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Product market regulation and the direction of technological change in the electricity sector

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Abstract

This paper investigates empirically the effect of market regulation on the quality of new patents developed in the electricity sector. In particular, since the concept of patent quality is very broad, here we decided to focus our attention on one aspect of the latter, i.e. technological impact on future technologies. For the OECD countries and years 1980 to 2007 we built a unique dataset containing information on patent quality and proxies of market regulation. Our findings suggest that while the technological impact of traditional energy technologies was negatively affected by the introduction of competition, renewable energy technologies reacted better to said reform.

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Introduction

This paper investigates the relationship between competition and technological progress in the electricity sector. Our contribution is motivated by the fact that, while the existing literature concerned with this issue often measures innovation in quantitative terms, we think that also the technological impact of new technologies is likely to be affected by the introduction of competition in the electricity market.

In particular, we argue that the technological impact of newly developed renewable energy technologies (henceforth RETs) is likely to increase when the electricity market is subjected to higher level of competition, while we expect the opposite trend for traditional energy technologies. To the best of our knowledge, this paper is the first that empirically assess the effect of deregulation on technological impact of new innovations in the electricity market. To do so, we gathered data on patents filled between 1970 and 2008 in 27 OECD countries. The level of deregulation in these countries is measured through the product market regulation (PMR) index developed by OCDE and the technological impact of the underlying technology is measured through the breakthrough indicator, developed by Squicciarini et al (2013).

To control for unobserved endogeneity which may arise in our analysis (see for instance Nicolli & Vona 2019) we used an instrumental variable approach. Following the literature, to assess the real level of competition in the electricity market of a given country we have chosen as instruments the overall index of globalisation and the level of deregulation in the telecommunication sector. The reasons of these choices are explained in sub-section 4.2.

The remainder of the paper is organized as follows: the section “Theoretical framework” discusses the theoretical underpinnings of our analysis and our research hypothesis. The section “Data” goes more in depth on the sources of our data and how the dataset was built, providing also some descriptive evidence to support our hypothesis. In the “Methods” section we present our empirical strategy while in the section “Results” we present the baseline results and discuss them. The final section concludes.

2. Theoretical framework

2.1 Deregulation and Traditional Electricity Technologies

Due to the large-scale and high investments needed to generate energy from traditional sources, after deregulation incumbents (e.g. Electric utilities) are likely to remain the main actors to demand and develop new traditional energy technologies (Nicolli and Vona 2016). Having said that, in order to understand the effect of deregulation on the latter we will focus our attention on the effects that this reform is expected to have on the innovative process of electric utilities.

As pointed out by Dooley (1998), liberalization encourages utilities to reduce their overall level of R&D and their R&D intensity. This is partially due to the transformation of electricity from a public service to a commodity and the consequent pressure to cut costs, which has been particularly strong for R&D investments. [Jamasb and Pollitt (2008), Sterlacchini (2012)].

The literature on this topic also suggests that this decrease has been coupled with a shift in the innovation priorities of electric utilities. For instance Wang and Mogi (2017) found that after deregulation the qualitative nature of R&D investments by Japanese utilities changed and their priorities became cost-saving and business oriented projects. In the same line, a study by Defeuilley and Furtado (2000) review the changes in R&D spending following electricity reforms in the US and UK. They conclude that after the reform there was an overall reduction in R&D expenditures coupled with a shift towards a more concrete application which improved the short term comparative advantage of the firm, helping it to face the uncertainty brought by competition. Similar results were also reached by Sanyal and Ghosh (2013), who found a decline in the quality and generality of patents granted at Electric Equipment Manufacturer (henceforth EEMs) after the electricity market has been deregulated in the US. They attribute this decline to the pressure to shorten the innovation cycle, which push EEMs to build on narrow previous knowledge.

This changes are likely to results in patents that are incremental improvements of existing technologies and therefore are expected to have a limited impact on future generation technologies.

Having said that, we can formulate our first hypothesis:

HP1: We expect the technological impact of traditional energy technologies to decrease after deregulation.

