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The Political Economy of Energy Innovation

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7.1 INTRODUCTION

Technological change directed towards more efficient and eco-friendly technologies is a priority for both developed and developing countries. Insights on past trends and determinants of energy innovation, including political economy factors and non-financial drivers, are important to set the basis for cost-effective climate and energy policies in the coming years. Issues such as the role of institutions and lobbying as enabling or inhibiting factors are critical factors that have been only marginally examined by the existing literature.

This chapter uses two commonly used indicators of innovation, energy industrial R&D and energy patents for 20 countries for the years 1995–2010 to examine the influence of political economy factors on energy-related innovations using econometric analysis. Political economy factors can be broadly defined as those concerning the interactions and tensions between de jure and de facto power, including the distribution of resources, the rules for the exercise of power and the enforcement of contracts, the procedures and institutions for settling conflicts over these rules, or the physical and organizational infrastructure supporting economic activities, transactions, and collective actions.[1] We focus on four aspects: the types and stringency of government support to energy innovation (e.g., the various policy instruments implemented to this end such as environmental and R&D policies); the quality of governance (e.g., government effectiveness); the political orientation of the government; and the distribution of resources across interest groups.

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[1] Stavins (2004) refers to political economy as the process through which political decisions are made.

The role of these factors in relation to energy innovation dynamics, energy transition, and sustainable development has been acknowledged by several contributions both in the policy and in the economics realms (Anadón 2012; Friedrichs and Inderwildi 2013; Hughes and Lipscy 2013; IPCC 2014; IEA 2015a). More than other sectors, energy can be dominated by large incumbent companies and utilities, which often seek to influence policy. Their investments, especially in new technologies are shaped by the incentives and regulations set by policy makers (Lockwood 2013a). Moreover, the actual impact of regulations and government policies is affected by the broader institutional settings (Stavins 2004). Good governance is particularly important as many of the government interventions are economic policies (Lockwood 2013a) and bureaucrats are the actors ultimately implementing these policies (Lockwood 2013b).

The role of governance quality, political orientation of the government, and distribution of resources across interest groups have received only marginal attention and have not been explored jointly in the empirical literature on energy innovation. In this specific domain, the role of public policies as drivers of innovation has received more attention than institutions and political economy factors. The multiple sources of market failures that characterize the energy sector and the recent debate regarding the actions governments should undertake to curb rising greenhouse gas emissions partly explains the focus of the current literature on the role of environmental, energy, and innovation policies. In the energy-environmental realm, state intervention is motivated by the presence of environmental externalities (a gap between private and social returns to pollution control), as well as of innovation externalities (a gap between private and social returns to innovation). Moreover, in comparison to other sectors, energy R&D often entails large-scale projects, which need public support (Anadón 2012).

This chapter contributes to the debate by jointly assessing the influence of environmental and R&D policies, governance quality, political orientation, and distribution of resources to energy intensive industries on energy innovation. The rest of the chapter is organized as follows. Section 7.2 discusses our measures of energy innovation. Section 7.3 provides the empirical framework and describes the main hypotheses explored in the empirical analysis. Section 7.4 discusses the results. Section 7.5 concludes, highlighting policy implications and future research needs.

7.2 MEASURING ENERGY INNOVATION TRENDS

Studying innovation systems and dynamics using an empirical approach is challenging, as innovation comprises both tangible and intangible outputs (e.g., new technologies, machines, products, patents but also ideas, process innovation, managerial, and organizational innovation). Following a large empirical innovation economics literature, we study the more tangible and measurable aspects of the innovation process. While these constitute only a part of the innovation output relevant for the energy system and sector, they nonetheless provide important insights that can complement those from qualitative and bottom-up case studies focusing on more intangible and less measureable aspects such as organizational innovation.

Here we focus on R&D expenditures and patent counts.[2] The former informs on the inputs of the innovation process, while the latter is a proxy of innovation outputs. Both indicators suffer from some specific shortcomings. R&D investments provide insights on innovation effort but not on innovation quality. Conversely, patent statistics provide a partial measure as not all innovations are patented, even though they can be weighted using information on several indicators to control for quality (for instance, claims or citations, see Griliches 1990). Furthermore, patents may increase due to changes in patent law or strategic reasons to signal in which companies to invest in, regardless of innovative activity (Mazzucato 2013).

