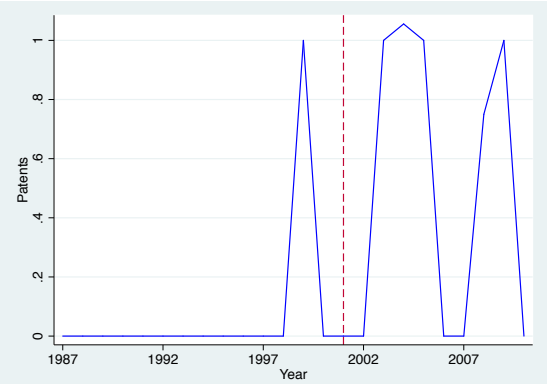


Source: OECD ETCR Data Regulation and OECD Patent Grants (Priority date, IPC H – Electricity).

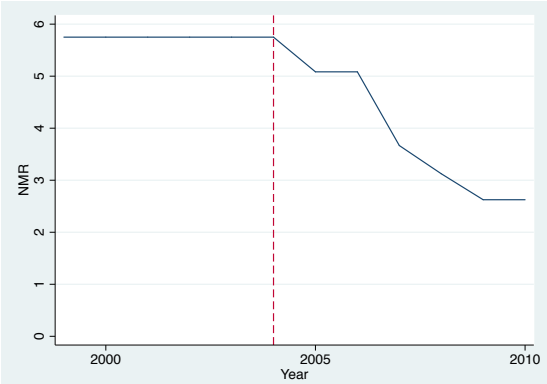
Slovak Republic: NMR



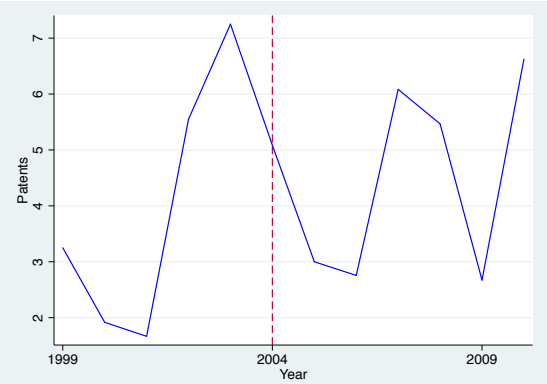
Slovak Republic: Patent grants (EPO)



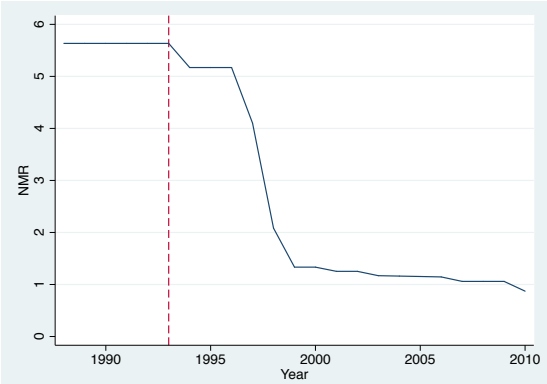
Slovenia: NMR



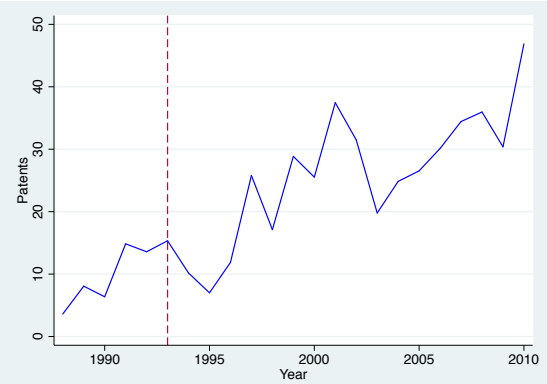
Slovenia: Patent grants (EPO)



Spain: NMR

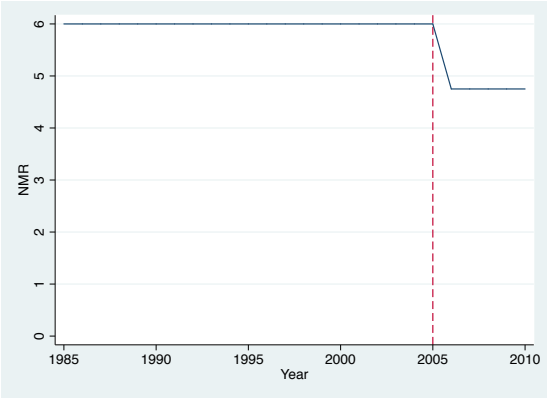


Spain: Patent grants (EPO)

