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Electricity (De)Regulation and Innovation

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Abstract

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

JEL Classification: K23, L51, L94, O31.

Keywords: Regulation, patents, innovation, electricity.

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1 Introduction

The World Energy Council considers technological innovation as one of the necessary elements (together with global cooperation and economic growth) to balance the “Energy Trilemma”:¹ a simultaneous pursuit of secure, affordable and environmentally sound energy policies. Similarly, the International Energy Agency considers innovation as “central to meeting climate mitigation goals while also supporting economic and energy security objectives”.²

Even if it seems rather intuitive that, in tightly regulated industries, the absence of competition hampers the incentives to innovate, it is not entirely clear how, and to what extent, the liberalization wave that has concerned the the electricity industry over the last 30 years (alongside other network industries like telecommunication and transport) has affected the willingness to invest in innovation among the various firms that are operating in this sector. At a theoretical level, the effect of deregulation on innovation is rather ambiguous: if deregulation increases competition, where competition is scarce, then companies might be pushed to innovate in order to increase the competitive gap between them and their rivals. If competition becomes too intense then imitation may become a more profitable option than innovation (Aghion et al. [1]).

Despite the differences in the content of each policy reform, there are some recurrent elements characterizing the reforms implemented over the last three decades across many OECD countries: vertical separation of potentially competitive segments (i.e., generation, marketing and retail supply) from segments that will continue to be regulated (i.e., transmission and distribution), the formation of wholesale and retail power markets open to the entry of new competitors, the privatization of state-owned utilities, the establishment of an independent regulator and the implementation of a system of third party access to the transmission and distribution systems. In spite of the consensus about the fact that these are the key ingredients for deregulation to achieve, in the short term, the objectives of economic efficiency and security of supply

¹World Energy Council [45].

²International Energy Agency [27].

(Al-Sunaidy and Green [2], Jamasb and Pollit [28]) these positive effects may be offset, in the long term, by possibly lower rates of innovation associated with the liberalization process, as observed by Jamasb and Pollit [29].

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

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

When it comes, more specifically, to the relationship between deregulation and innovation in the electricity industry the evidence is rather mixed. Jamasb and Pollitt [29] provide a series of theoretical arguments and descriptive evidence that liberalization has had negative effects on innovation in the sector. In a different contribution (Jamasb and Pollitt [30]) they report further descriptive evidence about the United Kingdom: they show that electricity-related patents as a whole and those specific to non-nuclear and renewable technologies have increased, to some extent, after the deregulation but the lasting decline in R&D spending could possibly reduce patents and innovation in the long term. Also Sanyal and Gosh [40], who describe the the impact of the 1990s U.S. electricity reform on patenting, find that the introduction of the reform led to a net decrease of patenting by electric equipment manufacturers. On the other side of

the spectrum, in a recent study involving the electricity industry of 15 EU countries, Cambini et al. [14] find that a decrease in the intensity of regulation has rather had a positive impact on innovation both in terms of R&D expenditure and in terms of patenting activity.

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

Our main results suggest that deregulation is generally associated with a higher number of patent grants at EPO. However, the effect of (further) deregulation on innovation, after a sharp decrease in regulation intensity, is negative: a 1 % reduction in regulation intensity during the post-reform period significantly decreases the number of patent grants by 1.76 %. This effect appears to be driven mainly by the reduction of entry barriers associated with the regulatory framework, i.e., a greater degree of market contestability decreases firms' incentives to innovate extensively. Interestingly, we also find evidence of an inverse U-shaped relationship between deregulation and innovation. This relationship is positive when regulation intensity is high (to

put it differently, deregulation fosters innovation if the market is tightly regulated), it reaches its peak at some intermediate level of regulation intensity and starts decreasing afterward (deregulation hampers innovation once the market liberalization process is already fairly advanced). Assuming that a lower regulation intensity can be associated with more competition, this relationship is remarkably consistent with the one between competition and innovation described by Aghion et al. [1]. Thus, the effect of deregulation on innovation, after a drop in regulation intensity, depends on whether the deregulation process has been more or less extensive. Specifically, countries going through profound deregulatory changes may hinder the innovativeness of their electricity industry, while the opposite may happen for countries implementing moderate adjustments.

The remainder of this paper is organized as follows. Section 2 describes the relevant literature. Section 3 offers a brief overview of the deregulation process of the electricity sector in OECD countries. Section 4 describes the empirical model. Section 5 presents the data and provides descriptive statistics and prima-facie evidence of the relationship under analysis. Section 6 discusses the empirical findings. Section 7 concludes the paper. The Appendix provides further descriptive evidence.

2 Literature review

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

Several studies have already focused on the effect of deregulation on several economic variables. Barone and Cingano [9] study the effects of regulation on downstream

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

At a more specific level, the studies aiming at assessing the impact of regulatory reforms in the electricity industry have primarily focused on their impact on prices and cost efficiency often attaining mixed conclusions. Steiner [43], using a panel dataset of 19 OECD countries for the 1987-1996 period, tries to assess the separate effect of different aspects of the reforms. Unbundling is not associated with significantly lower prices but with a lower industrial to residential price ratio and higher capacity utilisation rates and lower reserve margins. The introduction of a wholesale market reduces prices and the ratio of industrial to residential prices. For third party access the sign on prices and the price ratio is negative as expected but not significant. It is also not significant for the cost efficiency measures. Privatisation has a positive impact on prices and price ratios but has no significant effect on the cost efficiency measures.³ Another study by Fiorio, Florio and Doronzo [23] also looks at the impact of the regulatory reforms, in 15 EU countries, on household electricity prices over the 1978-2005 period. To measure the extent of the reform they use some components of the NMR index that we use in our study and they try to see how certain reform elements - public ownership, entry regulation and vertical integration - affect prices separately. They find that the reform variables do not affect prices in a statistically significant way.⁴

The evidence about the relationship between regulation and innovation, and its

³Hattori and Tsutsui [26] find similar results in a replication of Steiner's study for the same 19 OECD countries and extend it through 1999.

⁴Using the same sample and reform variables, and relying on their self-assessed satisfaction, Fiorio and Florio [22] find that a higher consumers' satisfaction is associated with public ownership of electricity industry.

theoretical understanding, seems even less straightforward. At a theoretical level, the debate on the relationship between innovation and competition, assuming that less regulation fosters competition, goes back to Schumpeter who famously argued that the prospect of an increased market power and large scale foster innovation (Schumpeter [41]). By contrast, Arrow [5] has argued that a firm earning substantial profits, resulting from its substantial market power, would rather focus on the protection of the status-quo instead of investing resources in trying to find a disruptive new technology. As argued by Motta [34] a “middle ground environment, where there exists some competition but also high enough market power coming from the innovative activities, might be the most conducive to R&D output”. This is also probably the best way to describe the theoretical and empirical relationship between competition and innovation that has been proposed by Aghion et al. [1]. If competition is low, an increase in competition may boost the incremental increase in profits resulting from innovation thus encouraging R&D investments aiming at “escaping competition”. On the contrary, too much competition may lead to more rapid and complete imitation that could reduce post-innovation rents of laggard firms and thus their incentive to catch up with the leader.

One of the first attempts to provide some evidence of the relationship between regulation and innovation, specifically for the electricity industry, is the paper by Dooley ([18]) that describes reductions in energy R&D investments occurring in several advanced countries following the deregulation of their respective energy sectors. The author argues that such reduced level of investments, occurred both in the public and private sectors, tends to shift the focus of investments towards shorter-term R&D. Thus, despite the short-term benefits experienced by customers who eventually face lower energy prices, a breakdown of energy R&D investment is very likely to have long-term negative impacts on national energy sectors, the economies, and environmental well-being. This view is reinforced by the observations of Jasmab and Pollit [29] and Sterlacchini [44]: from 1990 to 2004, the most advanced economies of the world have experienced an important reduction of the R&D expenditures devoted to energy or electricity. Moreover, patenting activity in the UK electricity sector seems

to follow a similar path as that of R&D investment, as reported by Jasmab and Pollit [30]. However, these papers just describe a trend so that it is not possible to infer the actual impact of the reform, within each country, and across countries, on innovation in the electricity industry.

To the best of our knowledge very few studies attempt, more specifically, to find a more precise empirical relationship between some measure of innovation (R&D expenditure, number of patents) and some measure of the intensity of regulation (over time) within each country. A recent example is given by Cambini et al. [14]. The study matches data on R&D budgets and EPO applications and a series of indicators of market regulation in the electricity sector from OECD (the same we use in our study), in order to test the impact of liberalization on the propensity to innovate in new energy technologies. Deploying a fixed-effects panel analysis, Cambini et al. [14] provide evidence of an increase in the aggregated Electricity R&D and in patenting activities following market deregulation. In particular, policies aimed at a reduction in vertical integration have a positive impact on both industry-level R&D and patenting while policies aimed at the reduction of public ownership of incumbent operators and the reduction of entry barriers mostly affect R&D expenditures.⁵ Another recent contribution focuses more precisely on the role of deregulation in affecting the trends of quantity and quality of innovation, in the electric equipment manufacturing sector, in the United States. Using patents as a metric for innovation, Sanyal and Ghosh [40] find that the 1992 Energy Policy Act had a specific role in the decline of patents granted to electricity equipment manufacturers showing that an increase in competition in the downstream generation sector, due to the reform, adversely affected the innovation behavior of electric equipment manufacturers.

Different from previous studies, our paper aims to evaluate the effect of deregulation on innovation, after a drastic reduction in regulatory intensity occurs, in a large sample of OECD countries during a relatively long time period (1985-2010). Exploiting sharp

⁵Relying on data from the telecommunication industry, Prieger [39] finds a similar relationship between regulation intensity and service innovations proposed by telecommunications providers in US.

reductions in regulation linked to the introduction of laws or reforms, we are able to identify a pre- and post-reform period and to perform a difference-in-difference analysis. In addition, we also test whether the effect of deregulation on innovation varies by regulatory component and with respect to the strength of the deregulatory process.

3 Historical background

The production and the supply of electricity have been typically considered a key aspect of economic activity with considerable social and environmental consequences. This fact, together with the characteristics of the industry (natural monopoly), have led in most countries to a heavy regulation of the whole sector. Regulation has taken different forms: public ownership of electricity supply assets or private ownership with strict regulation of many aspects of electricity production.

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

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

Ever since, the regulatory framework of the electricity supply industry has begun

to change rapidly. Most OECD countries have introduced reforms meant to stimulate competition by attempting to liberalize the industry.⁶ 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 markets where price is determined by supply and demand.

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 [38]). In Australia, the state of Victoria set up a pool in 1994, followed by New South Wales in 1996, at the same time New Zealand also established its Wholesale Electricity Market.

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

In the meantime, also the The European Commission started to push toward an

⁶A detailed overview of the reform process in OECD countries is provided by Al-Sunaidy and Green [2].

EU-wide policy of electricity deregulation. In particular the Commission directives of 1996 [19] and 2003 [21] were putting forward an institutional setting aimed at the creation of a European wide competitive electricity market. The directives had the dual objective of requiring, on the one hand, a certain level of deregulation, at national level, to each Member State and, on the other hand, to fix trading rules and favor cross-border transmission links across Member States. The main objectives, fixed by the second directive, were to obtain by July 2007, the complete unbundling of the several segments of the market in each Member State, free entry at the generation level, full market opening, promotion of renewable resources, definition of the functions of the regulator, the creation of a single European market for electricity.⁷

4 Estimation strategy

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

$$\begin{aligned} \ln_patents_{it} = & \alpha + \beta \ln_regulation_{it} + \gamma PolicyChange_{it} + \\ & \delta \ln_regulation X PolicyChange_{it} + \eta_i + \theta_t + X'_{it} \omega + \varepsilon_{it} \end{aligned}$$

where i refers to the country and t to the year. $\ln_patents$ is the outcome we are interested in, which is the log-transformation of the patent count at the country-year

⁷The European Commission has also complemented its effort in achieving the objectives fixed by the Directives by keeping under the scrutiny of competition law the incumbent electricity utilities whenever they were abusing of their pre-existing market power in the newly liberalized market (European Commission [20]).

level. We add 0.10 to both the patent count and some regulatory components (entry regulation, market structure and public ownership) to include observations that would otherwise be associated with missing values. The variable *ln_regulation* is the log-transformation of the index measuring the intensity of regulation. *PolicyChange* is a dummy variable indicating whether the drop in the regulation occurred or not in a given country. *ln_regulationXPolicyChange* is the key variable, which is the interaction between *ln_regulation* and *PolicyChange* and that carries the DID coefficient δ . η and θ control for unobserved country fixed effects and symmetric business cycle shocks, respectively. Except for the dummy variables, we decided to take the main variables in log-levels to ease the interpretation of the estimates, which therefore are elasticities. The matrix X includes further controls at the country-year level, namely GDP growth rate, and exports and imports as shares of GDP. ε is assumed to be an idiosyncratic term, unrelated with the other independent variables. However, the standard errors are robust and clustered at the country level, i.e. we de facto allow for correlation between residuals.

