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Energy Sustainability

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ABSTRACT: We investigate the effect of energy liberalizations on policies that support renewable energy in a long panel of OECD countries. We estimate this effect accounting for the endogeneity of liberalization related to joint decisions within a country's energy strategy. Using regulation in other industries as instruments, we find that energy liberalization increases the public support to renewable energy. The effect of liberalization is the second largest after the effect of per-capita income and is fully driven by reductions in entry barriers, while the effect of privatization is negative. Finally, our results are robust to dynamic specifications and various policy indicators.

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1. Introduction

Environmental problems typically call for government interventions to address the market failures associated with pollution and investment in green technologies. Although international policy agreements such as the Kyoto Protocol have acquired prominence in the public debate, national policies still represent the main tools to fight climate change and global warming. Compared to other environmental policies, policies that support renewable energy (REPs henceforth) affect several targets other than pollution abatement, such as energy security, technological change and energy efficiency, because REPs are often combined with measures that promote energy efficiency. For instance, technological learning is particularly important to reduce the cost of energy production from renewable sources relative to that of traditional ones. Energy security is also a long-term and uncertain objective of REP because renewables are difficult to store and require backup capacity from traditional fossil-fuel plants.[1]

To the best of our knowledge, only a few papers have empirically investigated the determinants of REPs (see, e.g., Lyon and Yin 2010, Jenner et al. 2012). However, by focusing on the adoption of a specific REP, these papers have neglected the fact that each country uses an array of policy instruments to promote renewable energy (RE). Recent research has shown that an appropriate policy mix that combines policies to reduce pollution

[1] An evaluation of the welfare effects of REPs is beyond the scope of this paper. In general, these policies appear to have a positive effect on RE technologies (Johnstone et al., 2010), with a remarkably stronger effect on high-quality inventions (Nesta et al., 2014) and a weaker one on per-capita investments in renewable capacity, which is a proxy for technology diffusion (Popp et al., 2011). Moreover, the various policy instruments have displayed heterogeneous effects across various technologies (Johnstone et al., 2010). Finally, Jenner et al. (2013) for EU states and Yin and Powers (2009) for US states evaluate the impact of, respectively, feed-in-tariffs (FITs) and renewable portfolio standards (RPSs) on RE electricity generation. The former paper finds that FITs have a positive effect on solar but not on wind development, and the latter finds a positive effect of RPSs on RE deployment. See also Schmalensee (2012) for an original and provocative discussion of the pros and cons of REPs.

(e.g., emission trading schemes) with policies for learning (e.g., RE production subsidies) and innovation (e.g., R&D subsidies) stimulates the search for new technological solutions rather than mere compliance with existing standards.[2] Following on this argument, we examine the determinants of REP indicators that combine various policy measures; therefore, we complement previous studies by analysing the overall country's commitment to RE rather than the intensity of a single REP.

Our empirical analysis contributes to the growing empirical literature on environmental political economy. A well-established result in this literature is that policy stringency is negatively associated with the level of corruption, which is interpreted as a proxy for the brown lobby's ability to influence environmental policies (e.g., Fredriksson and Svensson, 2003; Damania et al., 2003). Although corruption is certainly a good measure of the quality and independence of the political system, it does not capture the sector-specific features of the political process that are highlighted in the literature on lobbying (Helpman and Grossman, 1994). The recent wave of energy market liberalizations offers a unique opportunity to investigate the effect of a decrease in the incumbents' lobbying power, which is proportional to their market power, on a sectoral policy aimed at improving citizens' welfare, i.e., REPs. In this paper, we show that liberalization has a large effect on the adoption of REPs by controlling for corruption and environmental preferences.

The new mechanism highlighted here is not obvious: even if the adoption of REPs and liberalizations went hand-in-hand in the last two decades, the two policies were implemented for different reasons. The former had the main objective of reducing electricity prices, while the latter's primary targets were environmental externalities through the support of cleaner but more expensive energy sources. However, there are two reasons for liberalizations to have an

[2] See, e.g., Fisher and Newell (2008), Midttun and Gautesen (2007), Johnstone et al. (2010), Acemoglu et al. (2012), Nesta et al. (2014).

independent and perhaps unintended effect on REP. First, granting free access to the grid to new and often smaller players is likely to favour decentralized energy production, which is highly compatible with RE generation. Because large utilities have a comparative advantage in centralized energy production, they will contest the approval of REPs to avoid jeopardising their investments. Conversely, new players are likely to invest in small-scale productions, including renewable ones. Lowering entry barriers should reduce the capacity of utilities to influence energy policies and should favour the emergence of new green actors. Therefore, we expect a positive effect of liberalization on REPs. Second, the typical state-owned monopoly that characterizes the energy sector before liberalization should be willing to internalize the pollution externalities stemming from traditional energy sources. As a result, it should be easier to support REPs in a market with widespread public ownership than in a market dominated by private utilities. Overall, which effect prevails is an empirical issue that we investigate by exploiting variation in policies in 28 OECD countries over 28 years.