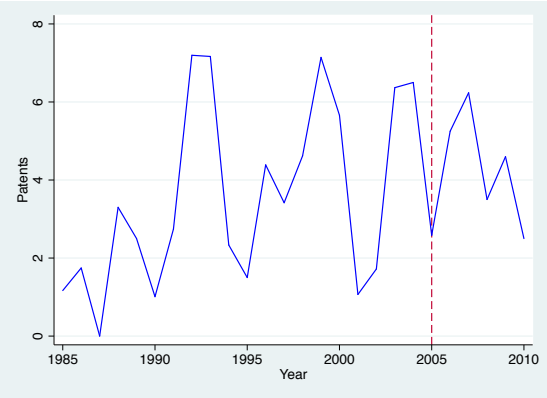


Source: OECD ETCR Data Regulation and OECD Patent Grants (Priority date, IPC H – Electricity).

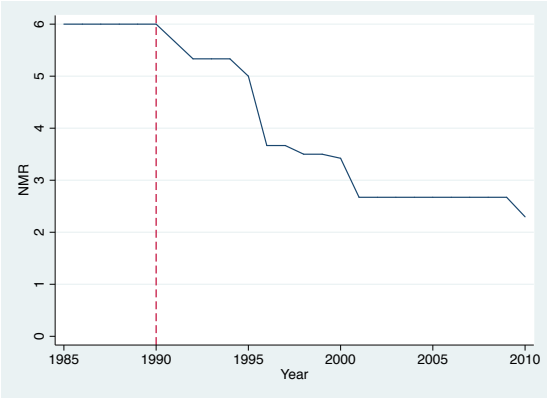
South Africa: NMR



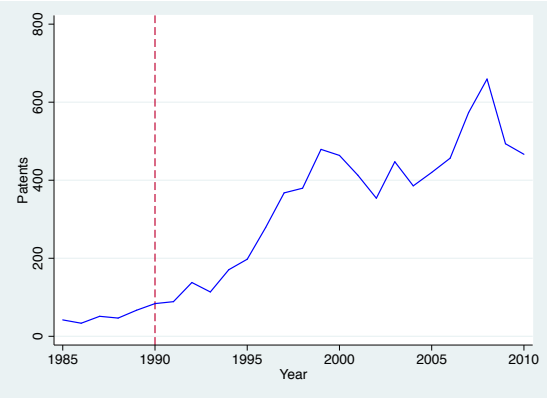
South Africa: Patent grants (EPO)



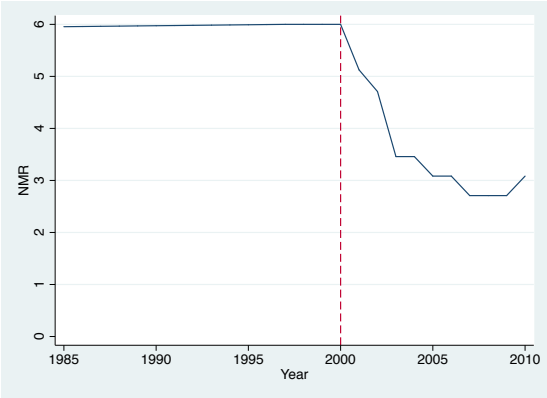
Sweden: NMR



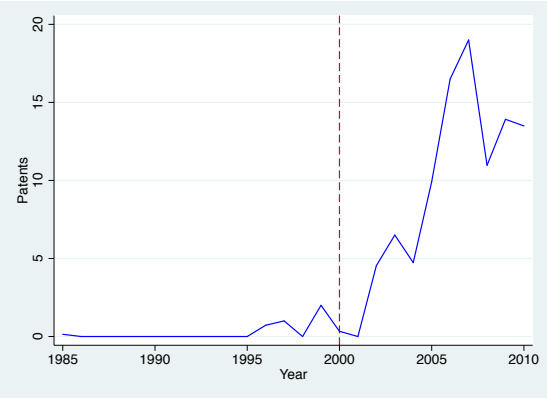
Sweden: Patent grants (EPO)