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

5 Data

In this section, we report the data sources used to build up the final data set and the related variables. We also discuss the descriptive statistics and preliminary evidence concerning the link between regulation and innovation in the electricity industry.

5.1 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. We retrieve our policy variable, regulation intensity of the electricity industry, and outcome variable, patent grants at EPO, from the first and second data sources, respectively. The latter source allows us to use 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 countries⁸ 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 the regulation intensity associated with a change in the legal framework. Because of the missing observations, our panel is unbalanced. All of the reported findings refer to the electricity industry, being the latter our sole unit of analysis.

Our policy variable is the NMR index developed by the OECD. More details on the NMR indicators can be found in Conway and Nicoletti [17], who provide an in-depth description of the indicators for each non-manufacturing industry.⁹

The NMR index focuses on industrial regulations that restrain efficiency-enhancing competition in each regulated sector: each sectoral index is built with the sole purpose of quantifying regulatory measures that restrict competition whenever market conditions are otherwise open to it, any other policy goal is not taken into account. In general, all the indexes are constructed in a similar way across sectors. They gather information concerning four main areas: barriers to entry, state control, degree of vertical integration and market structure. The information gathered is objective (as opposed to

⁸Australia, 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.

⁹These indexes are complementary to indicators of economy-wide regulation also published by the OECD (see Conway et al. [16]).

survey-based) since it is based on specific measurement criteria related to regulations and market.¹⁰ For each sector the NMR index is computed using a bottom-up approach: for each of the four main areas the regulatory score, which provides a *low-level* indicator, is computed using a specific algorithm. Each low-level indicator measures on a scale from 0 to 6 (from least to most restrictive) the presence of barriers to entry, the amount of state control, the degree of vertical integration and concentration (market structure) each representing a measure of a different kind of restriction to competition. The results so obtained are finally aggregated into summary indicators by sector of activity using pre-determined weights.¹¹

The NMR indexes cover energy, transport and communication over the 1975-2013 period in OECD countries. We use the NMR index for the electricity sector. Like the other sectoral indexes it can take value between 0 and 6 and it is calculated as the weighted average (with equal weights) of the four sub-indicators mentioned above.¹² A low level of the index denotes a high level of competition or, alternatively, a low level of regulation, within the sector.

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

The second sub-indicator, *Public Ownership*, aims at measuring the level of public ownership of the largest companies operating in the various segments of the whole

¹⁰The value of each component is determined from the answer to questionnaires sent by the OECD to experts on a regular basis.

¹¹As mentioned also in Conway and Nicoletti [17] even if this approach involves a degree of discretion (in the choice scores and aggregation weights) it has nonetheless the merit of being rather transparent and consistent over time and across sectors.

¹²For certain countries and for certain years the sub-indicators on market structure is missing. Whenever it is the case, the total index is built giving equal weight to the three available sub-indicators.

industry. The inclusion of this dimension may be helpful in detecting soft regulations often characterizing the management of public companies, which may enjoy state guarantees and low financial stringency. Privatization is not necessarily a condition for liberalization: competition and incentive-based regulation may still be a viable option in presence of publicly owned companies. Nonetheless, there are compelling arguments suggesting substantial economic benefits deriving from privatization, in particular if it is associated to effective market design, competition and regulation (Newbery [35]). Among the other things, this may be explained by the influence of policy makers pursuing a political agenda, which may considerably influence public ownership of firms and negatively affect their economic performance (Shleifer and Vishny [42]), leading to an inefficient level of investment and an inefficient allocation of public resources.

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

Finally, the sub-indicator, *Market Structure* provides a measure of the degree of concentration (and hence, indirectly, of their competitiveness) of the various segments of the whole market by measuring the market share of the largest company in each segment.

Using an indicator rather than a more direct measure of competition such as the market share or the number of competing firms presents the advantage of “mitigating” the potential endogeneity issue arising when attempting to measure competition (Cette

et al., 2013). Bourls et al. [12] argue that these indicators have the clear advantage of accounting for three major issues: the endogeneity bias, the effects of competitive pressures in upstream industries on downstream industries and the role played by public policies that affect competition. Unlike widely used indicators exploited for this type of analysis when looking at market power or market structure, which are not univocally related to product market competition, the OECD NMR indicators provide a more direct link to policy and regulation.

Our outcome variable is the number of patents granted by the EPO (1985-2010) in the section (IPC) H, which refers to the electricity industry. Patents are often used as a reliable measure of innovation because they are subject to formal tests of ‘novelty’ and ‘non-obviousness’. Patents may be seen as ‘successful innovations’ and typically have a close link to inventions. There could exist a number of drawbacks in using patent counts as a measure of innovation. For instance, some innovations are not patented because firms prefer to protect their inventions using other methods, such as secrecy or lead time. In addition, differences across countries and industries in the patent law and regulations affect the propensity to patent and make more difficult a comparison over time. We partly cope with some of these issues as we (i) focus on a single industry, (ii) include controls for time and country specific effects, and (iii) perform a number of robustness checks on a relatively homogeneous group of countries in terms of patent law and regulations (e.g. European countries). A further critique, raised by Jamasb and Pollitt [28], concerns the fact that some patents relevant to the electricity sector are classified under classes different from H (e.g. F03 “Machines or engines for liquids” and G21 “Nuclear physics; nuclear engineering”). Although we agree that the patent class H may not include all patents relevant to the electricity industry, the OECD database does not inform on such patent classes and therefore we focus exclusively on IPC H, which is however a good proxy at the country level of the innovations introduced in the electricity sector.

5.2 Descriptive evidence

We describe the sample composition and policy reforms in *Table 1* that shows the number of observations, the observation periods and the year of the policy change (i.e., a sudden drop in the NMR index) we consider in the analysis. For the sake of consistency, for each country (listed in alphabetical order), we always consider the first policy change, in chronological order (given the availability of data), whenever several policy changes occur. We do not necessarily consider the most drastic one. Interestingly, we are able to associate a change in the legal framework (last column in the table) with each of the policy changes we consider. This table, combined with *Figure 1* and the graphs collected in the Appendix, provides detailed information on the structure of the sample, the definition of the *PolicyChange* variable and potential associations between the after-reform period and evolution of patent grants.

[*Table 1 and Figure 1 about here*]

Figure 2 shows the average regulation intensity (i.e., the average value of the NMR index) in the electricity sector by country over the sample period (1985-2010). As one could already infer from *Figure 1*, the 5 highest average regulatory intensities are observed for Mexico, South Africa, Iceland, Greece and France, whereas the lowest 5 are observed for Japan, UK, Spain, Norway and Germany. On average, policy changes occur between 1998 and 1999, respectively the mean and median values. This is an interesting information to be used while describing the evolution of the average patent grants in the electricity sector (see *Figure 3*). Indeed, it appears to exist an inverted U-shaped relationship between the number of patents and the regulation index by collapsing our sample by observational year. Specifically, after-reform years are associated with a decreasing number of patents as a whole. This descriptive finding is remarkably consistent with the results of Aghion et al. [1] who have famously described an inverted U-shaped relationship between competition and innovation. In our framework a very high level of regulation intensity describes a situation where competition is essentially absent. A decrease of the NMR index can then be associated with an increase of the

competitiveness of the market. The prospect of new entries may induce the incumbent firms to push on innovation in order to keep a competitive distance with their new rivals. Once some level of competition is already present in the market, further deregulation may lead to a situation where, by the very same reasoning, the prospect of low post-innovation rents may hinder the incentive to innovate.

[*Figures 2 and 3 about here*]

Figures 4 report a linear fit between patent grants and regulation 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. This is in line with what found by Cambini et al. [14].

[*Figure 4 about here*]

Table 2 reports observations (obs), mean and standard deviation (SD) for the outcome variables (*patents* and *ln_patents*), and the control variables *GDP growth rate*, and *export GDP ratio* and *import GDP ratio*. The table also reports descriptive statistics of the NMR index and its low-level components. A higher regulatory burden seems to be associated with *Public Ownership* and *Vertical Integration* compared to the other components, even in the period subsequent to the sharp change in regulation (*regulationXPolicyChange*). Among the regulatory components, larger reductions are observed for *Entry Regulation* and *Market Structure*, which respectively decrease by 79 % and 65 %, whereas both *Public Ownership* and *Vertical Integration* decrease by slightly more than 50 %.

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

[*Tables 2 and 3 about here*]

6 Results

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

We infer from the estimates on *ln_regulation* 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. This decrease is about 2.72 patent grants. When focusing on our treatment variable, *ln_regulationXPolicyChange*, it turns out that (further) deregulation, following a sharp reduction in the intensity of regulation, appears to hinder innovation. Specifically, we find that a 1 % reduction in the NMR index, during the post-reform period, significantly decreases the number of patent grants by 1.76 %. This may imply that an excessively feeble regulatory setting may generate disincentives to innovate, probably due to the lower profitability associated with a tougher competitive environment. Of course, we are not able to directly test such hypothesis because we have no information on firm profitability at the industry level. In any case, any welfare evaluation goes beyond the scope of our study. Nonetheless, this results seems to shed some light on the seemingly conflicting findings concerning the relationship between deregulation and innovation in the electricity sector.

[*Table 4 about here*]

Benefiting from the information on the different components of the NMR index, we try to disentangle the role specifically played by changes occurring in each of the

specific areas of regulation they cover in affecting innovation. *Table 5* reports estimates by regulatory component. In this table and in the following ones, all specifications include the full set of controls. *Entry Regulation* appears to be the main driver of the overall effect of deregulation on patents, i.e. market contestability seems to be the main factor contributing to a decrease of the incentive of the firms to innovate after a drastic reform has occurred. Indeed, we find that facilitating the entry of firms in the electricity sector in the post-reform periods decreases patents grants considerably: the associated elasticity is 3.48. Examining the results for *Market Structure* and *Public Ownership*, we observe that the treatment variable carries a similar and significant coefficient of about 0.25. This elasticity is however considerably lower (about 14 times) than the one associated with *Entry Regulation*, showing thus the different relevance of different policy measures when it comes to their impact on innovation. Finally, the channel *Vertical Integration* appears not to matter much, given the size of the elasticity and its insignificant statistical level.

[*Table 5 about here*]

Finally, we try to find empirical evidence of the pattern described by *Figure 3*, which shows an inverted U-shaped relationship between the average regulation intensity and innovation by year. In order to do so we divide the sample in two complementary subsets: countries whose average NMR index is respectively below or above the threshold value of 4. Although the choice of this threshold value is somehow arbitrary, it appears to be fairly close to the turning point of the regulation – innovation pattern described by *Figure 3*. The ‘below-threshold’ sub-sample includes Australia, Austria, Belgium, Brazil, Finland, Germany, Japan, Norway, Spain, and United Kingdom. The ‘above-threshold’ sub-sample includes the remaining countries. As one can see from *Table 6*, we find that for the ‘below-threshold’ sub-sample the signs of the coefficients associated with $\ln_regulation$, $PolicyChange$ and $\ln_regulation \times PolicyChange$ are the same as those found for the entire sample (as reported by *Table 3*). However, quite interestingly, the estimates for the ‘above threshold’ sub-sample show opposite signs. This may entail that a decrease in regulation intensity following a drastic policy change

fosters (hinders) innovation in markets with a high (low) level of regulation intensity. This evidence is consistent with the pattern observed in *Figure 3* because it seems to point out that regulation may have opposite effects on patenting activity depending on whether one considers countries experiencing a relatively more or less intense liberalization process. Specifically, we find that a 1 % reduction in regulation intensity, in the after-reform period, increases the number of patents by 6.79 % for countries belonging to the ‘above- threshold’ sub-sample, whereas a similar reduction in the treatment variable decreases the number of patents by 2.37 % for the complementary sub-sample.