The identification of the effect of liberalization on REPs is problematic because the two variables are affected by common determinants such as unobservable institutional quality and are two features of a country's energy strategy. Moreover, our index of regulation, which is the product market regulation (PMR henceforth) in the electricity sector developed in the OECD, is an imperfect proxy for the effective incumbents' market power, on which the capacity to capture policies depends. Because controlling for country fixed effects and for institutional factors may alleviate but not fully solve this problem, we use regulation in other sectors to instrument regulation in electricity. The idea is that widespread liberalizations are implemented to pursue general goals and reflect policy learning and the diffusion of a liberal political ideology. The sequence of reforms across sectors validates our instrument choice, as early liberalizations in telecommunications and air transport have paved the way for energy liberalizations (Høj et al., 2006).

Three main findings stand out clearly from our analysis. First, we find that a higher degree of regulation in electricity undermines the approval of ambitious REPs. Second, this effect is considerably larger when accounting for endogeneity in electricity regulation. Third, the effect of liberalization is fully driven by reductions in entry barriers, while privatization has a negative effect on REPs.

The paper is organized as follows. The next section reviews the drivers of environmental and energy policies in greater detail. Section 3 describes our instrumental variable (IV) strategy and the REP indicators used as dependent variables. In Section 4, we present the main results for various indicators and various features of the liberalization process using a dynamic specification. The final section concludes the paper.

2. Drivers of Renewable Energy Policies

Theoretical and empirical studies on the determinants of environmental policy agree on the prominent role of private and public interest in affecting policy outcomes (e.g., Peltzman 1976). Formal politico-economy models are generally inspired by the seminal paper of Grossman and Helpman (1994), in which multiple lobbies attempt to capture sector-specific policies by offering perspective bribes to politicians. The basic model's prediction is that the extent to which the chosen level of environmental tax differs from the optimal Pigouvian tax depends on the lobbies' capacity to influence policy (see, e.g., Fredriksson, 1997; Aidt, 1998). In turn, this difference depends on the weights the politician assigns to social welfare and citizens' preferences on the one hand and to the lobbies' bribes on the other. Empirically, the weight assigned to brown lobby bribes has been approximated by the level of corruption, which has been shown to negatively affect the stringency of environmental regulation.[3] Although the negative effect of corruption on environmental policy is a consolidated result, using a sectoral measure of the brown lobby appears more appealing when the policy of interest is also sector specific, as in the case of REPs.

The political process in the energy sector is well described by a lobbying game. Damania and Fredriksson (2000) show that the incentive to form lobbies to influence environmental policies is stronger in highly polluting sectors such as the energy sector. Fredriksson et al. (2004) provide empirical support for this prediction by showing that the effect of corruption on energy intensity is greater in more energy-intensive sectors. The influence of lobbies on REPs has also been documented by a growing strand of empirical literature. The opposition of energy utilities to REPs is documented both in single-country case studies (e.g., Neuhoff, 2005; Jacobsson and Bergek, 2004; Nilsson et al., 2004; Lauber and Mez, 2004) and in some recent econometric analyses for the US states (Chandler, 2009; Lyon and Yin, 2010) and for EU countries (Jenner et al., 2012). This opposition is primarily related to the intrinsic comparative advantage of large utilities in centralized energy production. Whereas the production of energy from renewable sources is decentralized in small to medium-sized units, the competencies of utilities are tied to large-scale plants using coal, nuclear power or gas as the primary energy inputs. The high sunk costs of large-scale generation further exacerbate