Turkey: NMR

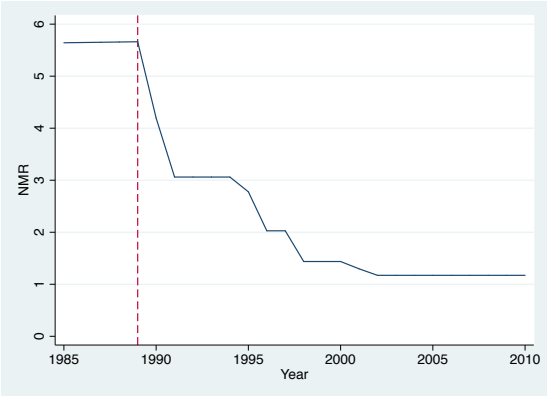


Turkey: Patent grants (EPO)

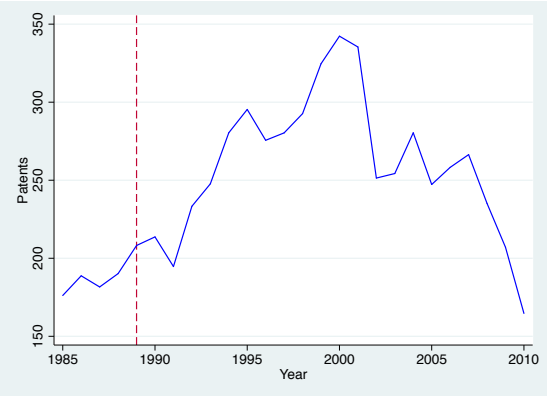


Source: OECD ETCR Data Regulation and OECD Patent Grants (Priority date, IPC H – Electricity).

United Kingdom: NMR

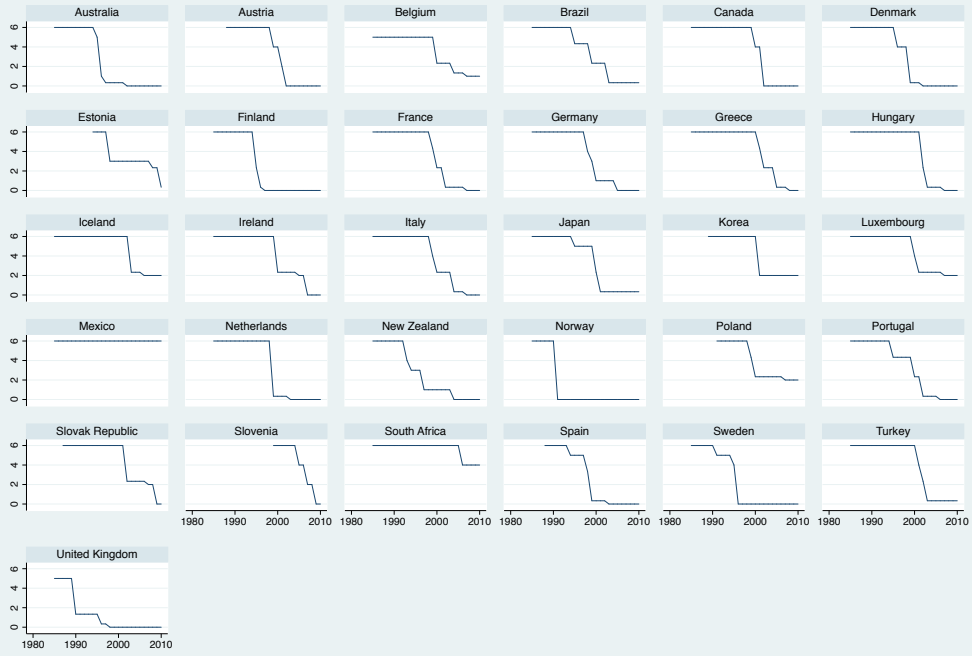


United Kingdom: Patent grants (EPO)