[*Table 6 about here*]

Finally, *Table 7* reports a few robustness checks that we perform to evaluate whether and how (i) the sample composition, columns (1)-(2), (ii) the unbalanced nature of the sample, column (3), (iii) a different imputation in the patent count,¹³ column (4), (iv) taking the lead values of *PolicyChange* and *regulationXPolicyChange*, column (5), (v) using the patent granted by USPTO (US Patent and Trademark Office) as dependent variable, column (5), affect our results. Specifically, the focus on relatively homogeneous country groups (European and historical EU members) allows us to remove potential bias arising from differences in patent legislations. The exclusion of countries not observed for the whole sample period tests the influence of observations related to country entering the sample later than 1985. Using a different imputation of the dependent variable, and allowing for anticipation effects by taking the first lead of the treatment variable and treatment period are informative checks to corroborate our main findings. Lastly, performing the same analysis on an alternative measure of innovation (patents granted by USPTO) in the electricity sector tests the external validity of this analysis and its policy implications. All robustness checks show treatment effects in line with the main results (see *Table 4*).

[*Table 7 about here*]

¹³The argument of the logarithm is $(1 + patents)$ rather than $(0.10 + patents)$.

7 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 sector. 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 the firm's willingness to innovate. Two opposing forces seem to be at stake (in line with Aghion et al. [1]). A radical liberalization, inducing a complete opening of the market and a considerable increase of the competitive pressure firms have to face, may hinder the incentive to innovate as the prospective profit increase deriving from innovation may be too meager. On the contrary in a tightly regulated market the arrival of new competitors may prompt the incumbent (the entrant) to push on innovation in order to protect (or increase) its market share.

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

We find that, even if one can associate deregulation, in general, with an increase in patent grants, a further decrease in regulation intensity, after a drastic reform has occurred, has the opposite effect on innovation. Quite interesting, the main driver of this force seems to be the degree of contestability of the market. Finally, we divide the sample in two complementary groups: countries with a relatively high regulation intensity and countries with a relatively low regulation intensity (i.e., countries whose

average NMR index is, respectively, above and below a value of 4). We find that a further decrease in regulation intensity following a reform has opposite effects on innovation across the two sub-samples reflecting the fact that deregulation may indeed produce two countervailing forces driving innovation in opposite directions, depending on whether one considers countries experiencing a more or less intense liberalization processes in their electricity markets. This may have the rather stark implication that, in a long term perspective, settling for some “middle ground environment” may be a better option than pushing the liberalization of the electricity sector too far. Indeed, the immediate positive effects one may obtain by fully liberalizing the market, in terms of production efficiency and price reduction, may be offset, in the long term, by a reduced innovativeness that may have significant implications considering the many challenges (meeting the growing energy demand using more efficient and sustainable ways to produce it) that the industry is facing.

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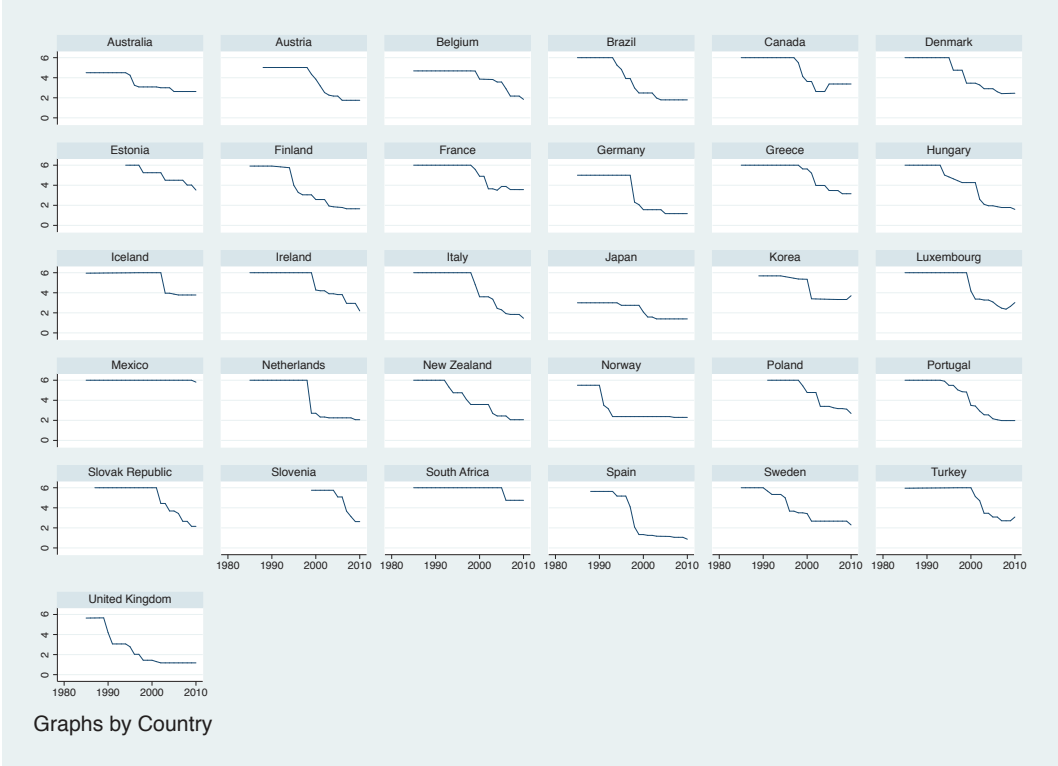
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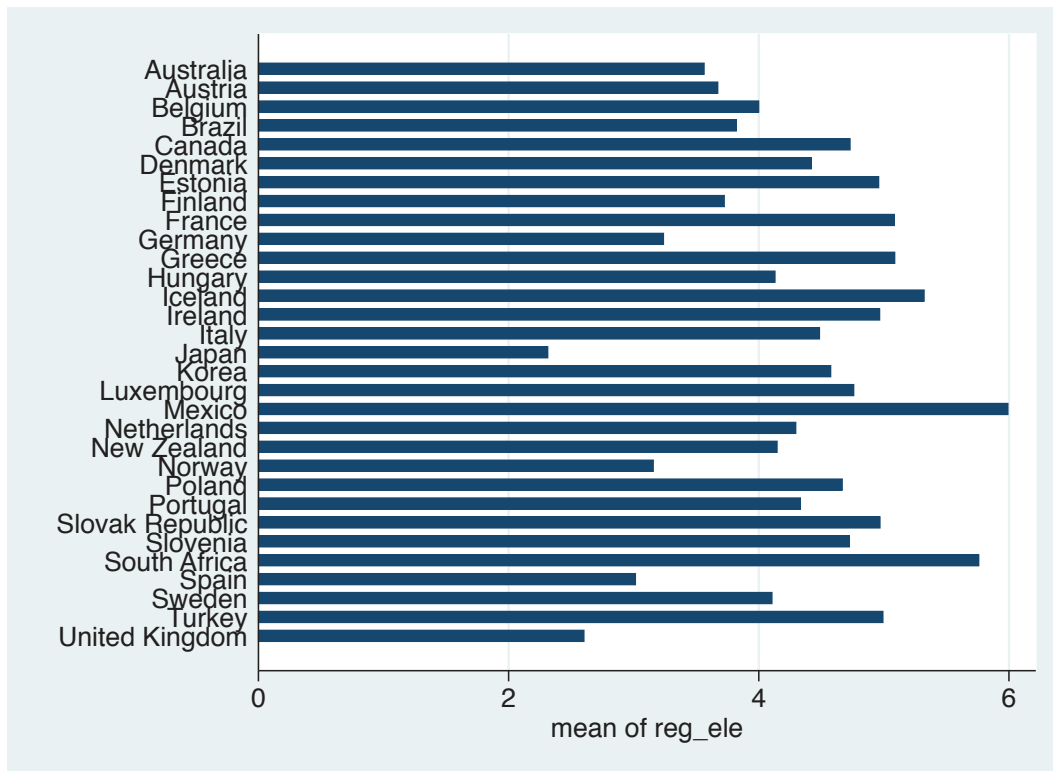
Figures and Tables

Figure 1: *Regulation intensity in the electricity sector over time and by country*



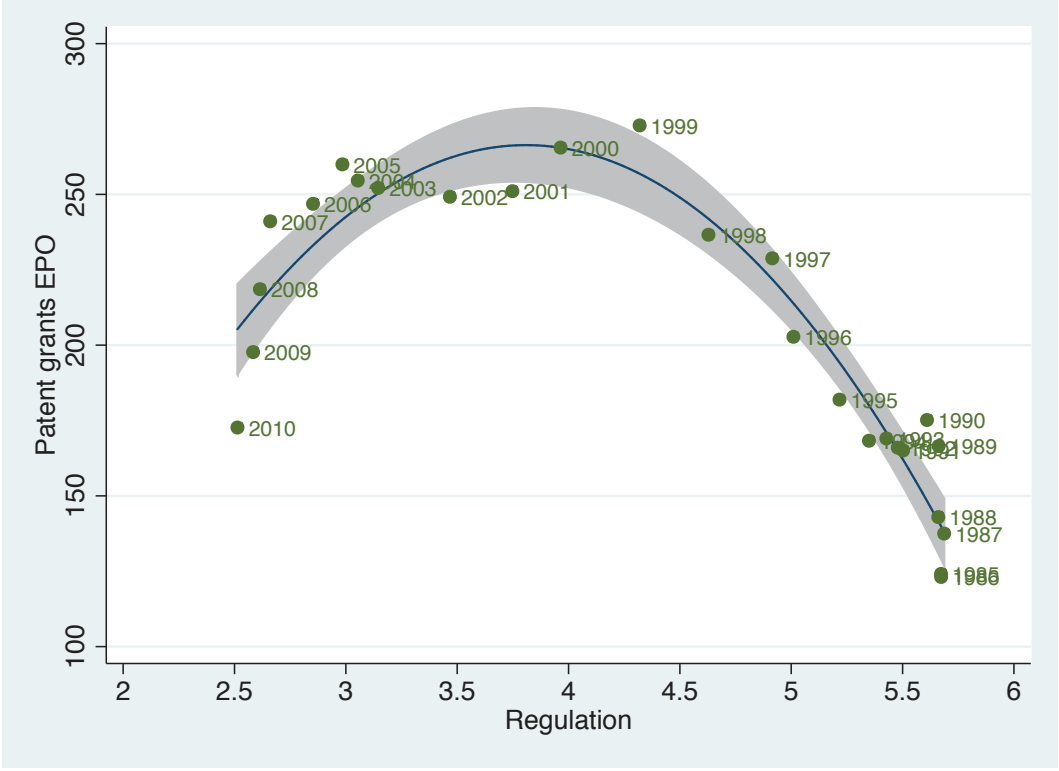
Source: OECD ETCR Data Regulation.