[3] Fredriksson and Svensson (2003) extend the Helpman and Grossman (1994) and Fredriksson (1997) models to include political instability. Their model shows that the effect of corruption decreases when political instability increases because incumbent officeholders are less able to credibly commit to a policy. This prediction is confirmed in their empirical analysis of the stringency of environmental regulation in agriculture. Other aspects of the impact of corruption on environmental policies are considered in variants of the same models and tested empirically by Fredriksson et al. (2004), who consider multiple lobbies and their organizational costs, Fredriksson and Vollebergh (2009), who show that the effect of corruption is lower in federal systems, and Damania et al. (2003), where the effect of corruption greatly depends on the degree of trade openness. Regarding the green lobby, recent works by Fredriksson et al. (2007) and List and Sturm (2004) show that it may have substantial influence on the approval of ambitious environmental policies. For a theoretical treatment, see also Canton (2008).

the technological lock-in of incumbents and fuel their political opposition to the distributed generation paradigm involving the diffuse use of RE. At the same time, however, the mere replacement of public utilities with private ones will not result in more political support for REPs as long as large private players do not internalize the negative externalities generated by fossil-fuel plants.

In summary, we expect that the recent reduction in entry barriers, i.e., opening new producers' access to the grid, should have favoured the adoption of ambitious REPs but that the mere privatization of energy utilities should have reduced the support for REPs. Our empirical strategy allows us to test these two predictions along with the overall effect of liberalization on RE policy indicators.

The paper of Jenner et al. (2012) is closely related to ours as it estimates the effects of the green and brown lobbies, which they also proxied with the PMR, on the probability of adopting feed-in tariffs (FITs) or renewable energy certificates (RECs). Our work extends this work in four directions. First, we address the issue of endogeneity in the effect of energy market liberalization. Second, we build an indicator of policy commitment to capture various dimensions of public support for RE (see Section 3.2). Third, we disentangle two aspects of the liberalization process that are expected to have contrasting effects on REPs: entry barrier reduction and privatization. Finally, we modify the set of controls to better account for environmental preferences. In particular, following a simple median voter argument, citizens' willingness to pay for higher environmental quality depends on both the first and second moment of the income distribution. Because environmental quality is a normal good, wealthier households demand more stringent environmental policies, which is a prediction consistent with the empirical evidence at both the micro and macro levels.[4] In turn, for a given level of income per capita, a lower level of inequality implies a richer median voter and thus greater support for ambitious policies, as recent theoretical and empirical studies have shown.[5] In sum, whether the increasing willingness to pay for cleaner energy has been more important than the liberalization process in explaining the rapid adoption of REPs remains an unresolved issue that we attempt to address in the following.

3. Empirical Protocol

3.1 Empirical Strategy

Exploiting the panel dimension of our data, we are interested in estimating the effect of an index of electricity market regulation ($\mathbf{PMR}$, or $\mathbf{PMR}_{elec}$ when we wish to distinguish energy regulation from regulation in other sectors) on an indicator of REP commitment for country *i* at time *t*, conditional to a set of controls:

$$\mathbf{REP}_{it} = \beta\mathbf{PMR}_{elec,it-1} + \gamma\mathbf{X}_{it-1} + \mu_t + \mu_i + \varepsilon_{it}.$$

We include country μ_i and time effects μ_t to eliminate, respectively, time-invariant unobservable factors affecting REP, such as wind and solar endowments, and common time shocks, such as cyclical trends. The right-hand-side variables are lagged one year to capture the retard in the effect of institutional factors on policy outcomes. The vector of controls X_{it-1} is composed of variables that depict the evolution of preferences and other institutional

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[4] See: Arrow et al. (1995), Diekmann and Franzen (1999), Dasgupta et al. (2001), Esty and Porter (2005) and OECD (2008). At the micro level, several studies have also shown that wealthier and more educated households are generally more willing to pay higher prices for renewable energy (Roe et al. 2001, Wiser 2007) and voluntarily participate in clean energy programs (Rose et al. 2002, Kotchen and Moore 2007, Kotchen 2010).

[5] See Magnani (2000), Eriksson and Persson (2003), Kempf and Rossignol (2007), McAusland (2003) and Vona and Patriarca (2011). In general, a large political economy literature considers inequality to be a political driver through median voter preferences, see, e.g., Lindert (1996) and Perotti (1996).

constraints that are likely to affect REPs.[6] The minimal set of controls used in this study includes the usual proxy of the brown lobby, i.e., an index of the perception of corruption, and the two variables to account for environmental preferences, i.e., GDP per capita and income inequality. Our favourite specification adds two features of a country's energy strategy, i.e., the share of energy produced from nuclear power and energy dependency. Finally, we consider an extended specification where we include two proxies for the green lobby, i.e., the share of green deputies in the parliament and a dummy equal to one since the year in which a solar association began (Jenner et al., 2012), a measure of energy intensity and the Polity 2 index capturing the level of democracy.[7] We prefer not to include energy prices to avoid additional an endogeneity problem due to the joint determination of REP, PMR and energy prices. However, the results are qualitatively unaffected if energy prices are included in the set of controls.