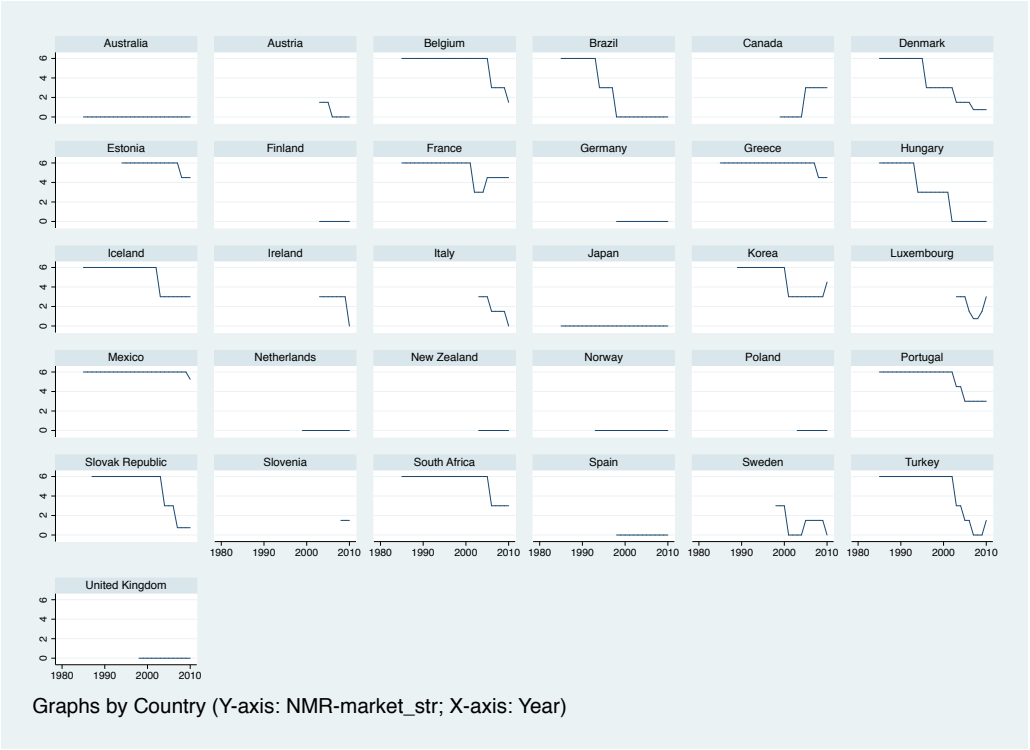
Source: OECD ETCR Data Regulation and OECD Patent Grants (Priority date, IPC H – Electricity).

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



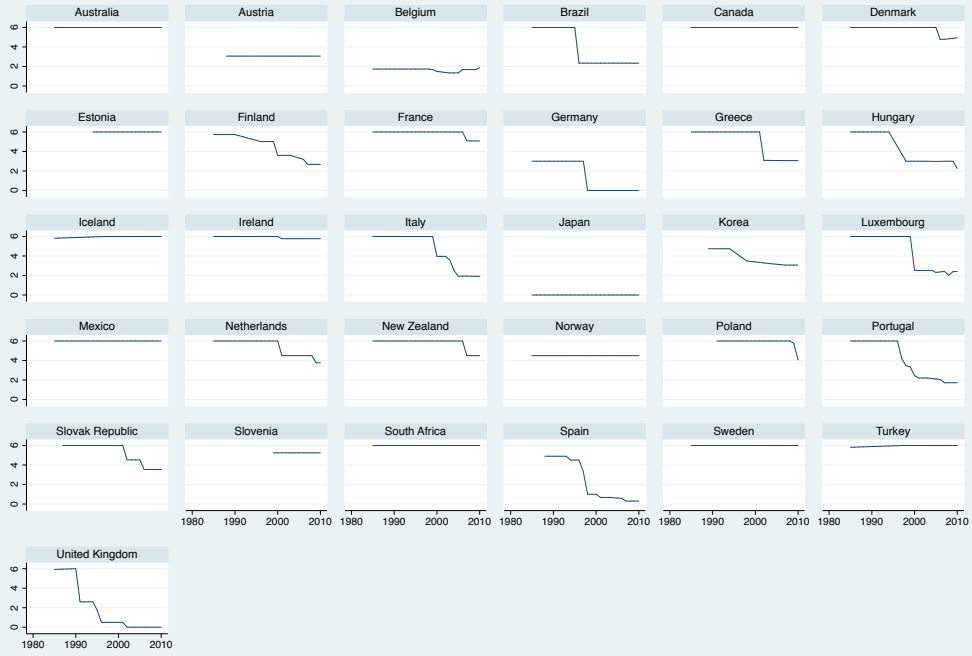
Source: OECD ETCR Data Regulation.