In the case of energy innovation, matters are further complicated by the fact that it is unclear how clean innovation or even energy innovation are defined (Gallagher et al. 2011). A number of studies focus specifically on the energy supply sector (Salies 2010; Sterlacchini, 2012; Costa-Campi et al. 2014) but energy-saving R&D and innovation are pervasive. Energy is an input for nearly all sectors of the economy and the way in which energy is produced, transformed, and distributed depends on innovative activities well beyond those of the energy supply sector itself. All R&D expenditures are inputs into complex processes that ultimately lead to innovations that may or may not be clean. In order to proxy for industrial R&D investments in energy, we rely on the Analytical Business Enterprise Research and Development (ANBERD) database (OECD 2016), which provides information on the R&D expenditures at the sectoral level for 30 countries for the years 1990–2013.[3] We define energy R&D investments in two ways. First, we focus on R&D spending in the 'Electricity, water and gas distribution industry', which represents the downstream sector for energy production (power R&D). Second, we define energy investments as a combination of R&D expenditures from 'Electricity, water and gas distribution industry' and 'Mining', which capture the combined R&D effort in the upstream and downstream energy supply sector (energy R&D).

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[2] Arguably, R&D investments and patents represent only part of the full innovation process, as they somewhat disregard the issue of technology diffusion. Specifically, patent data is an imperfect indicator of technology diffusion, but nonetheless widely used in the literature to proxy for the other, earlier stages of innovation (see, for instance, Hall and Rosenberg 2010).

[3] Our analysis focuses on the 20 countries between 1995 and 2010 for which both policy and institutional data are available.

These measures arguably represent a lower-bound estimate of energy-related innovation (Upstill and Hall 2006), as they only include the R&D directly performed by the energy supply sectors. Indeed, non-energy sectors indirectly contribute to energy-related innovation. For instance, improvements in the manufacturing of chemicals and chemical products, and in computer and electronics, contribute to the development of energy system technologies, such as solar power or smart grids. These are 'embedded' in the capital that is supplied to the energy supply sector. The sum of the direct and 'embedded' R&D can be considered an estimate of the upper bound of industrial energy-related R&D in a given country. Input–output data can be used to provide an estimate of energy-related R&D expenditures including the research performed in other economic sectors that are embedded in the capital purchased by the electricity and the mining sectors. Dasgupta, De Cian, and Verdolini (2016) provide a detailed description and application of this method.

While providing insights on the extent of energy innovation efforts, the ANBERD statistics have some shortcomings. For instance, they report R&D expenditure by sector of performance expenditure, regardless of whether funds were provided by the private or by the public sector. This means that industrial R&D reported by ANBERD statistics might include a fraction of R&D expenditure funded by the government and therefore reported in the government budget outlays as well. For this reason, we refer to the R&D reported in the ANBERD statistics as industrial rather than private R&D.

Another widely used proxy for innovation is patent counts, which is an indicator of the output of the industrial R&D process (Griliches 1990).[4] The temporal and country coverage of patent data is often broader than that of R&D statistics and makes it an attractive empirical proxy. In the specific case of energy-related innovation, a further advantage of using patent data is the possibility of assigning patents to specific energy technology classes in the energy sector, which also include renewables (Johnstone, Ivan Haščič, and Popp 2010) and efficient fossil-based technologies for electricity generation (Lanzi, Verdolini, and Haščič 2011). We collect patent statistics from the Organization for Economic Co-operation and Development (OECD) Patent Statistics Database (OECD 2015b) and count applications through the Patent Cooperation Treaty (PCT) by the inventor country and priority date. The technologies included in our patent counts are the following:[5]

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[4] Indeed patents are positively correlated with power R&D (correlation coefficient for power patents is 0.41 and 0.62 for environmental patents) and with energy R&D (power patents 0.50 and environmental patents 0.44).

[5] Please refer to Haščič and Migotto (2015) and OECD (2015a) for more details about the technologies included.

(1) Power Patents: related to energy generation, they include both energy generations from renewable and non-fossil sources and technologies improving the efficiency of fossil fuels, such as Integrated Gasification Combined Cycle and improved burners. Both renewable and fossil-efficient technologies have significant mitigation potential (IEA 2014).

(2) Green Patents: include power patents as well as the patents in the technology domains of general environmental management, technologies specific to climate change mitigation, energy efficiency in buildings and lighting, technologies with potential or indirect contribution to emissions mitigation, emissions abatement, and fuel efficiency in transportation.

7.3 EMPIRICAL MODEL AND RESEARCH FRAMEWORK

Combining the data sources on our variables of interest described in Section 7.2, we build an unbalanced panel of 20 countries for the years 1995–2010. Please refer to Dasgupta, De Cian, and Verdolini (2016) for a detailed description of the data and descriptive statistics. The literature has used alternative methods to examine the role of political economy in the context of energy technology choices and in the context of innovation, such socio-technical transition studies (see Johnstone and Stirling (2015) for an example of such approach and Turnheim et al. (2015) for a review of the approach). Socio-technical transition studies can analyse multiple dimensions of change, including economic, political, and socio-cultural aspects at different levels and temporalities. Econometric analysis, specifically panel regression analysis, can complement this approach and isolate the influence of environmental policy, institutional quality, political orientation, and resource distribution conditional on each of the other factors, controlling for country-invariant and time-invariant characteristics.