2.2 Deregulation and Renewable Electricity Technologies

First of all, it is important to stress that some of the effects described in the previous section will likely affect also RETs (e.g. pressure to shorten the innovation cycle and a tendency towards short-term projects). However, we also expect liberalization to have positive effects on the development of RETs. The first channel through which these positive effects are expected to unfold is by breaking the previous market paradigm dominated by a large monopolist with skills tied to large plants and large-scale generation. Anecdotal evidence on how this market structure could prevent the development of successfull RETs is provided by the case of Vattenfall in Sweden, the Californian wind case and the Dutch wind case where the large-scale of the wind turbine led to "poor technological designs, unreliable technology and therefore problematic diffusion of the technology" [Negro, Alkemade and Hekkert (2012) page 3841]. Deregulation, by opening the market to competition, can help solve this issue allowing small-medium firms to enter the electricity market, thus encouraging decentralized energy generation.

Another important problem when it comes to RETs has been the strong path-dependency exhibited by the electricity sector, which has lead the sector towards incremental innovations rather than radical ones [Markard and Truffer (2006)]. In fact, incumbents have little incentives to develop or demand new and "impactful" RETs because these will jeopardize their core business and are difficult to integrate in their existing paradigm of generation (Nicolli and Vona 2016). On the other hand, the new actors entering the market will actively search for radically new RETs which are able to jeopardize the incumbents' business, creating incentives for EEMs to develop high quality technologies which, in turn, are more likely to forster technological progress of RETs.

Other benefits which new entrants in a market can bring in terms of technological progress are presented in the literature. For instance, Klepper (1996) looks at the evolution of R&D investment during the industry's life cycle, stressing that as firms get older they will gradually shift towards routinized R&D activities, which very rarely lead to breakthrough innovations. In a similar vein, a study by Akcigit and Kerr (2012) provide empirical evidence from the US Census of Manufacturers that small firms, and in particular new entrants, have a comparative advantage in undertaking explorative R&D[1]. They also use patent citations to assess the technological impact of exploitative R&D and explorative R&D, concluding that the external impacts of explorative innovation is higher respect to the impact of exploitative innovation.

The last channel through which new entrants in the market are expected to foster RETs' development is through the so called "appropriation effect" Sanyal and Ghosh (2013). This effect can be summarized as the greater incentive for Electric Equipment Manufacturers to develop high quality innovation once the monopsony in the regulated market is broken. The appropriation effect tends to be stronger the more non-utilities generator actors enter the wholesale market and since, as we already mentioned, we expect these new actors to focus on RE generation, the appropriation effect is expected to be significantly stronger for RETs with respect to general electricity [Nicolli and Vona (2016)].

Having said that we can now state our second hypothesis.

HP2: We expect RETs to react better to liberalization than traditional energy technologies in terms of impact of new innovations on future technologies (technological progress).

1 Explorative R&D is defined as R&D aimed at creating new products and gaining market share

3 Data

We have constructed a unique database by merging together data from different sources, which will be presented in this section. Ultimately we were left with data for 63,636 patents filed from 1970 to 2007 in 27 OECD countries[2].

Dependent Variable: we measure the technological impact of a patents by means of the breakthrough indicator. The latter, which is part of the well established set of indicators presented by Squicciarini et al (2013), is a dichotomous variable which takes value 1 if an invention is part of the top 1% cited patents and zero otherwise [Ahuja and Lampert (2001)]. The choice of this indicator was motivated by the fact that "breakthrough inventions are high-impact innovations which serve as a basis for future technological developments, new products or services." [Squicciarini et al (2013) pag 42].

Competition: We characterized competition using the product market regulation (PMR), the time-varying sector-specific index developed by OECD. In particular, since our theoretical framework heavily revolves around new firms entering the electricity market, we will focus our attention on the subsection of the PMR index which measures the level of entry barriers. The latter ranges from 0 to 6, where high value denote lack of product market competition.

Control variables: We augment the econometric specification with a series of standard control variables that may affect the technological impact of electricity-related innovations.

Since patents of higher quality will generally receive more citations, we decided to control for general quality using two indicators presented by Squicciarini et al (2013): Patent Scope and Family Size. Patent scope is the sum of different 4-digit subclasses of the IPC[3] the patent is allocated to [Lerner (1994)]. Higher values for this indicator mean higher potential applicability of the innovation and consequently higher quality of the latter. Family Size, as defined by the European Patent Office, is "the collection of patent applications covering the same or similar technical

2 Patents were assigned to countries using the nationality of the patent assignee as provided by PATSTAT. Patents with several applicant from different country will be assigned to each applicant's country.

content."[3]. This indicator is often associated with the economic value of the invention because, for each patent added to the family in a new country, applicants must sustain additional costs and wait more time.