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



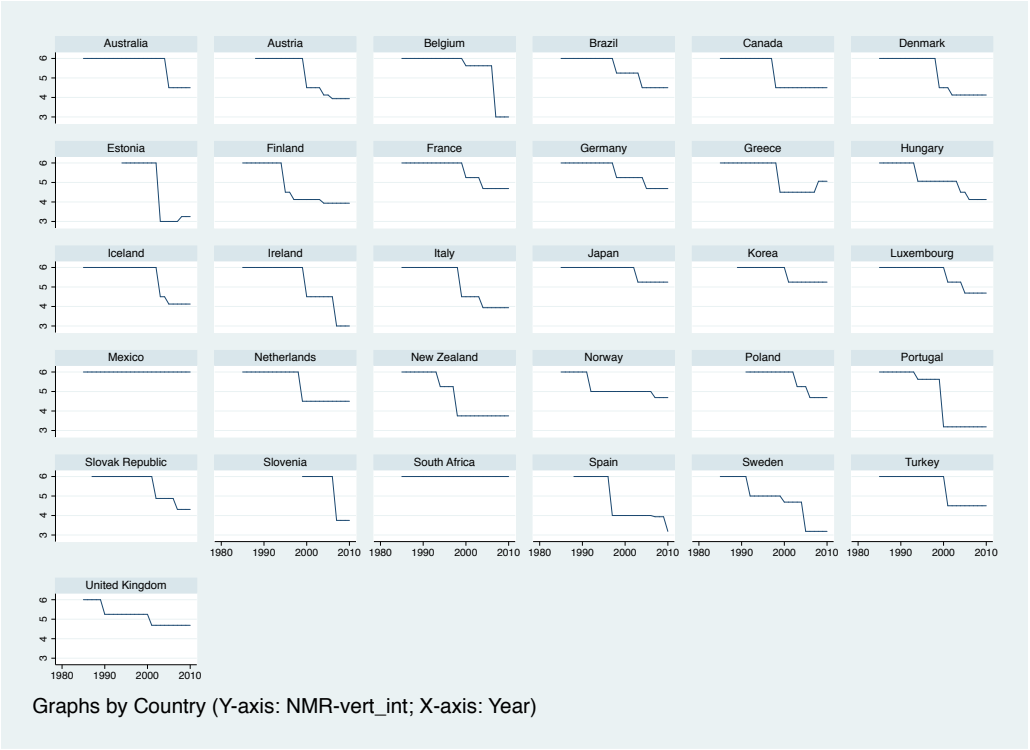
Source: OECD ETCR Data Regulation.

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



Source: OECD ETCR Data Regulation.

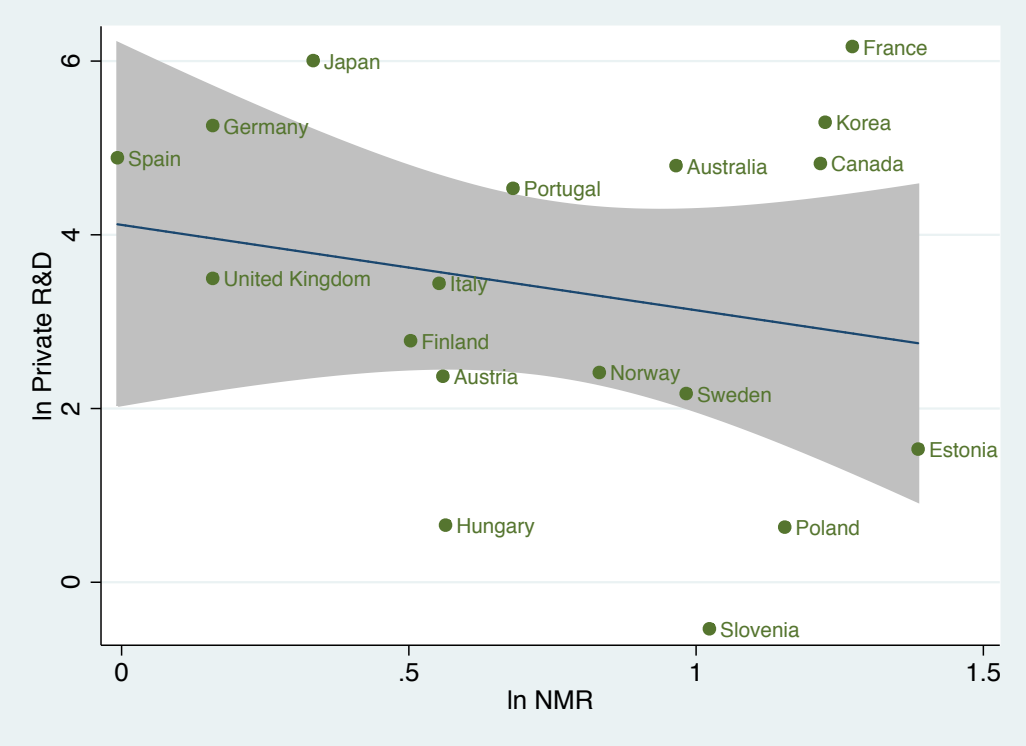
Figure A4: *NMR-vert_int index in the electricity sector (vertical axis) over time (horizontal axis) by country*