Figure 2: *Average regulation in the electricity sector by country*



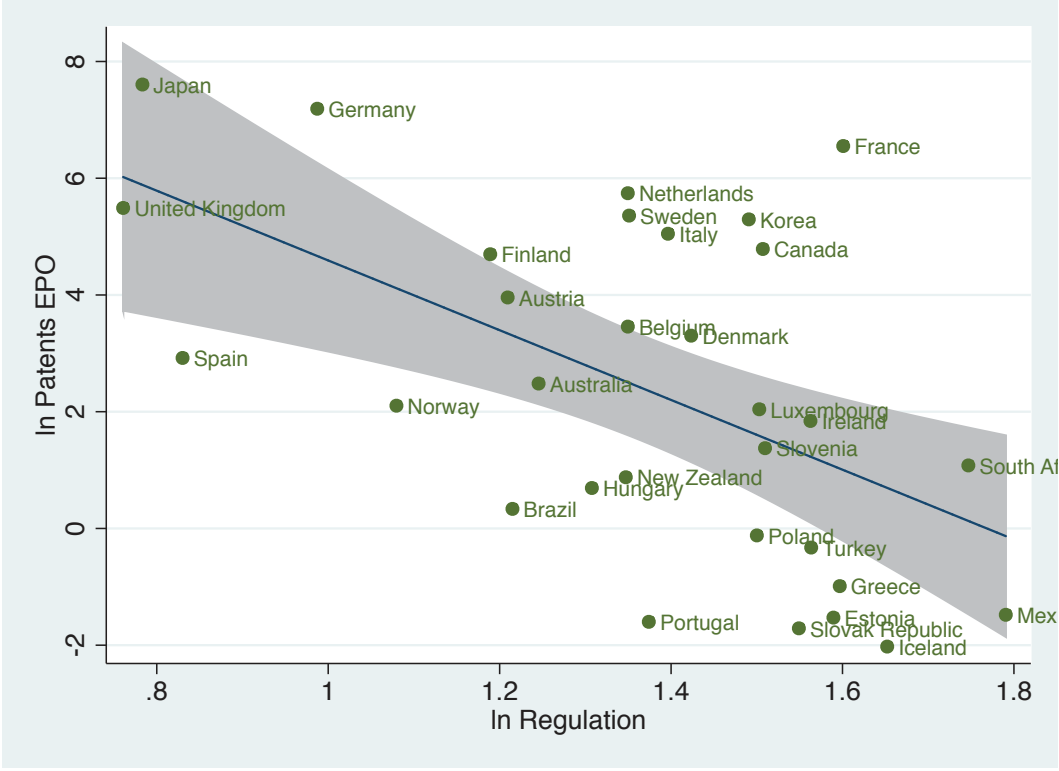
Source: OECD ETCR Data Regulation.

Figure 3: Average patent grants at EPO and regulation in the electricity sector by year



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

Figure 4: *Linear relationship between patent grants at EPO and regulation in the electricity sector*



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

Table 1: *Sample composition and policy reform*

<i>ID</i>	<i>Country</i>	<i>Observations</i>	<i>Period</i>	<i>Policy Change</i>	<i>Liberalization</i>
1	Australia	26	1985-2010	1995	Electricity Industry Act for Victoria (1994)
2	Austria	23	1988-2010	1999	Law of Electricity Supply (1998)
3	Belgium	26	1985-2010	2000	Law for the Organisation of the Electricity Market (1999)
4	Brazil	26	1985-2010	1994	Concession Law and IPP Law (1995)
5	Canada	26	1985-2010	1998	Energy Competition Act (1998)
6	Denmark	26	1985-2010	1996	Amendment to Danish Supply Act (1996)
7	Estonia	17	1994-2010	1998	Energy Law (1997)
8	Finland	26	1985-2010	1995	Electricity Market Act (1995)
9	France	26	1985-2010	1999	Law No. 2000-108 (2000)
10	Germany	26	1985-2010	1998	Act on the Supply of Electricity and Gas (1998)
11	Greece	26	1985-2010	1999	Electricity Law (1999)
12	Hungary	26	1985-2010	1994	Electricity Act (1994)
13	Iceland	26	1985-2010	2003	Electricity Act (2003)
14	Ireland	26	1985-2010	2000	Electricity Regulation Act (1999)
15	Italy	26	1985-2010	1999	Bersani Decree (1999)
16	Japan	26	1985-2010	1995	Amendments to Electric Utility Law (1995)
17	Korea, South	22	1989-2010	2001	Act on Promotion of Restructuring of the Electricity Power Industry (2000)
18	Luxembourg	26	1985-2010	2000	Law on the organization of the electricity market (2000)
19	Mexico	26	1985-2010	2010	Energy reform (2008)
20	Netherlands	26	1985-2010	1999	The Electricity Act (1998)
21	New Zealand	26	1985-2010	1993	Energy Act and Companies Act (1992)
22	Norway	26	1985-2010	1991	Energy Act (1990)
23	Poland	20	1991-2010	1999	Energy Act (1997)
24	Portugal	26	1985-2010	1994	Decree Laws 182/95, 183/95, 184/95,185/95 (1995)
25	Slovak Republic	24	1987-2010	2002	Amendment to the Law on Energy of 1998 (2001)
26	Slovenia	12	1999-2010	2005	Amendment to the Energy Act of 1999 (2004)
27	Spain	23	1988-2010	1994	Electricity Act (1994)
28	South Africa	26	1985-2010	2006	Electricity regulation act (2006)
29	Sweden	26	1985-2010	1991	Governmental Bill 1990/91:87 (1991)
30	Turkey	26	1985-2010	2001	Electricity Market Law (2001)
31	United Kingdom	26	1985-2010	1990	Electricity Act (1989)
Total		765	1985-2010		

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

Table 2: *Descriptive statistics*

	<i>Obs</i>	<i>Mean</i>	<i>SD</i>
<i>Outcome variable</i>			
patents	765	205.48	471.34
<i>Key policy variables</i>			
<i>(NRM index)</i>			
regulation	765	4.30	1.64
regulationXPolicyChange	765	1.59	1.73
<i>(Entry regulation)</i>			
regulation	765	3.55	2.60
regulationXPolicyChange	765	0.74	1.44
<i>(Market structure)</i>			
regulation	554	3.18	2.66
regulationXPolicyChange	554	1.10	1.87
<i>(Public ownership)</i>			
regulation	765	4.58	1.94
regulationXPolicyChange	765	2.06	2.47
<i>(Vertical Integration)</i>			
regulation	765	5.31	0.87
regulationXPolicyChange	765	2.47	2.41
<i>Control variables</i>			
GDP growth rate	765	2.71	3.15
import GDP ratio	765	38.20	22.54
export GDP ratio	765	39.50	25.77

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

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

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

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

Table 4: *DID results – overall regulation index*

	<i>ln_patents_EPO</i>			
	(1)	(2)	(3)	(4)
ln_regulation	-10.44*** (2.23)	-1.95** (0.71)	-1.47** (0.70)	-1.40* (0.71)
PolicyChange	-14.05*** (3.73)	-2.04** (1.01)	-2.80*** (1.00)	-2.72*** (1.01)
ln_regulationXPolicyChange	7.87*** (2.15)	1.68** (0.63)	1.81*** (0.61)	1.76*** (0.61)
Country FE	No	Yes	Yes	Yes
Year FE	No	No	Yes	Yes
Other controls	No	No	No	Yes
<i>Clusters</i>	31	31	31	31
<i>Observations</i>	765	765	765	765
<i>R-squared</i>	0.22	0.92	0.93	0.93

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

Table 5: *DID results – by regulatory component*

	<i>ln_patents_EPO</i>			
	(1)	(2)	(3)	(4)
	<i>Entry regulation</i>	<i>Market Structure</i>	<i>Public Ownership</i>	<i>Vertical integration</i>
ln_regulation	-3.38*** (1.13)	-0.39** (0.14)	-0.03 (0.09)	-0.76 (0.51)
PolicyChange	-5.06*** (1.93)	-0.05 (0.12)	-0.16 (0.09)	0.00 (0.00)
ln_regulationXPolicyChange	3.48*** (1.12)	0.25*** (0.07)	0.25*** (0.08)	0.07 (0.08)
<i>Clusters</i>	31	31	31	31
<i>Observations</i>	765	554	765	765
<i>R-squared</i>	0.93	0.95	0.93	0.93

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

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

	<i>ln_patents_EPO</i>	
	(1)	(2)
	<i>below threshold</i>	<i>above threshold</i>
<i>ln_regulation</i>	-2.24* (1.05)	7.70** (3.00)
<i>PolicyChange</i>	-3.80* (1.72)	12.48** (5.21)
<i>ln_regulationXPolicyChange</i>	2.37* (1.05)	-6.79** (2.92)
<i>Clusters</i>	10	21
<i>Observations</i>	254	511
<i>R-squared</i>	0.95	0.92

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

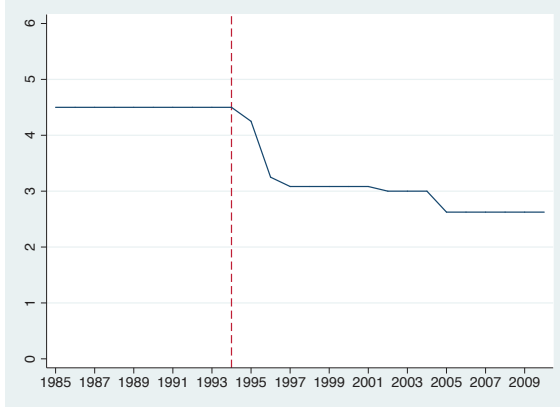
Table 7: *Robustness checks*

	<i>ln_patents_EPO</i>					<i>ln_patents_USPTO</i>
	(1)	(2)	(3)	(4)	(5)	(6)
	<i>European countries</i>	<i>Historical EU countries</i>	<i>Balanced panel</i>	<i>Different imputation</i>	<i>Lead value PolicyChange</i>	<i>Patent grants at USPTO</i>
<i>ln_regulation</i>	-1.81 (1.15)	-2.36* (1.12)	-1.24 (0.76)	-0.89* (0.45)	-1.40* (0.71)	-0.53 (0.40)
<i>PolicyChange</i>	-3.98** (1.79)	-4.58** (1.90)	-2.60** (1.02)	-1.45** (0.61)	-2.63** (0.99)	-1.21** (0.57)
<i>ln_regulationXPolicyChange</i>	2.39** (1.06)	2.73** (1.13)	1.70** (0.63)	0.98** (0.38)	1.71*** (0.59)	0.81** (0.38)
<i>Clusters</i>	21	17	24	31	31	31
<i>Observations</i>	509	434	624	765	734	641
<i>R-squared</i>	0.95	0.96	0.94	0.96	0.94	0.95

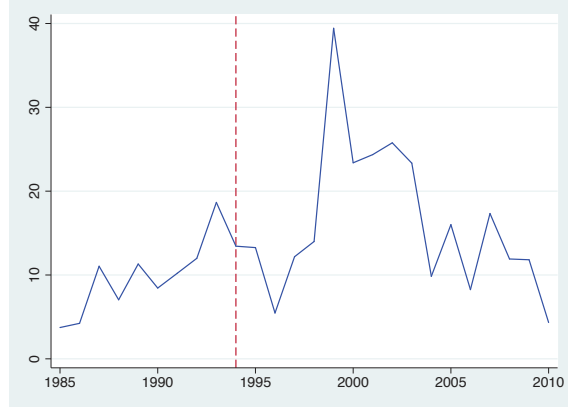
Notes: All specifications include the full set of controls. Standard errors are robust and clustered at the country level. *, **, and *** denote significance at the 10, 5, and 1 percentage level, respectively. The sub-sample ‘European countries’ includes Austria, Belgium, Denmark, Estonia, Finland, France,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

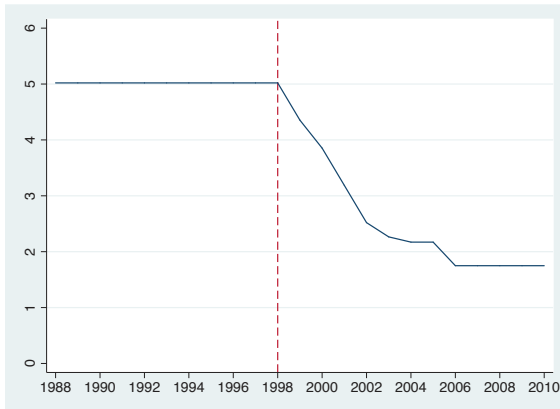
(a) Australia: Regulation



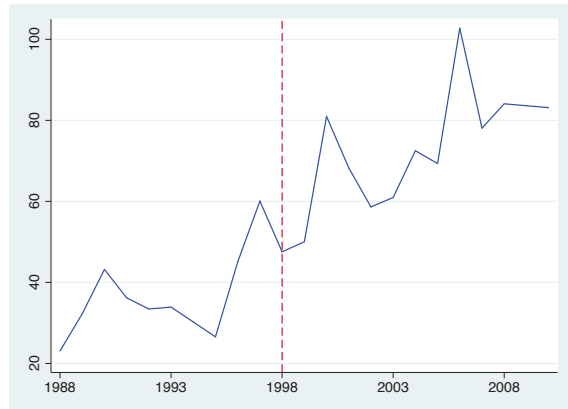
(b) Australia: Patent grants (EPO)