Combined with country fixed effects, our set of controls should in principle eliminate the time-varying sources of unobservable heterogeneity that affect both REPs and PMR. However, there remain good reasons to believe that the effect $\mathbf{PMR}_{elec\,it-1}$ is not estimated consistently because it remains correlated with future policy shocks ε_{it}. First, PMR is an imperfect measure of the real level of competition in the electricity sector because entry barriers are at least partially endogenous. If large utilities maintain sufficient market power to

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[6] The data sources are standard and hence reported in Table 1. For our two main variables of interest, REPs and PMR, the data sources are presented in the Appendix.

[7] Environmental policies tend to be more stringent in democratic societies. In particular, Fredriksson and Newmayer (2013) show that a country's historical experience with democracy, more than the actual level of democracy, influences the adoption of climate change policies. Murdoch et al. (2003) show that democracy influences the level of participation in an environmental treaty, the Helsinki protocol, on curbing sulfur emissions in Europe. Newmayer (2002) finds that the degree of democracy exerts a positive effect on the overall country commitment to environmental issues and policies, and Friedrikson et al. (2005) demonstrates that democratic participation positively affects environmental policy stringency in countries with a sufficient degree of political competition (measured as the share of votes won by the largest party). These last results recall the seminal model of McGuire and Olson (1996), in which the presence of democracy would positively affect the provision of public goods such as environmental quality, and the work of Congleton (1992), which shows that democratic policy makers are more likely than authoritarian regimes to ratify the Vienna and Montreal protocols for chlorofluorocarbons reduction.

block the approval of REPs after liberalization, the coefficient associated with PMR may be reduced in absolute terms as a result of successful and unsuccessful reductions in entry barriers.[8] Second, reductions in entry barriers may be induced by certain REPs, such as FITs, that mandate the provision of priority access to the grid to energy produced from renewable sources. Therefore, after FITs are approved, the power of incumbents is *de facto* reduced, new green players enter the market, and the support for further reductions in entry barriers is stronger, which leads to a reverse causality problem. Third, omitted variables may always be present even if we saturate the model with a very broad set of political variables. For instance, Belloc et al. (2014) show that both right- and left-wing parties implement liberalizations and thus that it is difficult to claim that proxies for government ideology would reduce the unobservable correlation between PMR and REP.[9]

These arguments support our claim that instrumenting PMR is better than including a larger set of political controls. Our IV strategy is designed especially to solve the measurement error bias. We argue that liberalizations are more likely to be successful and hence effective in reducing the market power of existing incumbents if an ambitious liberalization plan is pursued. The underlined politico-economic logic is that liberalizations are first carried out in sectors where the benefits clearly exceed the costs and then in sectors where the outcomes are more doubtful in terms of welfare (Høj et al. 2006).[10] By way of example, the model of Blanchard and Giavazzi (2003) shows that labour market deregulation becomes more politically acceptable after product markets have been deregulated, which increases

[8] According to standard econometric theory (Wooldridge, 2002), the module of the OLS coefficient is downwardly biased in the presence of measurement error. Therefore, if the effect of the variable affected by measurement error is negative, the OLS estimate is biased upward.

[9] Notice that a good candidate instrument for liberalization used by a large literature cannot be used here: right- and left-wing politics have preferences on both REP and PMR, and the same is true for government ideology.

[10] Høj et al. (2006) document the sequence of reform across sectors. Sectors characterized by elements of a natural monopoly such as electricity have been generally liberalized after sectors where new technologies allow for more competition (telecommunications) or the natural monopoly argument was simply absent (air transportation). On the other hand, railways, gas and postal services have not been liberalized in all countries. In EU countries, electricity's liberalization has generally followed the liberalization of telecommunications.

investments and employment opportunities. A similar argument applies to liberalization in telecommunication compared to the one in electricity, with the latter having less clear welfare effects.[11] A trickle-down effect of liberalization between sectors is likely to occur for three reasons: the influence of international organizations (Høj et al., 2006), strong complementarities (see, e.g., Li et al. 2002 on the case of finance and telecommunications), and policy learning (see, e.g., Levi-Faur 2003). The empirical analysis of Høj et al. (2006) provides evidence on the existence of these spillovers between product market reforms, especially in sectors that were deregulated later, such as electricity.[12]