Source: OECD ETCR Data Regulation.

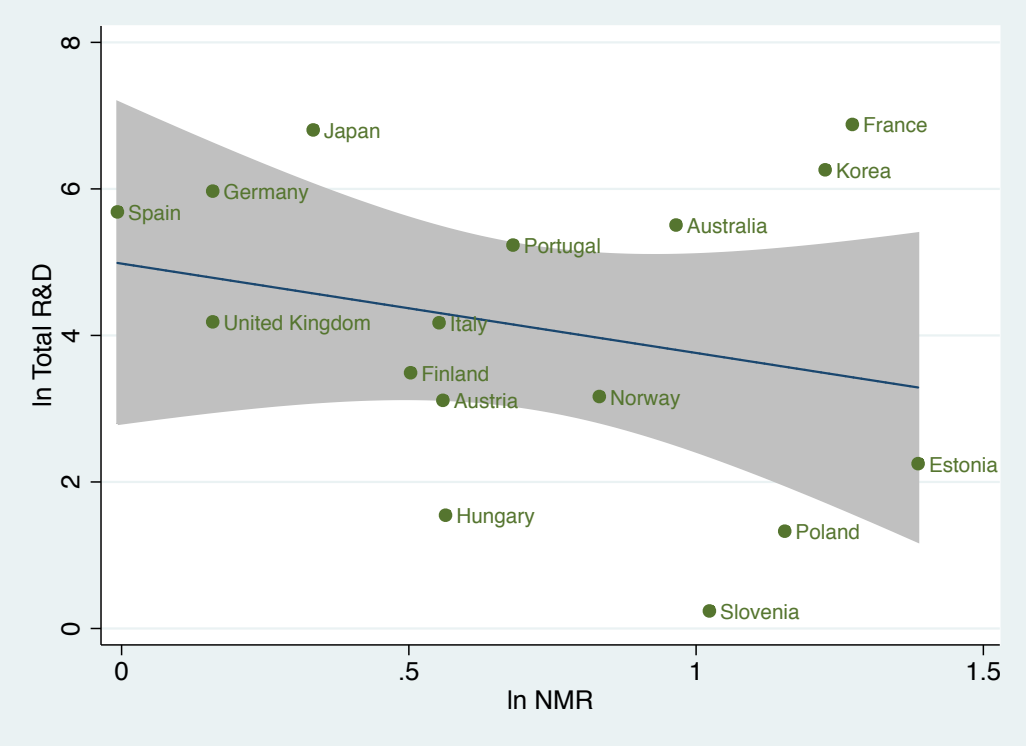
Appendix B

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



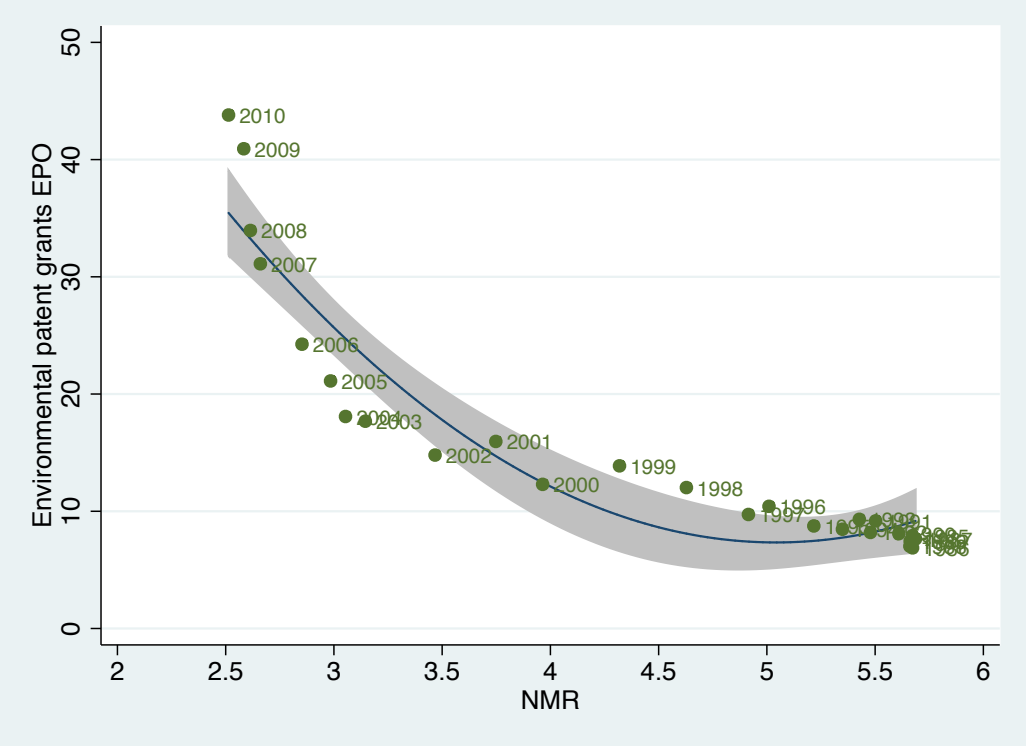
Source: OECD ETCR Data Regulation and OECD R&D data (Electricity, gas, steam and air conditioning supply; water collection, treatment and supply).