7.3.1 Empirical Model

We use our data to estimate the following general reduced form equation:

$$y_{it} = \alpha_i + \gamma_t + \pi_{it}\beta_1 + x_2\varphi_{it} + \beta_3\rho_{it} + \beta_4\theta_{it} + Z_{it}\omega + \epsilon_{it}, \qquad (1)$$

where the subscripts *i* and *t* indicate respectively the country and the year, and:

- y_{it} is a variable measuring the energy innovation intensity of the economy. Specifically, we define y_{it} as the share of one of our innovation proxies discussed in Section 7.2 (i.e., industrial energy R&D, power

R&D, power patents, or environmental patents) over total value added. We scale all innovation proxies relative to the total value added to account for the heterogeneity in the countries included in our sample. This is in line with the general literature on this topic (see, for instance, Popp 2002).

- π_{it} is a vector of policy stringency measures, discussed in detail in Section 7.3.2 and includes both market-based and non-market-based instruments directly targeting the environmental externality, such as taxes or standards, as well as government R&D investments in energy innovation targeting the knowledge externality.
- φ_{it} is a proxy for institutional quality, measured either by government effectiveness or by an aggregate indicator of governance quality discussed in Section 7.4.
- ρ_{it} is a proxy of the political orientation of the government.
- θ_{it} is a proxy of the distribution of resources to the energy sector relative to the rest of the economy, which in our framework inform on two different aspects, market-size effect and the power of the energy lobby within each country.
- $\mathbf{Z}_{it}$ is a vector of other relevant control variables influencing innovation investments, including an index for industrial energy prices and trade openness. Higher energy prices are expected to increase innovation incentives, net of any political economy consideration (Popp 2002), whereas trade openness can have an ambiguous effect.
- α_i and γ_t are country and year fixed effects, while ϵ_{it} is a random error term. Country fixed effects control for time-invariant factors, including persistent institutional factors, such as the democratic/autocratic characteristics and system of government of countries. The time fixed effects control for inter-temporal trends that are uniform across countries, such as the economic cycle.

The expectations about the roles of the variables of interest, π_{it}, ρ_{it}, θ_{it}, is detailed in the research hypotheses presented in Section 7.3.2. The regressions are estimated using fixed effect linear models, as both our R&D and patent data are continuous variables.[6] Due to the different nature of R&D investments and patents, we use a different lag structure in our models. Specifically, we assume that R&D investments react faster to environmental policies than patents. This is due to the fact that patents measure the output of the innovation process. Applying for patent requires first to put the R&D investment to work and then develop and test new ideas. Thus, the

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[6] The patents from the OECD database are computed using fractional counting and hence are continuous in nature.

R&D specifications use a one-year time lag, while the patent equation uses a two-year time lag.[7]

7.3.2 Research Hypotheses

We use the model presented in Section 7.3.1 to test a set of hypotheses inspired by the existing literature. The four hypotheses of interest are discussed in this section.

> **Hypothesis 1 (H1):** *Environmental policy stringency* (π_{it}) *results in dynamic efficiency gains. Stringent regulations provide long-term incentives for innovation in energy-saving and pollution-reducing technologies.*

Overcoming environmental issues requires addressing two market failures. Since pollution is not priced appropriately, private firms tend to over-pollute with respect to the social optimum. The environmental externality can be directly targeted by using two different policy instruments: market-based policies, such as a tax on pollution, feed-in tariffs, or trading schemes, and non-market-based policies, such as standards or incentives for R&D investments in cleaner energy. Both instruments have been widely used in the countries in our sample.