To account for public support to RETs we use: government R&D expenditure in this field, expressed in million Euro; average feed-in tariffs and renewable energy certificates (RECs). Control for the level of public policies in different countries is particularly important because the 90s have been a period of strong use of public policies to sustain RETs so, a regression which does not control for the latter, is likely to find a spurious correlation.

Finally, following the literature, we control also for energy price for industries, total number of green patents in our dataset by year; share of renewable energy on energy supply; electric consumption per capita.

Variables	*Definition*	*Obs.*	*Mean*	*Std. Dev.*	*Source*
Breakthrough	Technological impact indicator	63,636	.0166258	.1278657	Squicciarini and Criscuolo (2013)
Pmr entry	regulation indicator in electricity sector	98,923	3.679926	2.46899	We used the 2008 version of the PMR dataset, which were retrieved from Nicolli and Vona (2016). [4]
Family Size	Patent quality indicator	99,240	5.045425	4.179334	Squicciarini et al (2013)
Patent Scope	Patent quality indicator	99,235	2.337794	1.383277	Squicciarini et al (2013)
Log R&D in Renewable Energy	Log of the government R&D expenditure per	96,487	5.017797	1.279191	International Energy Agency (IEA) database on public policies[5]

[3] https://www.epo.org/searching-for-patents/helpful-resources/first-time-here/patent-families.html

4 The 2013 is available at https://stats.oecd.org/index.aspx?DataSetCode=PMR (21/02/2019)

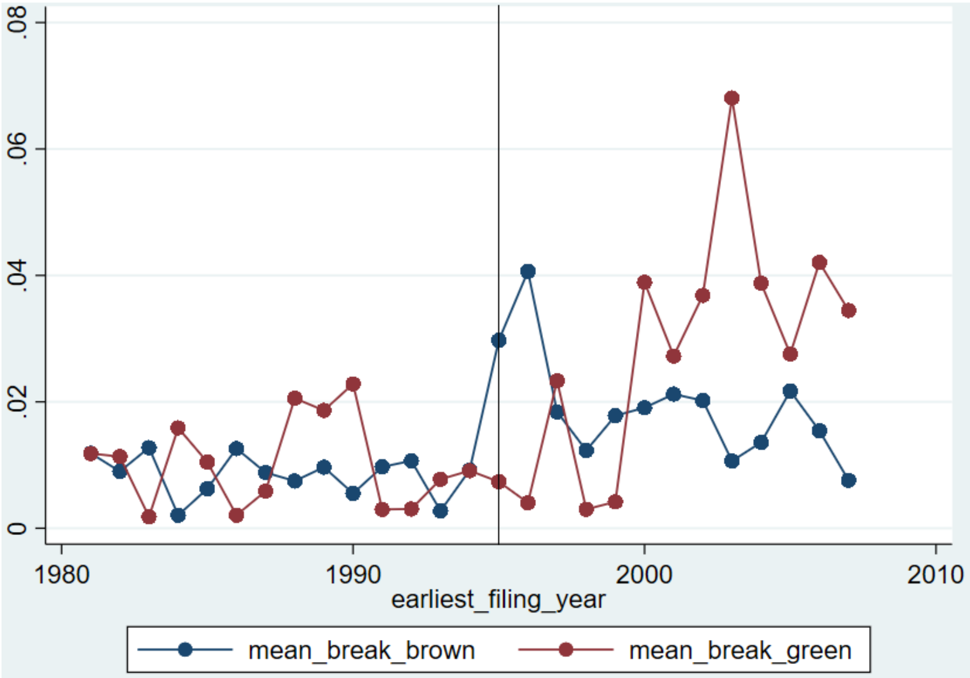
5 Last access from http://wds.iea.org/wds/ReportFolders/ReportFolders.aspx (21/02/2019)

	year, expressed in million Euro				
Industry Energy prices	energy price for industries	89,723	.0631128	.0241609	Downloaded from Nicolli and Vona (2016)
Log Electricity Consumptions	Log of the electric consumption per capita	99,240	1.725218	.3540488	Downloaded from Nicolli and Vona (2016)
Average Feed -in Tariffs	Log of the average amount of feed-in tariffs	99,240	.0195688	.0263692	Downloaded from Nicolli and Vona (2016)
Log RE certificates (RECs)	Log of Renewable Energy certificates	99,240	-.3265103	1.094328	Downloaded from Nicolli and Vona (2016)
Log % of RE on Energy Supply	Log of the percentage of RE on the total primary energy supply.	99,075	1.476321	.8006098	IEA World Energy Statistics and Balances: Extended world energy balances
Log Total patents in RETs	Total number of green patents in RETs in our dataset by year	99,240	7.175887	.531935	Patstat
KOF Globalisation Index	Overall globalisation index	99,230	74.95327	8.384779	KOF globalisation index (2018)[6]
Pmr telecom	regulation indicator in the Telecom sector	98,923	2.192746	2.021981	OCDE PMR dataset