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



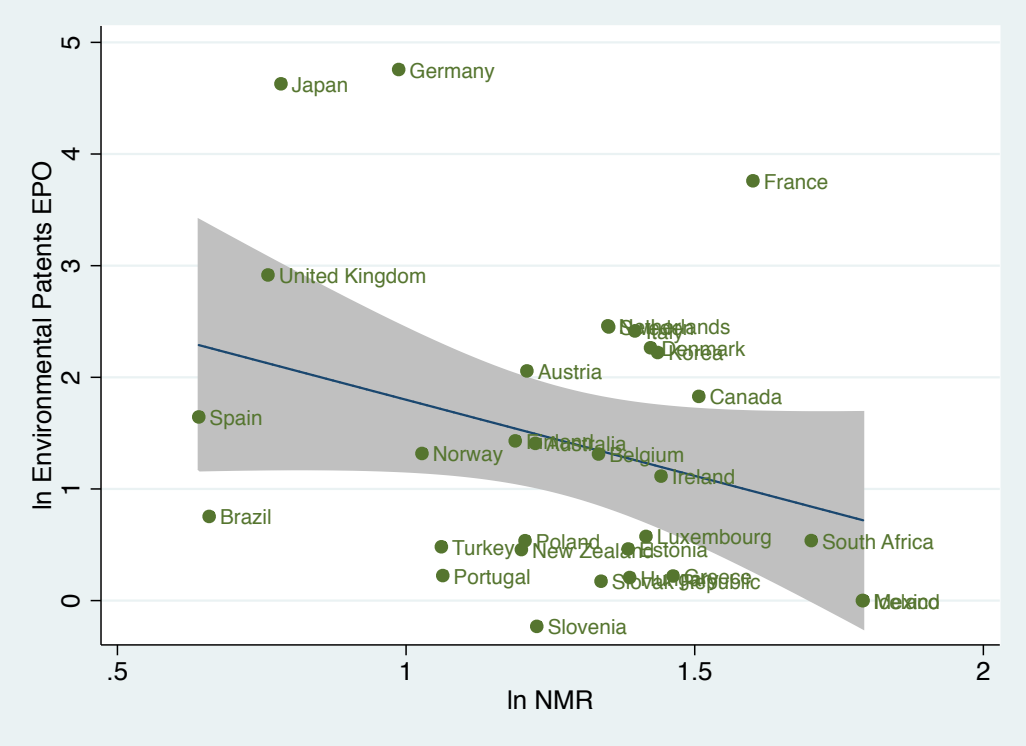
Source: OECD ETCR Data Regulation and OECD R&D data (Electricity, gas, steam and air conditioning supply; water collection, treatment and supply).

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	554	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.