In summary, the real effect of energy liberalizations on the market power of incumbents, which is the variable that affects REPs, depends on a country's willingness to embrace liberal policies and on the past success of less debatable liberalizations. The bias in the estimated effect of liberalization thus should disappear when we use the instances of PMR in telecommunication, an industry that was liberalized slightly earlier, and in railways, an industry that has been liberalized in only certain countries, as instruments for PMR in electricity. The former instrument captures regulatory spillovers, and the latter captures the broad country's commitment to liberalization. Each of these instruments fulfils the two crucial conditions for being a good instrument. That is,

$$E\left(\mathbf{PMR}_{tel,it-1}, \varepsilon_{it} \middle| \mathbf{X}_{it-1}\right) = 0,$$

$$Corr\left(\mathbf{PMR}_{tel,it}, \mathbf{PMR}_{elec,it} \middle| \mathbf{X}_{it}\right) > \underline{\rho}.$$

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[11] An evaluation of the effect of liberalization on welfare is beyond the scope of this paper. The general consensus is that liberalization does not reduce electricity prices (e.g., Fiorio and Florio, 2013) and that the effect on energy R&D expenditures is negative (e.g., Jamasb and Pollitt, 2008; Sterlacchini, 2012).

[12] A related argument is that partial liberalizations may have a completely different effect on REP than full liberalization. Chick (2011) and Pollitt (2012) suggest that partial liberalization is likely to emerge because governments wish to maintain their ability to subsidize favoured interest groups. In this case, an external instrument that captures a country's willingness to liberalize in other sectors should convey more information on the true level of regulation in the electricity sector than the observed measure of regulation in electricity.

The first condition is a standard exogeneity condition that should be satisfied if unobservable variables, i.e., unobservable market power and lobbying effort, in the electricity sector are uncorrelated with telecommunication or railway regulation. The second condition simply states that the instrument is a good predictor of the endogenous variable and hence that the conditional correlation should be above a certain threshold $\underline{\rho}$. This condition is equivalent to saying that the F statistics of a first-stage regression of $\mathbf{PMR}_{elec}$ on $\mathbf{PMR}_{tel}$ is sufficiently high and above the usual cut-off of 10 (Stock et al., 2002, Angrist and Pischke, 2009, see table A1 in the appendix for details on the first-stage results).

Before presenting the main results of the paper, the next sub-section describes the policy indicators we use to measure a country's commitment to RE.

3.2 Policy Indicators

In the case of renewable energy, both theory and empirical evidence provide strong support for the use of a diversified policy portfolio rather than a specific policy instrument. In particular, a diversified policy portfolio is the best way to target the multiple externalities associated with RE (e.g., Fisher and Newell 2008, Acemoglu et al. 2012). Midttun and Gautesen (2007) show that the combination of RECs, FITs and R&D subsidies is the best means of managing technology at a different level of maturity. Nesta et al. (2014) suggest that each policy often targets a specific actor (i.e., RECs for large incumbents, FITs for small plants, investment incentives for specialized suppliers of electric equipment) and that a combination of several policies is the appropriate means of managing heterogeneous incentives and uncertainty.

Figure 1 presents a visual snapshot of the degree of policy heterogeneity in the International Energy Agency (IEA) dataset by detailing the types of policies applied in various countries.[13] As is evident from the figure, policy diversification increased substantially over time because previous policies were often maintained in conjunction with new ones.[14] This increasing diversification makes it exceedingly difficult to provide an aggregate measure of the effort delivered by each country in support of the adoption of RE. As a further complication, the IEA dataset provides information on only the year of adoption of a specific policy and not on the degree of intensity of the adopted policy. We thus integrate this dataset using other data sources in all cases for which policies measured on a continuous scale are available. Intensity measures are available for the following three instruments: public R&D expenditures in renewable energy, FITs and RECs (see Table 1 for a full description of the policies and data sources).