The available literature provides evidence on both market-based and non-market-based instruments, together with innovation policies, supporting cleaner technologies, and affecting the rate and direction of technological change (Jaffe, Peterson, and Portney 1995; Popp 2002; Johnstone, Ivan Haščič, and Popp 2010) but a priori their effectiveness may be different (Fischer, Parry, and Pizer 2003; Newell 2010). Previous empirical studies on the inducement effect of environmental and energy policy on innovation have employed different measures of environmental stringency, policy instruments, and innovation indicators (Brunel and Levinson 2013). Here we rely on the recent environmental policy stringency (EPS) database of the OECD (Botta and Koźluk 2014), which provides detailed cross-country information on several instruments and on the International Energy Agency (IEA) Energy

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[7] Note that, incidentally, allowing for a one (two)-year lag structure in the R&D (patent) equation also partly addresses concerns regarding the endogeneity of the explanatory variables. Regarding country-level variables such as good governance, the political orientation of the government and the lobbying power of the energy sector, endogeneity corners are weak to non-existent, since environmental innovation represents only a fraction of the innovative capacity of the countries in our sample during the time period explored. Hence, it is unlikely to be a major driver of country-level variables. Conversely, there may be concerns regarding the endogeneity of the EPS policy indicators, as the availability of cleaner and more efficient energy technologies may be influencing the ability of countries to propose, pass, and adopt environmental policies (Carrion-Flores and Innes 2010). Allowing for a time lag reduces concerns in this respect.

Technologies R&D database (IEA 2015b). The EPS aggregate policy indicator (EPS-Total score) is constructed using information on both market-based and non-market policies.[8] For each policy instrument, countries are scored on a scale from 0 to 6 depending on the stringency of the policy they implement. Such scores are then weighted and aggregated to construct the aggregate policy indicator.[9]

> **Hypothesis 2 (H2)**: *Institutional quality, measured as good governance, increases the incentives to invest in energy-related innovation.*

The role of governance quality has been widely examined in the context of investments by the literature on Foreign Direct Investment (FDI) drivers and to a lesser extent, by the general literature on innovation.[10] The dominant view is that good governance aids FDI (Ayal and Karras 1996; Globerman and Shapiro 2003; Biglaiser and DeRouen 2006; Gani 2007; Staats and Biglaiser 2012).[11] However, poor governance can also lead to more foreign investments if combined with high levels of corruption (Bellos and Subasat 2012). The literature on general innovation states that better institutions are likely to promote general innovation and investments (Habiyaremye and Raymond 2013; Tebaldi and Elmslie 2013; Silve and Plekhanov 2015). We test whether government effectiveness and more broadly good governance as measured by the World Governance Indicators (WGI) (Kaufman, Kraay, and Mastruzzi 2010)[12] affect energy-related innovation. WGI institutional quality indicators are measured on a normalized scale from (−)2.5 to (+)2.5, where the highest value indicates better governance. We focus on government effectiveness, which is an indicator of bureaucratic quality and speed. Low levels of government effectiveness can be associated with excessive regulations, lengthy processes, and lower transparency in the form of flow of information.

> **Hypothesis 3 (H3)**: *The political orientation of the government influences investments in energy R&D and patents. On the one hand, left-leaning*

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[8] Market-based policies include feed-in tariffs (FITs—solar and wind), taxes (on CO2, SOx, NOx, and diesel), certificates (White, Green, and CO2), and the presence of deposit and refund schemes (DRS). Non-market-based policies include standards, such as emission limits for SOx, NOx, and SO2 and on the sulphur content of diesel, as well as public R&D investment in energy technologies.

[9] We refer the interested reader to Botta and Koźluk (2014) for details about the indicators' construction.

[10] The general literature on the determinants of innovation in the manufacturing sector is broad (Becheikh et al. 2006; Hall and Rosenberg 2010) and focuses on several key internal factors, such as size, firm age, skills, and qualified personnel.

[11] Good governance is defined as a government that entails an independent judiciary and legislation, fair and transparent laws with impartial enforcement, reliable public financial information, and high public trust (Subasat and Bellos 2011).

[12] For more detailed information on the WGI, please see <http://info.worldbank.org/governance/wgi/index.aspx#home> (accessed 12 October 2016).

> *governments are more likely to implement regulations that attract innovation and investment in energy-related R&D. On the other hand, right-wing-oriented governments are more likely to take a laissez faire approach. Therefore, the impact of political orientation can be ambiguous.*

The role of government political orientation has been examined in the context of environmental policy adoption (Fankhauser, Gennaioli, and Collins 2014; Folke 2014) and to some extent, in the context of private investment and FDI. In the former, the consensus seems to be that right-wing governments generally oppose laws to support climate regulations (McCright and Dunlap 2011; Painter and Ashe 2012), while left-wing governments are more likely to pass them (Neumayer 2003 and Fankhauser, Gennaioli, and Collins 2014). On the contrary, right-leaning governments are more inclined to allow the market forces to stimulate investment efforts (Esping-Andersen 1990; Boix 1998). The FDI literature, however, provides somewhat contrasting insights. Shleifer (1998) states that right-wing governments consider the private sector to be more conducive in terms of innovation and therefore tend not to intervene in the market while Hawkins, Mintz, and Provissiero (1976) and Jensen (2006) mention that left-leaning governments are more likely to expropriate foreign assets, which discourages FDI. We use political orientation of governments from the Database of Political Institutions 2012 (DPI) (Beck et al. 2001) as proxies for political institutions, specifically, the political orientation of the executive party with respect to economic policy. This is a categorical variable that takes three values: right (1), centre (2), and left (3) orientations.