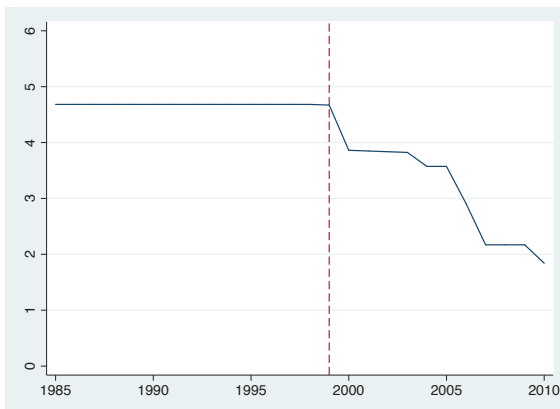
(c) Austria: Regulation



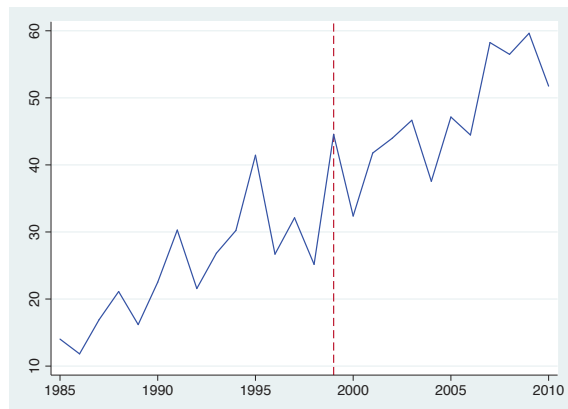
(d) Austria: Patent grants (EPO)



(e) Belgium: Regulation

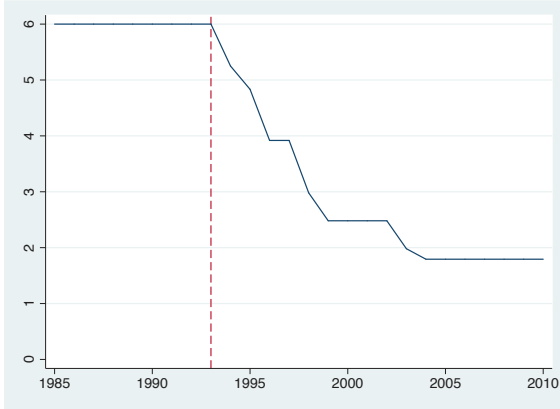


(f) Belgium: Patent grants (EPO)

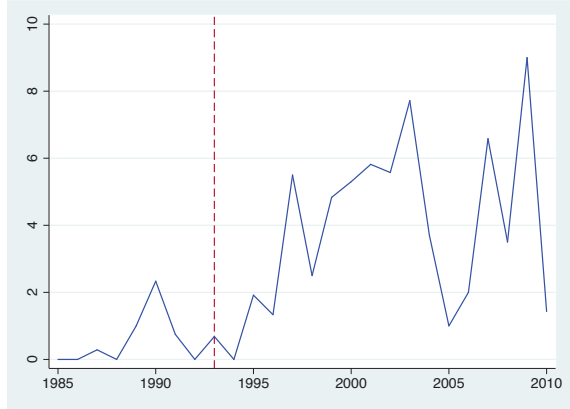


Source: OECD ETCR Data Regulation and OECD Patent Grants (Priority date, IPC H – Electricity).

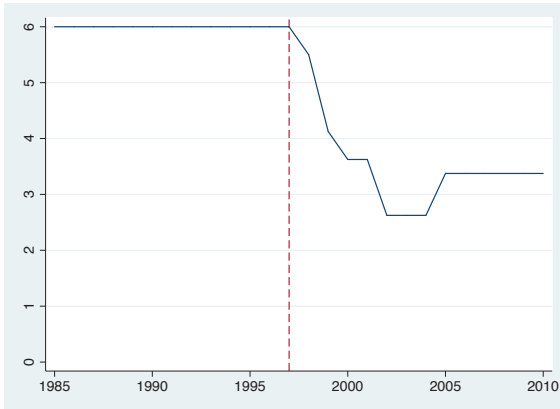
(a) Brazil: Regulation



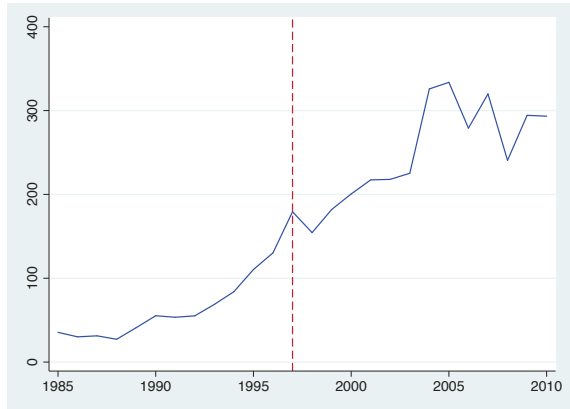
(b) Brazil: Patent grants (EPO)



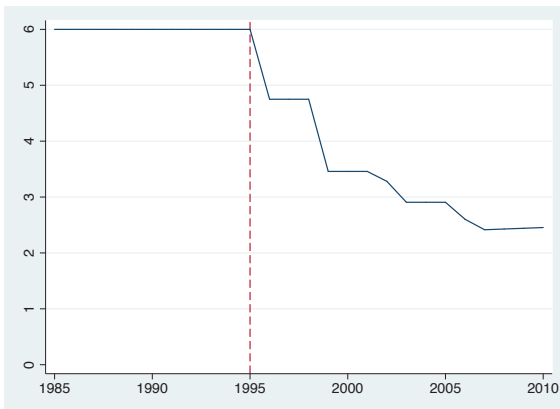
(c) Canada: Regulation



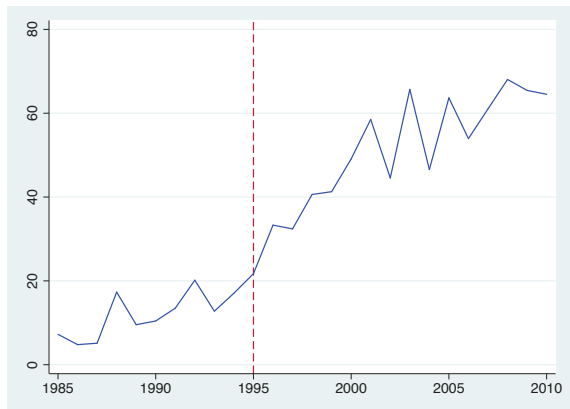
(d) Canada: Patent grants (EPO)



(e) Denmark: Regulation

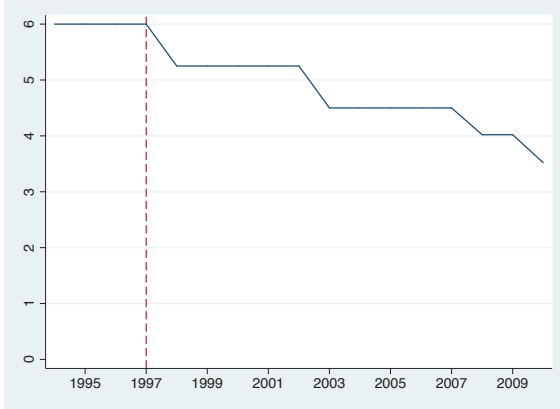


(f) Denmark: Patent grants (EPO)

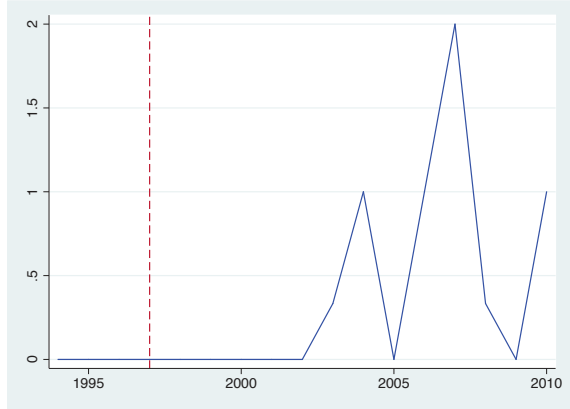


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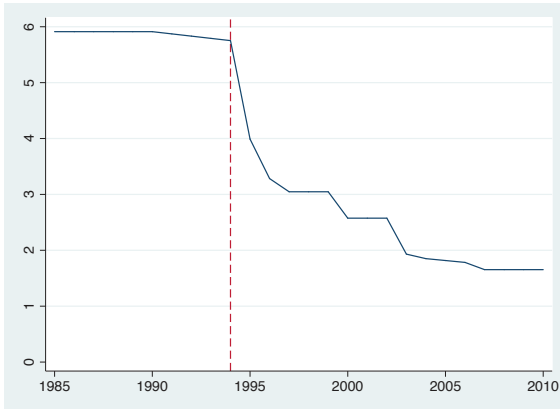
(a) Estonia: Regulation



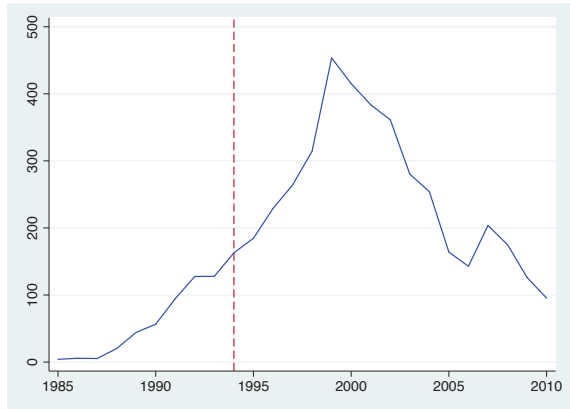
(b) Estonia: Patent grants (EPO)



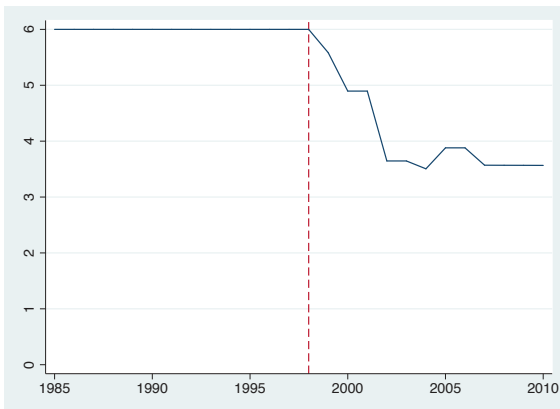
(c) Finland: Regulation



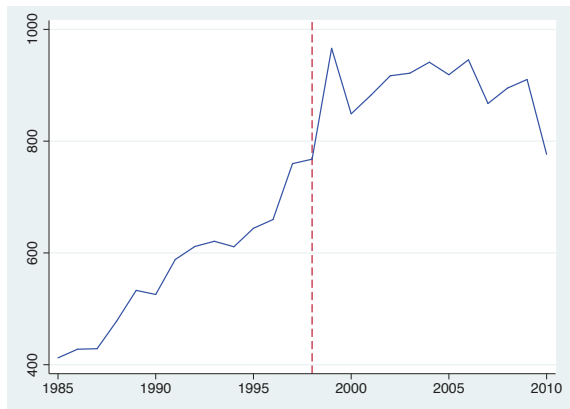
(d) Finland: Patent grants (EPO)