6 Last access from https://www.kof.ethz.ch/en/forecasts-and-indicators/indicators/kof-globalisation-index.html (07/05/2019)

3.1 Descriptive Evidence

Descriptive evidence provides a preliminary support to our hypothesis. In figure 1, we present the average value of the breakthrough indicator by year for green and brown patents. While the process of deregulation differed significantly across countries, the black line in 1995 loosely capture the moment in which the deregulation of the electricity sector really gained momentum as a global trend.



As we can see, after mid-1990s the breakthrough indicator for green patents starts outperforming significantly the indicator for brown technologies, suggesting that our hypothesis may contain some truth.

4 Methods

4.1 Empirical Strategy

The dichotomous nature of our dependent variable advocates the use of a probit (or logit) model. The chosen specification, which encompass all the variables presented in table 3.2, can be represented as follows:

breakthrough = f [β_1 *(family size) +* β_2 *(patent scope) +* β_3 *(green) +*β_4 *(pmr entry) +* β_5*(pmr_entry#green) +* β_6*log(R&D expenditure RE) +* β_7*(enrg_prices) +* β_8*log(electr consumption per capita)+*β_9*(average_Feed-In) +* β_{10}*log(RECs) +* β_1 *log(% RE on Total Supply)+* β_{12}*log(Total number green patents) +*δ_1*country +* δ_2*year +* δ_3*tech_field]*

The effect of deregulation and competition on the technological impact of brown patent is represented by the coefficient of PMR (β_4). The sum of the latter with the coefficient of the interaction term (β_5) tells us the effect for green patents.

An important matter we need to address in our estimation is the existence of unobservable time invariant characteristics that differ across technologies. We decided to tackle this issue using technology specific fixed effect and clustered standard errors. A more difficult problem is posed by the possible presence of endogeneity in the variable PMR. We will discuss this problem in the sub-section 4.2.

4.2 Endogeneity and instruments

A first problem we may face using the PMR index to measure the degree of competition in the electricity market is measurement error. To explain why this is the case let us use a concrete example, looking at the Japanese electricity reform. In 2009, the subsection of the PMR index which measures barriers to entry was relatively low, with a value of 0.33. In the same vein, also the overall value of the PMR index, being 1.4, showed a relatively deregulated market[7].

However, from a practical standpoint, in 2009 the market share held by independent power producers was only 2.8% (Jones and Kim 2013). In other words, despite formally the market was competitive, incumbents were able to maintain high market power even after deregulation and the effective level of competition was low. To make things worse, this measurement error is in likely to

7 To put this numbers into perspective, in the same year the values for the United Kingdom (a pioneer in deregulation) were only slightly lower, being respectively 1.17 and 0.00.

be correlated with the variable PMR and this would make our estimates biased. This is because, while it is certainly possible to imagine that incumbents, despite low entry barriers, may be able to maintain control of the market, it is very difficult to imagine the opposite scenario. Another issue we may encounter in our analysis is reverse causality, which may arise if countries which are able to produce green innovations of higher quality are also the ones with stronger green lobbies which are able to obtain deregulation first (Nicolli and Vona 2019).

To deal with these problems we use out-of-sample instruments, which serve as predictors of the real level of competition in the electricity market. In particular, the chosen instruments are the level of deregulation in telecommunication and an overall index of globalisation.

According to the existing literature, the former has been an important driver for deregulation in the electricity sector (Pollitt 2012) and countries with higher level of deregulation in the telecommunication industry are more likely to engage in more ambitious and successful reforms of the electricity market (Nicolli and Vona 2019). To measure the level of deregulation in telecommunication we use the aggregate value of the related PMR index developed by OECD for this sector.

Similarly, there is a wide literature showing that countries that are more open to the process of globalisation are also more likely to engage in deregulation of the electricity market (e.g. Chang and Berdiev 2011). Following Chang and Berdiev (2011) we measure the level of globalisation in the electricity market using the KOF globalisation index.

5. Results

The first column in table X.1 presents the results for the base regression. As we can see, the coefficients of PMR and the interaction are of the expected signs. In particular, our key variable is is negative and significant at 5%, providing empirical evidence that green technologies reacted better to deregulation than brown technologies. Instead, the coefficient for PMR is of the expected sign but significant only at the 10% level.