> **Hypothesis 4 (H4)**: A higher share of energy intensive sectors will (a) give rise to a market-size effect (i.e., higher demand for energy), (b) lead to more lobbying power of the energy intensive sectors towards the government, and (c) increase the coordination costs of such lobbying activities. Therefore, the impact of resource distribution on energy-related innovation is not clear a priori.

The distribution of resources across interest groups may give rise to several dynamics. First, if an economy relies more on energy intensive sectors, the market for new energy inventions will be larger. As a result, the value associated with any innovation relative to energy goods will be higher, as it is more profitable to develop technologies that have a larger market (see, for instance, the discussion of market-size effects in the directed technical change literature in Acemoglu (2002)). This would suggest that larger energy-intensive sectors will likely result in more energy-related innovation. Second, energy intensive incumbent industries with access to significant resources tend to engage in lobbying for government support and seek to influence policy decisions. For instance, Fredriksson and Svensson (2003) argue that strong industry lobbies may engage in corruption to reduce environmental policy

Table 7.1. Political economy factors: hypothesis and proxy variables

Hypothesis	Proxy Variables
H1: Environmental policy	EPS-Market,
	EPS-Non-market,
	EPS-Total
H2: Governance	Governance effectiveness,
	Governance Average WGI indicator,
	Governance x EPS-Total
H3: Left-wing political orientation	Political orientation
H4: Lobbying	Value added share of energy-intensive industries
	Value added share of carbon-intensive industries
	Value added share of electricity

Source: Authors' conceptualization.

stringency while Fredriksson, Vollebergh, and Dijkgraaf (2004) remark that incumbent industries utilize their lobbying power to oppose structural transformation. Third, larger sectors may imply more firms/actors, and this would result in higher coordination costs of such lobbying activities (Olson 1965; Fredriksson, Vollebergh, and Dijkgraaf 2004).

In line with previous literature (Fredriksson, Vollebergh, and Dijkgraaf 2004; Costa-Campi et al. 2014), we use the value-added share of energy-intensive industries (Coke, Refined Petroleum and Nuclear Fuel, Chemicals and Chemical Products, Rubber and Plastics, Water and Air Transport, Electricity, Basic Metals and Fabricated Metal Mining)[13] in the economy computed using industrial value added data from the WIOD database (Timmer et al. 2015) as an indicator of market-size, lobbying power, and coordination costs.

Table 7.1 summarizes the main proxy variables that are used to measure the key drivers behind the four hypotheses described in this section.

7.4 RESULTS

The empirical results of our analysis using the two main indicators of innovation described in Section 7.2 are provided in Tables 7.2 and 7.3. Table 7.2

[13] Energy-intensive sectors have been defined as the sectors with energy intensity above the 75th percentile. As a robustness test, two other proxy variables have been considered; the value-added share of carbon-intensive industries (other non-metallic mineral, inland, water, and air transport, electricity, mining), and value-added share of the electricity or energy (electricity +mining) sector. Carbon-intensive sectors have been defined as the sectors with carbon intensity above the 75th percentile.

Table 7.2. Regression results using R&D intensity over value added as innovation proxy: one-year lag for all independent variables