(e) France: Regulation

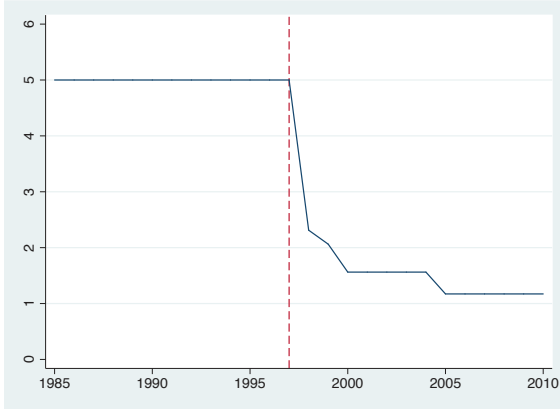


(f) France: Patent grants (EPO)

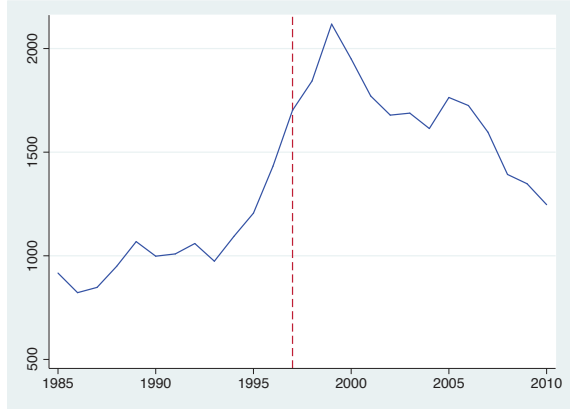


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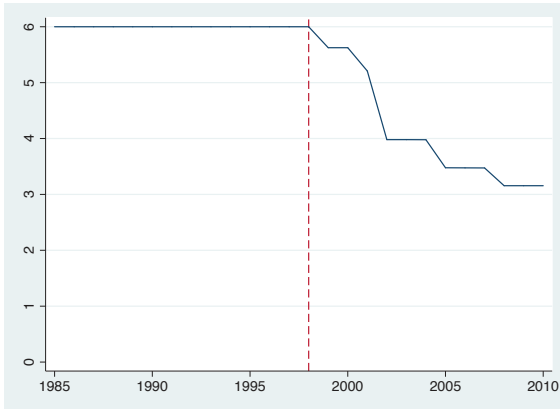
(a) Germany: Regulation



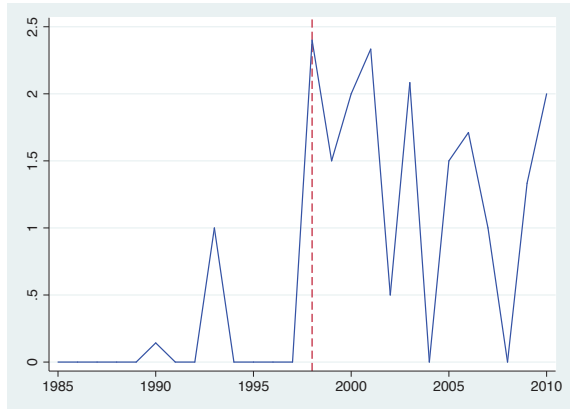
(b) Germany: Patent grants (EPO)



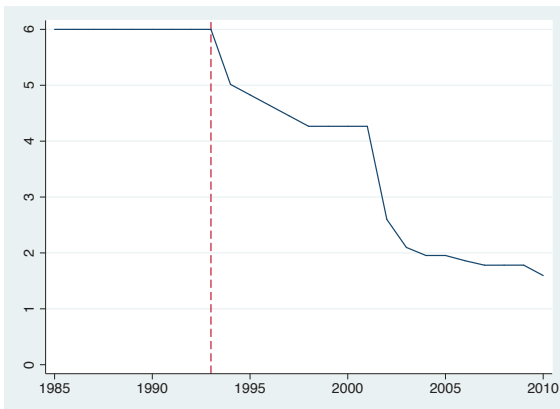
(c) Greece: Regulation



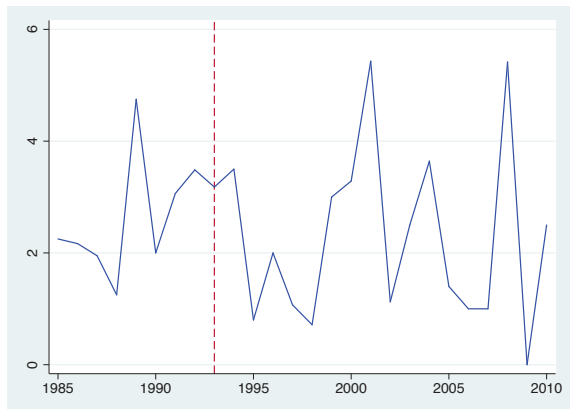
(d) Greece: Patent grants (EPO)



(e) Hungary: Regulation

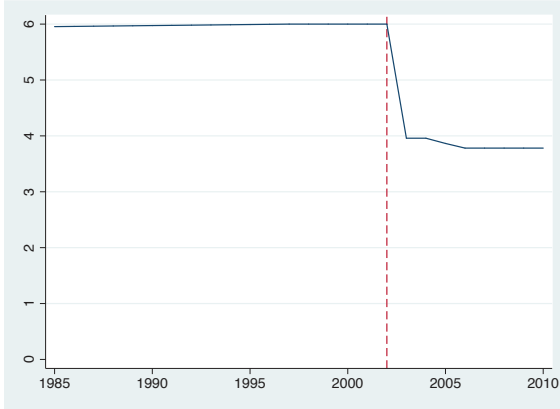


(f) Hungary: Patent grants (EPO)

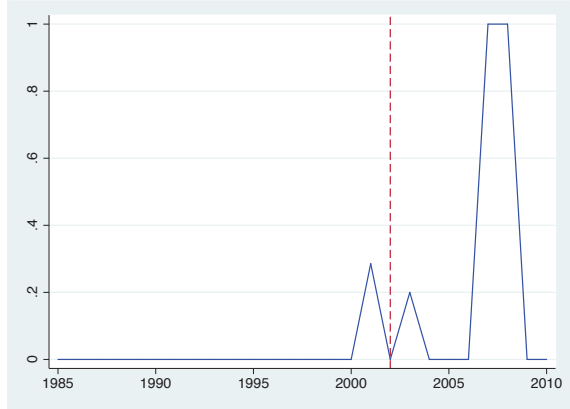


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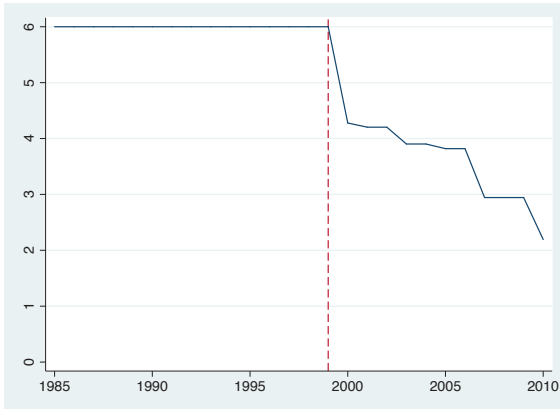
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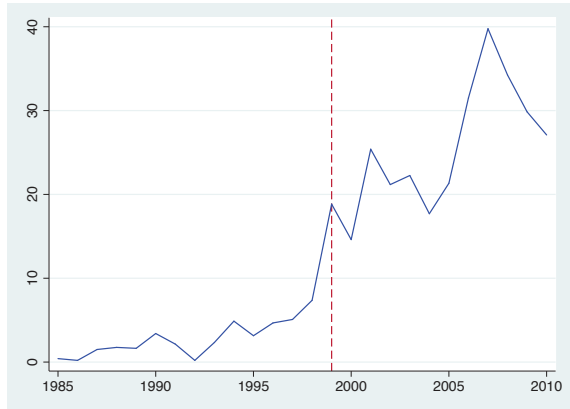
(b) Iceland: Patent grants (EPO)



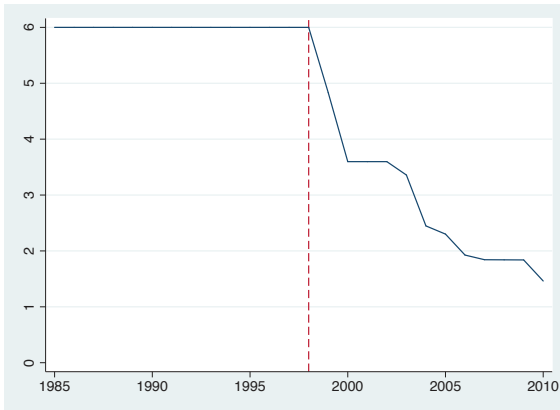
(c) Ireland: Regulation



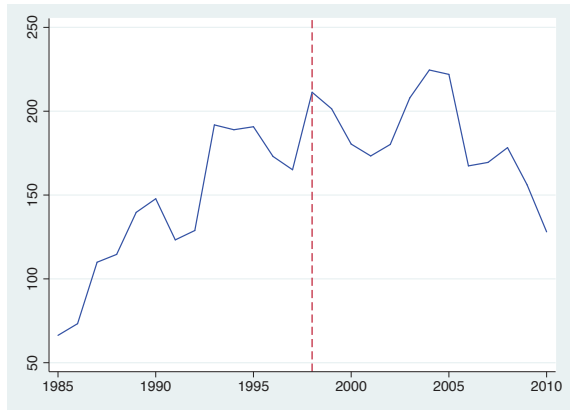
(d) Ireland: Patent grants (EPO)



(e) Italy: Regulation

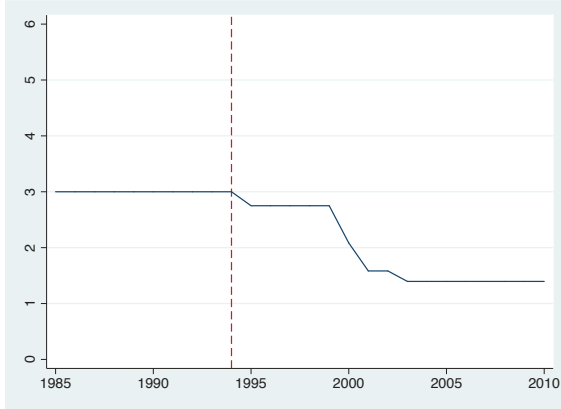


(f) Italy: Patent grants (EPO)

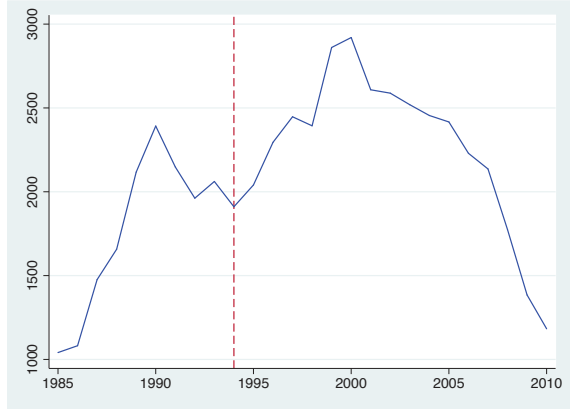


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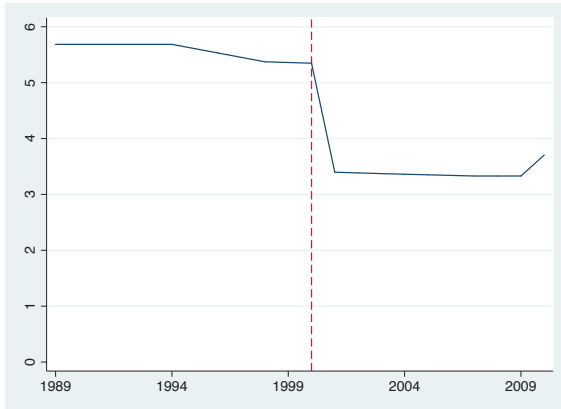
(a) Japan: Regulation