A more precise quantification of these results shows that going from a completely regulated market to a completely deregulated one increases of 0.5% the probability of developing a breakthrough RETs. This increase is economically significant because it amounts at 1/3 of the mean of the variable breakthrough. As far as brown technologies are concerned, the same change in the regulation framework lead to a 0.7% decrease in the probability of developing a breakthrough innovation, which is almost half a mean of the breakthrough variable. As we can see in the second column of Table X.1, our results are confirmed when using the IV approach.

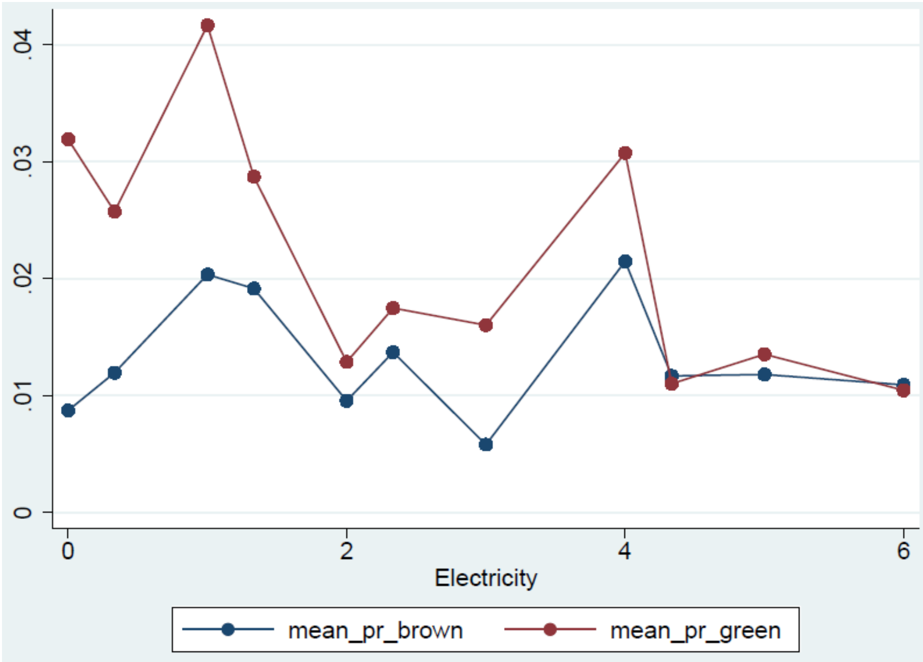
Breakthrough		
Green	0.406**	0.473**
	(2.68)	(3.03)
Pmr entry	0.0539*	0.398*
	(1.66)	(1.66)
Green#Entry	- 0.0741**	- 0.0953**
	(-2.11)	(-2.25)
Family_size	0.0582***	0.0579***
	(5.85)	(6.43)
Patent_scope	0.132***	0.127***
	(4.05)	(3.88)
Policy Controls	yes	yes
Time fixed Effect	yes	yes
Country fixed Effect	yes	yes

Technology fixed Effect	yes	yes
Weak identification Test	–	F = 602.541
Overidentification Test	–	*p =0.2086*
Instruments:	–	*Pmr telecom*
	--	*Kof globalisation index*

Roubust standard error in parenthesis

*** $p < 0.01$ ** $p < 0.05$ * $p < 0.10$

Further descriptive evidence supporting our second hypothesis is presented in Graph X.X. The latter shows the average probability of developing a breakthrough invention at different level of competition, as predicted by the IV model. As we can see, green and brown technologies perform almost the same when the market is highly regulated. On the other hand, once the market is deregulated, the difference between these technologies increases and green technologies perform a lot better than brown technologies at low level of regulation.



6 Conclusion

Our analysis suggests that the level of competition in the electricity sector affect the technological impact of new technologies developed in this industry. In particular, the empirical evidence seems to strongly support our second research hypothesis, suggesting the RETs reacted better to deregulation than traditional energy technologies. On the other hand, the empirical evidence supporting our first hypothesis, albeit being of the expected sign, is not particularly strong. Through further research, we aim at improving our understanding of how deregulation qualitatively affected new technologies in the electricity sector. In particular, we plan to expand on the matter looking at how the competitive pressure coming from deregulation affected the knowledge sources on which patents relies and their level of radicalness and originality.

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