		1	2	3	4	5	6	7	8	9
	Dependent Variable	Log of R&D Intensity—Power					Log of R&D Intensity—Energy			
	EPS Market Score	0.198+	0.189+	0.165			−0.006	−0.018		
H1		(0.125)	(0.121)	(0.122)			(0.111)	(0.111)		
	EPS Non-market Score	−0.089	−0.014	0.018			−0.058	−0.043		
		(0.108)	(0.107)	(0.108)			(0.098)	(0.098)		
	EPS Total Score				0.135	0.164			−0.079	0.006
					(0.110)	(0.162)			(0.101)	(0.148)
	Govt. Effectiveness	0.964***	0.769**		0.619**	0.666*	0.399		0.409	0.549+
H2		(0.323)	(0.317)		(0.312)	(0.367)	(0.294)		(0.288)	(0.338)
	WGI			0.754				0.418		
				(0.538)				(0.498)		
	Govt. Effectiveness*EPS Interaction					−0.033				−0.098
						(0.135)				(0.123)
H3	Political orientation	0.222***	0.211***	0.202***	0.200***	0.199***	0.112*	0.107*	0.111*	0.106*
		(0.065)	(0.063)	(0.064)	(0.063)	(0.063)	(0.058)	(0.058)	(0.057)	(0.058)
	VA Share Energy-intensive industries	0.710**	0.827**	0.814**	0.815**	0.822**	0.537+	0.525+	0.542+	0.553+
H4		(0.356)	(0.356)	(0.363)	(0.356)	(0.358)	(0.342)	(0.348)	(0.341)	(0.341)
	Energy price index		−3.053***	−3.203***	−3.193***	−3.202***	−8.309***	−8.629***	−8.286***	−8.388***
			(0.756)	(0.760)	(0.753)	(0.756)	(3.034)	(3.029)	(3.012)	(3.017)
	Trade openness		0.005	0.005	0.004	0.004	−0.027***	−0.027***	−0.027***	−0.027***
			(0.008)	(0.008)	(0.008)	(0.008)	(0.007)	(0.007)	(0.007)	(0.007)
	Observations	256	256	256	256	256	256	256	256	256
	R-squared	0.200	0.257	0.244	0.254	0.254	0.235	0.231	0.236	0.239
	Number of countries	20	20	20	20	20	20	20	20	20

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1, + p<0.15.
Source: Authors' estimations.

focuses on power and energy R&D intensity while Table 7.3 presents the results for the power and environmental patent intensity specifications.

7.4.1 Role of Environmental Policy Stringency

Our results generally confirm previous findings on the inducement effect of environmental policies with respect to energy-related innovation activities. We find that the effect is weaker in the case of energy-related R&D and stronger in the case of energy-related patents.

Focusing on the R&D specification (Table 7.2), the coefficient for EPS variables is positive only if we consider investments in the power sector alone (hence, electricity) and market-based policy instruments. Furthermore, the coefficient is only significant at the 15 per cent level. Non-market-based policies instead do not have any significant effect on R&D, in line with Ulph and Katsoulacos (1998) and Fischer, Parry, and Pizer (2003), who suggest that stricter regulations fail to have any significant effect on R&D.

Conversely, stronger results emerge when patent intensity (Table 7.3) is used as the indicator for innovation. Both market and non-market-based environmental policy stringency are positive and significant for both types of patents. The effect of market-based instruments is stronger in most specifications and the inducement effect is larger when the broader definition based on environmental patents is considered. Our results suggest that one unit increase in the market-based score (corresponding approximately to one interquartile range (IQR) change)[14] increases power patents intensity by between 1.3 and 1.4 per cent and environmental patent intensity by between 3 and 3.2 per cent. In the case of non-market-based policies, a similar change increases power patents intensity by between 1.2 and 1.5 per cent,[15] and environmental patents intensity by 2.3 per cent. It should be noted that the median improvement in policy stringency between 1995 and 2010 across the 20 countries has been approximately 1 unit for EPS market-based score and 2 units on a scale of 0–6 for EPS non-market-based score.[16]

These findings are in line with Johnstone, Ivan Haščič, and Popp (2010), who show that increasing number of international climate policies have resulted in an increase in renewable energy patents. These results are also in

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[14] In the case of EPS market score, moving from the 25th quartile (1.1) to the 75th quartile (2.3) is equivalent to a one-unit increase in the EPS and is equivalent to moving from the policy stringency of Belgium to that of Finland in 2010.

[15] In the case of EPS non-market score, the IQR is larger than one. Moving from the 25th quartile (1.1) to the 75th quartile (2.6) is equivalent to the increase in policy stringency observed in Portugal between 1995 and 2010.

[16] During 1995–2010, modest increases of 1 unit have been achieved in Italy, Australia, Portugal, while more ambitious increases of 3–4 units have been achieved in South Korea and The Netherlands, while Germany has achieved increase of about 2 units.

Table 7.3. Regression results using patent intensity over value added as innovation proxy: two-year lag for all independent variables