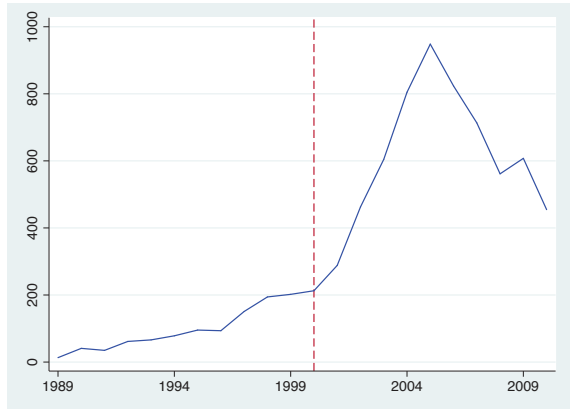
(b) Japan: Patent grants (EPO)



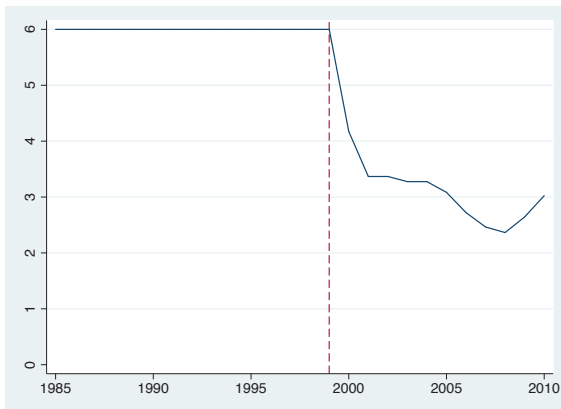
(c) Korea, South: Regulation



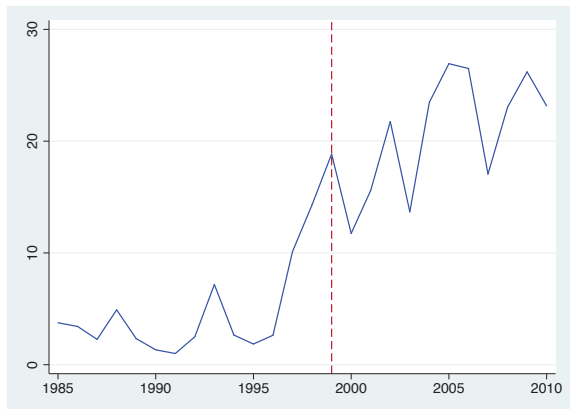
(d) Korea, South: Patent grants (EPO)



(e) Luxembourg: Regulation

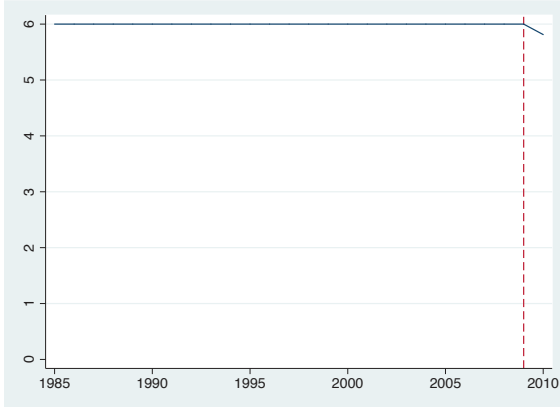


(f) Luxembourg: Patent grants (EPO)

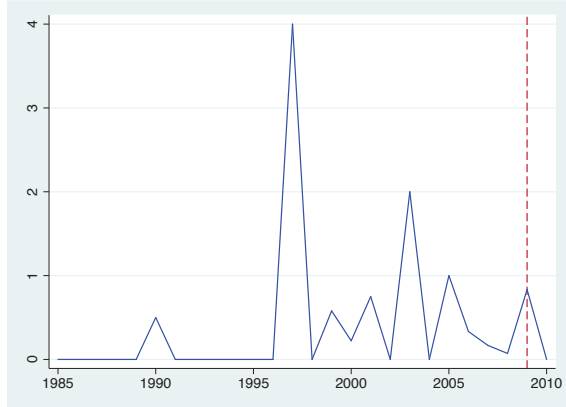


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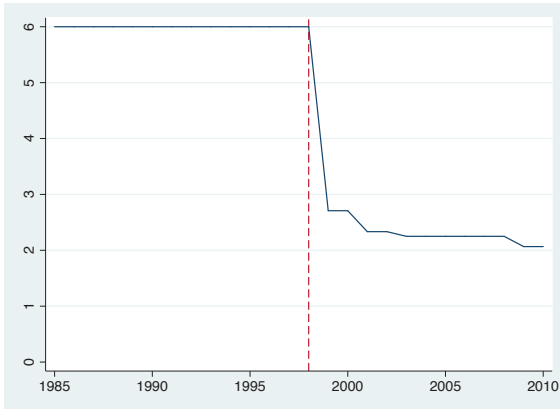
(a) Mexico: Regulation



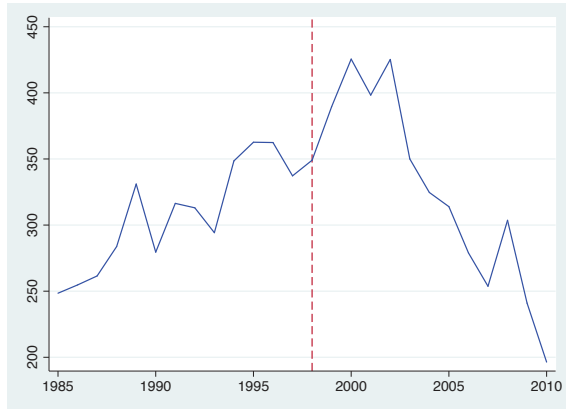
(b) Mexico: Patent grants (EPO)



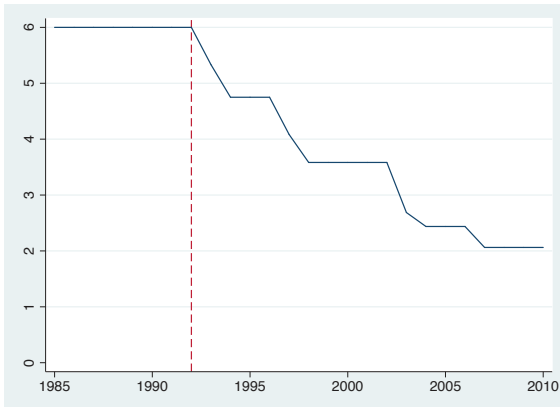
(c) Netherlands: Regulation



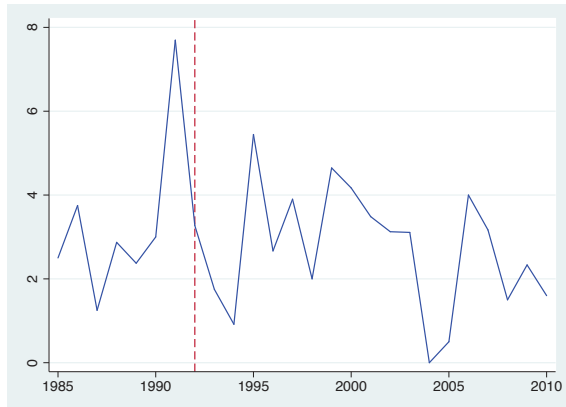
(d) Netherlands: Patent grants (EPO)



(e) New Zealand: Regulation

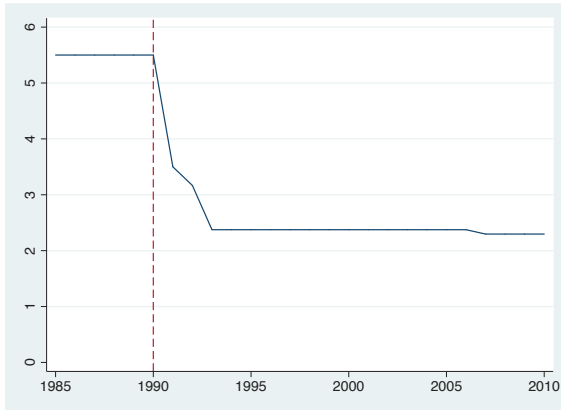


(f) New Zealand: Patent grants (EPO)

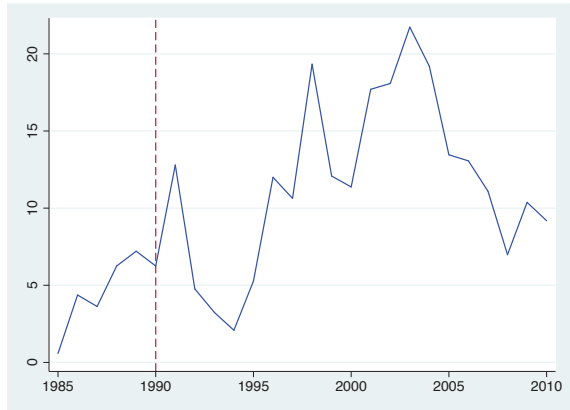


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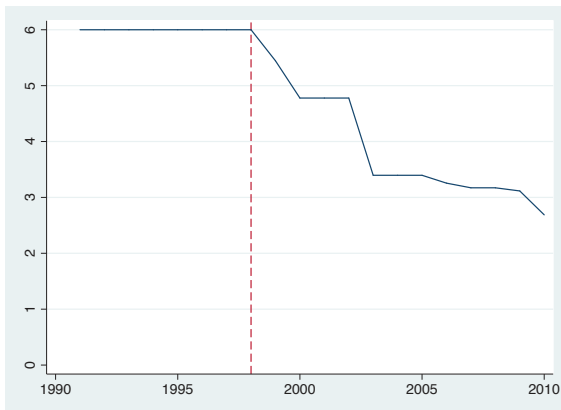
(a) Norway: Regulation



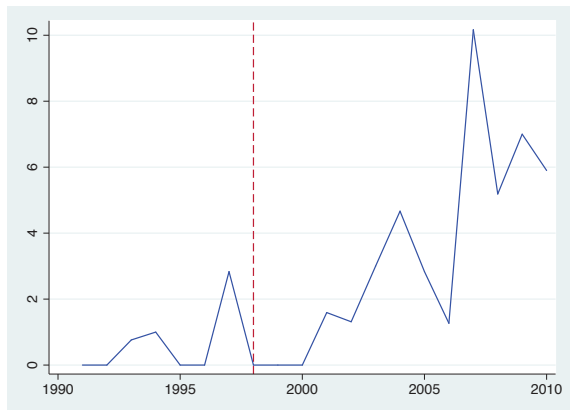
(b) Norway: Patent grants (EPO)



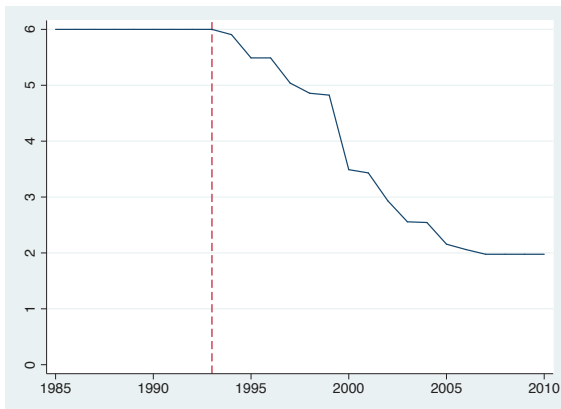
(c) Poland: Regulation



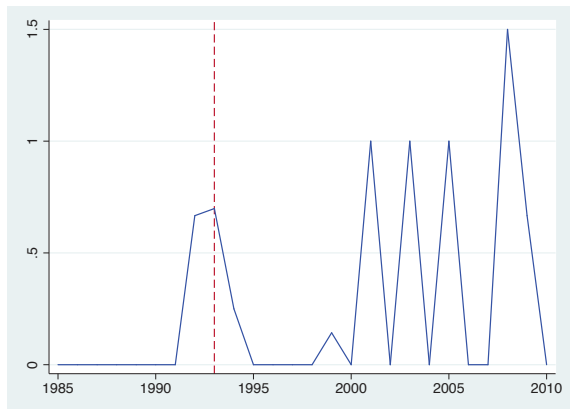
(d) Poland: Patent grants (EPO)