		1	2	3	4	5	6	7	8	9	10
	Dependent Variable	Log of Patent intensity—Power					Log of Patent intensity—Environment				
H1	EPS Market Score	0.013***	0.014***	0.013***			0.031***	0.032***	0.029**		
		(0.005)	(0.003)	(0.007)			(0.012)	(0.007)	(0.016)		
	EPS Non-market Score	0.012***	0.013***	0.015***			0.018+	0.018+	0.023**		
		(0.004)	(0.005)	(0.001)			(0.011)	(0.110)	(0.046)		
	EPS Total Score				0.017***	0.004			−0.007	0.030**	0.020
					(0.000)	(0.587)				(0.011)	(0.277)
H2	Govt. Effectiveness	0.069***	0.070***		0.065***	0.045***	0.211***	0.212***		0.199***	0.183***
		(0.013)	(0.000)		(0.000)	(0.003)	(0.033)	(0.000)		(0.000)	(0.000)
	WGI			0.095***					0.313***		
				(0.000)					(0.000)		
	Govt. Effectiveness*EPS Interaction					0.015**					0.012
						(0.010)					(0.416)
H3	Political Orientation	−0.002	−0.002	−0.002	−0.002	−0.002	−0.006	−0.007	−0.007	−0.008	−0.007
		(0.003)	(0.395)	(0.379)	(0.330)	(0.514)	(0.006)	(0.286)	(0.314)	(0.212)	(0.256)
H4	VA Share Energy-intensive industries	−0.003	−0.009	−0.009	−0.012	−0.012	−0.048	−0.061*	−0.058+	−0.068*	−0.069*
		(0.014)	(0.546)	(0.557)	(0.419)	(0.380)	(0.035)	(0.089)	(0.114)	(0.061)	(0.059)
	Energy price index		0.025	0.016	0.024	0.027		0.058	0.032	0.053	0.056
			(0.338)	(0.544)	(0.367)	(0.309)		(0.390)	(0.640)	(0.431)	(0.413)
	Trade Openness		−0.000	−0.000+	−0.000	−0.000		−0.001	−0.001+	−0.001	−0.001
			(0.170)	(0.130)	(0.175)	(0.277)		(0.180)	(0.127)	(0.189)	(0.224)
	Observations	256	256	256	256	256	256	256	256	256	256
	R-squared	0.662	0.666	0.651	0.657	0.663	0.634	0.638	0.623	0.630	0.630
	Number of countries	20	20	20	20	20	20	20	20	20	20

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1, + p<0.15.

Source: Authors' estimations.

line with findings from some of the previous literature including Lanjouw and Mody (1996) and Popp (2002), namely that the number of environmental patents tends to increase as the cost of pollution abatement rises. Finally, the apparently stronger results in the case of the patent specification than in the R&D specification are in line with the evidence presented by Rubashkina, Galeotti, and Verdolini (2015), who focus on overall patenting within different sectors of the economy. A reason for the stronger evidence of induced innovation when using patents as opposed to R&D in the present work might be due to the different ways patents and R&D are defined. Patents explicitly refer to clean and energy-saving innovations while the definition of energy R&D does not specify the purpose of the expenditure. Overall, with respect to Hypothesis 1, our regression results suggest that more stringent environmental policies provide dynamic efficiency gains and incentives for innovation in energy-saving and pollution-reducing technologies.

7.4.2 Role of Good Governance

Good governance appears to be an important driver of innovation. Depending on the governance proxy used, a one-unit increase in government effectiveness is associated with between 62 per cent and 96.4 per cent increase in power R&D intensity (Table 7.2) and between 6.5 per cent and 31.3 per cent increase in patent intensity (Table 7.3). This suggests that stronger economic institutions promote innovation and are in line with the existing literature (Ayal and Karras 1996; Habiyaremye and Raymond 2013; Tebaldi and Elmslie 2013; Silve and Plekhanov 2015).

The marginal effect of governance might appear substantial given the coefficient interpretation provided in the paragraph above. However, a one-unit increase in the governance proxy is a rather significant change. It is comparable to moving from the governance quality of a country such as Portugal (1.02) or Slovenia (1.03) to that of countries such as Sweden or Finland (2.01 and 2.25) in 2010. Historically, the biggest improvements in governance quality have been achieved by South Korea and Estonia, where the governance WGI score increased by 0.6 and 0.5 between 1995 and 2010, respectively.

Overall, with respect to Hypothesis 2, our regression results suggest that improvements in governance and government effectiveness provide incentives for energy-related innovation.

7.4.3 Role of Political Orientation

Political orientation seems to be a more important factor for the input rather than the output of innovation, as the variable has a statistically significant effect only in the case of power and energy R&D intensity. A change in the political orientation of the government from right towards a left-leaning position, which corresponds to an IQR change in our sample, is associated with an increase in industrial R&D of 11 per cent (power) and 22 per cent (energy), respectively. To put these effects in perspective, countries such as Portugal in our sample moved from a right-leaning orientation in 1995 to a left-leaning government in 2010, while countries such as Canada, The Netherlands, and Sweden underwent the opposite change.

Overall, with respect to Hypothesis 3, left-leaning governments are more likely to implement regulations that attract energy R&D investments, but this does not translate into higher patent intensity.

7.4.4 Role of Resource Distribution, Market-Size Effect, and Lobbying

The size of the energy sector, measured as the value-added share of energy-intensive industries, has a positive impact on R&D intensity, suggesting that either industries will allocate more resources towards R&D due to the larger size of the potential market for energy innovations, or a larger energy sector will be able to lobby for more resources to be allocated to energy R&D. A 1 per cent increase in the value added share of energy intensive industries, approximately corresponding to an IQR change, increases power R&D intensity by between 0.54 and 0.83 per cent. It should be noted that a 1 per cent increase is a rather modest increase in this case. Between 1995 and 2010, changes in the share of energy intensive industries in our sample varied between (−) 62 per cent to (+) 28 per cent in France and Australia, respectively.

The smaller marginal effect on energy R&D intensity might reflect a different relevance of political economy factors within the energy sector itself.[17] As explained by Hughes and Lipscy (2013), power markets tend to be more concentrated within domestic markets whereas many oil and gas companies are vertically integrated and international in scope. Therefore, the political economy factors that matter for electricity are likely to differ from those relevant for the oil and gas industry, which are included in our definition of energy R&D. Factors such as lobbying are therefore more relevant for the more inward-oriented sectors, such as power. Since the size of the energy sector is a proxy of the lobbying power of energy-intensive industries, it has the opposite effect on patent intensity, indicating that a larger energy sector reduces the incentive to carry out energy-saving and clean innovation.

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[17] Including the mining sector (oil and gas extraction).

Overall, with respect to Hypothesis 4, the larger the size of the potential markets for energy innovation, the larger the inducement effect for industries to invest in energy R&D. At the same time, larger energy sector has power to lobby for more resources to be allocated to energy R&D. These effects seem to prevail over coordination costs, however, market-size effects or lobbying from the energy sector do not result in a larger number of cleaner patents. This could mean that R&D investments are either used less effectively, or that they are used to improve other aspects of the technologies, which are more intangible and which are not codified in patents.

7.4.5 Role of Other Factors

We briefly comment here on the coefficients associated with our additional control variables, namely the energy price index and trade openness. The energy price index has a negative and statistically significant effect on both power and energy R&D intensities. A possible explanation in this respect is that higher energy prices increase energy expenditure, both in the private and public sectors, reducing resources available for other uses, including R&D. Energy prices provide a positive incentive for patents, but the coefficients are not statistically significant. Although the evidence is only imprecisely estimated, it suggests that even though fewer resources are allocated as input to innovation, the innovation process is more efficient at delivering new inventions.

Trade openness has a negative and significant effect on energy R&D intensity, suggesting that countries with developed trade relationships have fewer incentives to allocate resources to power and mining R&D and that technology adoption and imitation displace domestic innovation. Note that the effect is only significant when the definition of energy R&D include the mining sector, which is more outward-oriented than power, making the energy aggregate sensitive to changes in trade exposure.[18]

7.5 CONCLUSION

This chapter empirically investigates the impact of political economy and institutional factors on the incentives to innovate in the energy sector. We propose four empirical proxies that can measure energy-related innovation, namely power R&D, energy R&D (consisting of the investment of the power

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[18] Refer to Dasgupta et al. (2016) for additional regressions and robustness tests.

and mining sector), power patents (related to renewable and energy efficient technologies for power production), and environmental patents (including energy patents as well as patents generally aimed at environmental protection). We focus on the empirical analysis of the role of four political economy factors, namely environmental policy, good governance, political orientation, and the distribution of resources to energy intensive industries that can induce effects of both market-size and lobbying.

The analysis suggests that all abovementioned factors affect the incentives to devote resources to energy R&D and to create new clean and energy efficient technologies. Specifically, market-based incentives, and to some extent also non-market based incentives, results in dynamic efficiency gains. Countries with better governance are characterized by higher levels of energy-related R&D, while left-wing governments are more likely to devote R&D resources to the energy sector but this does not translate into higher power-related patent intensity. A larger distribution of resources towards energy-intensive sectors can induce market-size effects and have more power to lobby for more resources to be allocated to energy R&D but this does not translate into higher patent intensity.

The empirical analysis described in this chapter shows that political economy factors can act as barriers even in the presence of stringent environmental policy. This implies that in order to favour changes towards a greener economy, countries should combine environmental policy with a general strengthening of institutional quality, consider the influence of government's political orientation on environmental policy, as well as the size of energy intensive sectors in the economy, which affect both the lobbying structure and the demand for energy innovations. These results point to the need to move the literature on the determinants of energy-related innovation beyond the focus on environmental policy instruments that has dominated the environmental economics literature in recent years.

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