(e) Portugal: Regulation

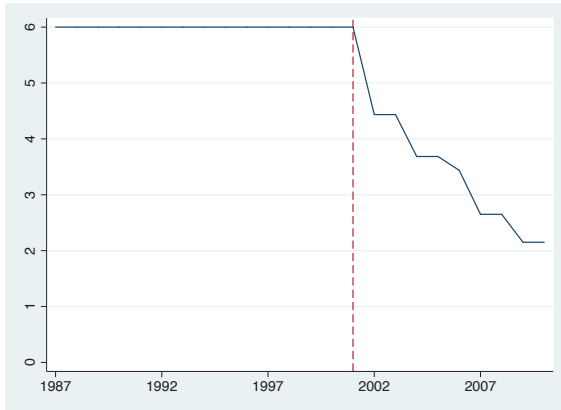


(f) Portugal: Patent grants (EPO)

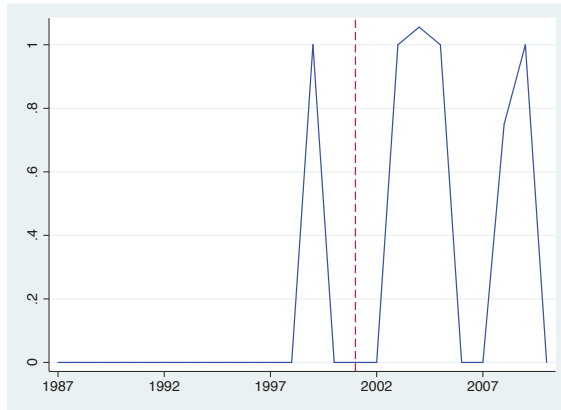


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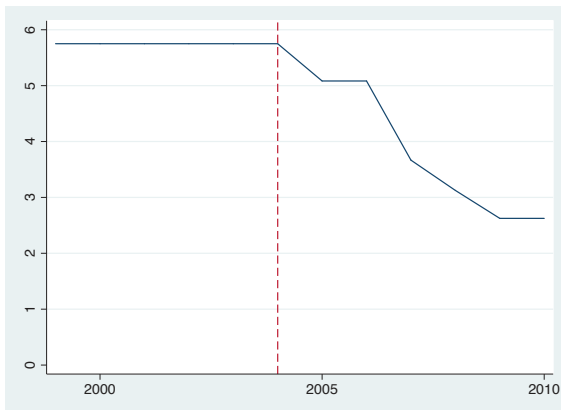
(a) Slovak Republic: Regulation



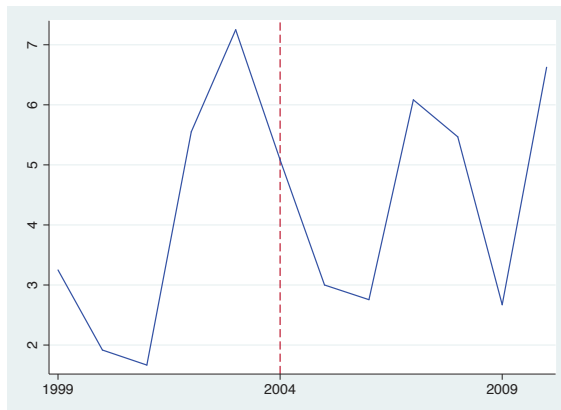
(b) Slovak Republic: Patent grants (EPO)



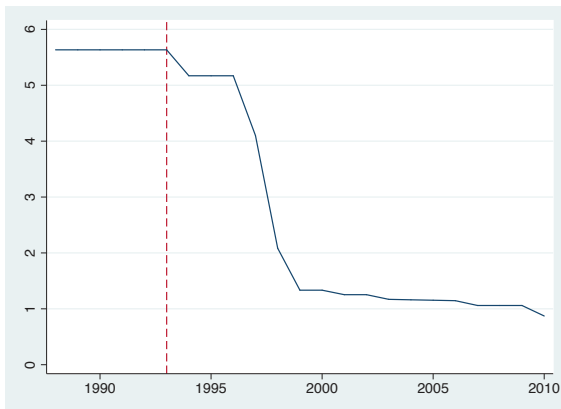
(c) Slovenia: Regulation



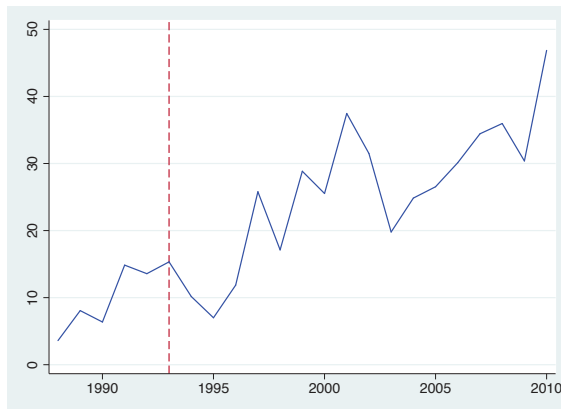
(d) Slovenia: Patent grants (EPO)



(e) Spain: Regulation

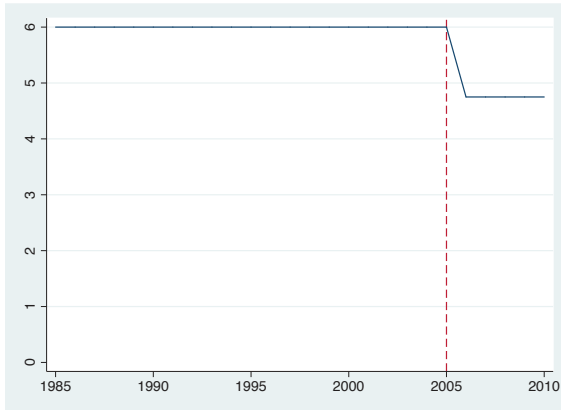


(f) Spain: Patent grants (EPO)

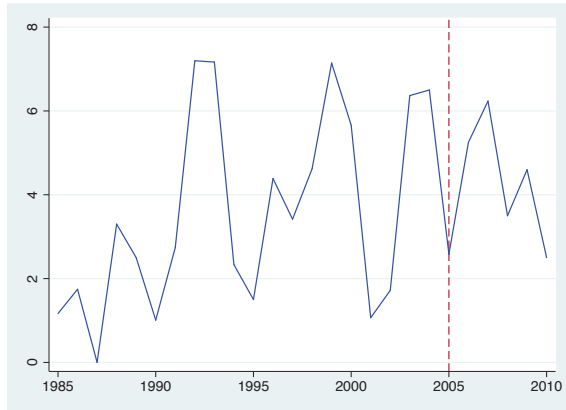


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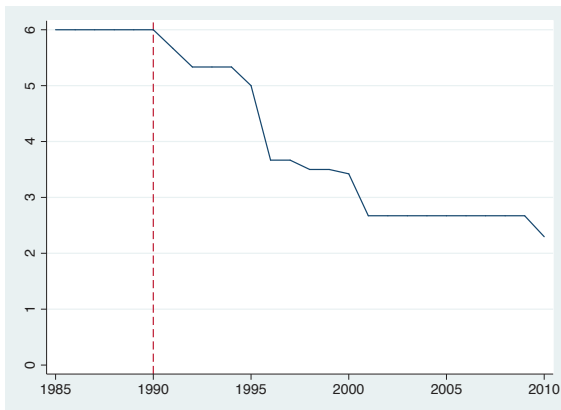
(a) South Africa: Regulation



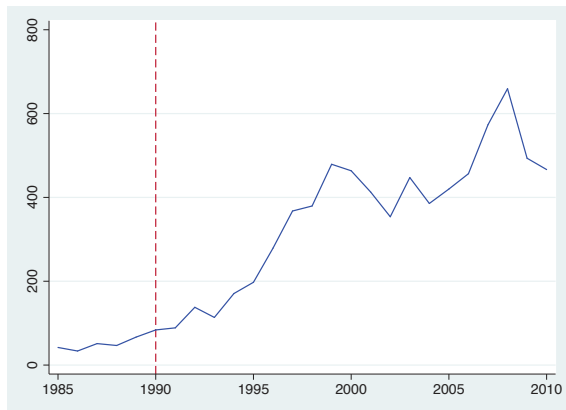
(b) South Africa: Patent grants (EPO)



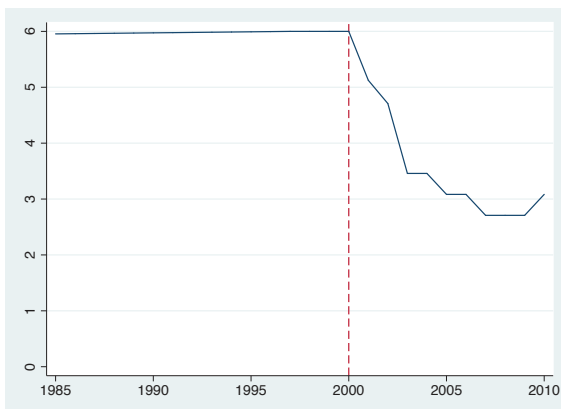
(c) Sweden: Regulation



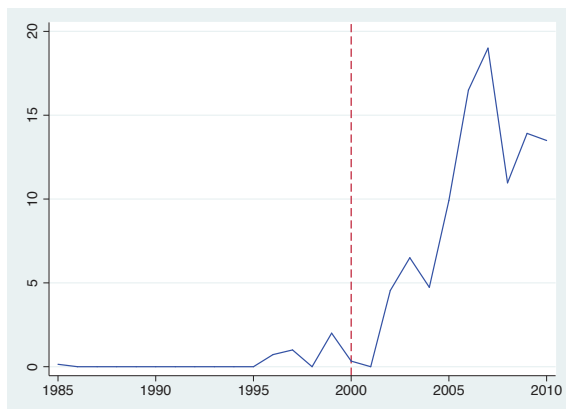
(d) Sweden: Patent grants (EPO)



(e) Turkey: Regulation

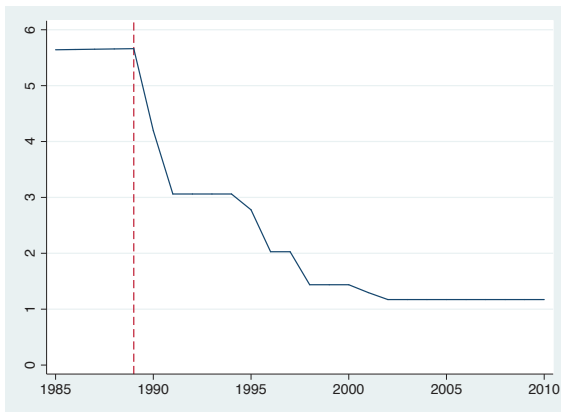


(f) Turkey: Patent grants (EPO)

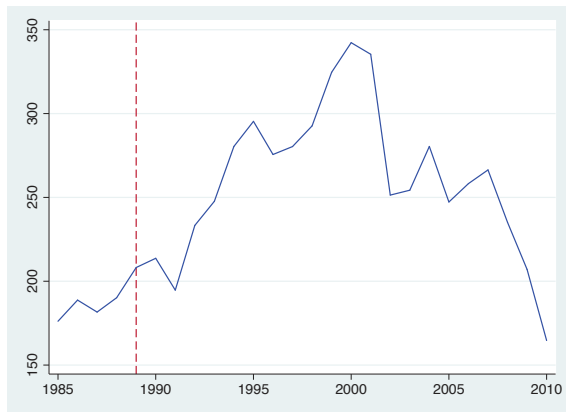


Source: OECD ETCR Data Regulation and OECD Patent Grants (Priority date, IPC H - Electricity).

(a) United Kingdom: Regulation



(b) United Kingdom: Patent grants (EPO)



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