[TABLE 1 ABOUT HERE]

[FIGURE 1 HERE]

To offer a complete picture of a country's commitment to RE, we build an indicator that consider both the signalling effect of policy dummies and the stringency of continuous policies. Previous research on policy indicators attempts to cope with heterogeneous information through the use of a variety of weighting schemes and aggregation methods.[15] Following Esty and Porter (2005), our favourite indicator is based on the robust and widely

[13] The dataset made available by the International Energy Agency (IEA) contains detailed country fact sheets to construct dummy variables reflecting the adoption time of selected REPs for most OECD countries.

[14] Figure 1 also shows that the two main policy drivers of RE occurred in the 1970s and especially from the mid-1990s on. The two oil crises of the 1970s stimulated policy responses in nearly all developed countries, but an abrupt halt in the expansion of these policies occurred when oil prices began to decline in the early 1980s. A second wave of REP was implemented in the 1990s in response to increasing concerns related to climate change mitigation. Regarding the adopted policy, certain cross-country regularities clearly emerge. This phenomenon justifies the inclusion of time effects in our econometric specification to capture these common shocks.

[15] Mazzanti and Zoboli (2009) weight policy signals to account for the cross-country differences in the intensity of the main policy instrument for which they have quantitative information, i.e., landfill taxes. Using survey data, Dasgupta et al. (2001) assign weights to each policy on a Likert scale that is built by converting the responses provided to specific questions in the survey into numeric values. Also using survey-based data, Esty and Porter (2005) summarize several policy indicators using a common factor analysis to collapse the substantial set of indicators into two main ones.

used technique of principal component analysis (PCA henceforth). PCA is interesting due to its ability to extract a small number of orthogonal sub-indexes (called principal components, PCs). The PCs are linear combinations of the wider set of original variables that maximize the explained covariance of the data. In our case, we construct our preferred PCA indicator (REP_fact) using the three available continuous policies (FITs, RECs and public R&D) and six dummy variables for the other policy instruments (see Table 1). The analysis produces three relevant PCs that together explain approximately 65% of the policy variance. Interesting, each relevant PC reflects a different policy-type, i.e., quantity, price and innovation (Menanteau et al., 2003), and has been used to construct REP_fact by taking the simple mean.

To mitigate concerns about the validity of the PCA used to construct our preferred indicator, we conduct extensive robustness checks of our results by using two different aggregation methods. Our second-favourite indicator (REP_poly) was developed by Kolenikov and Angeles (2009) to generalize PCA when both discrete and continuous variables are present. This method derives the correlation matrix used to build the PCA by estimating the latent continuous variable that corresponds to each discrete or categorical variable. Accordingly, the first PC explains a greater share of the variance compared to a standard PCA (58% in our case) and is the only one we use to build the second indicator: REP_poly. However, the first PC obtained with the Kolenikov and Angeles's procedure has no clear economic interpretation, and thus we prefer to retain a traditional PCA for our favourite indicator. The third indicator (REP_div) rewards policy diversity and is the sum of policy dummies; it takes the value 1 if any policy is adopted, including the one for which we have continuous information. The simple justification of REP_div is that because each policy generally targets a different actor, policy diversification reflects a country's commitment to

RE (see Nesta et al., 2014). Finally, we use PCA to build policy indicators for each subset of variables of the same typology: price, quantity and innovation policies (REP_price, REP_quan and REP_inno, respectively).

In the appendix, we provide further details on the construction of the indicators. Descriptive statistics for the main variables used in our analysis are presented in Table 2.

[TABLE 2 ABOUT HERE]

[FIGURE 2 ABOUT HERE]

The evolution of REP_fact and PMR is depicted in Figure 2 for selected years. The REP_fact indicator displays a monotonically increasing pattern for nearly all countries, while PMR tends to converge towards very low values almost everywhere, which depicts the widespread liberalization process. This preliminary evidence reinforces our expectation about the positive effect of market liberalization on the adoption of REPs. For instance, Scandinavian and Anglo-Saxon countries lead the process of market liberalization and have persistently high REP policy support, but transition economies are generally those with lower policy levels and a less liberalized energy market. The Appendix provides further details on the country rankings for the three policy indicators, their cross-correlations and their correlation with an external policy indicator of sustainable development.

4. Analysis

4.1 Main Results

Table 3 reports the main results for our preferred indicator, REP_fact. Recall that all models in this section include time and country dummies and that the explanatory variables are always lagged one year. For the sake of comparison, the policy indicators are standardized to have a mean of 0 and a unitary standard deviation.

Model 1 presents the FE model for a first parsimonious specification where we include four explanatory variables: the index of PMR in electricity,[16] the index of perception of corruption (CORR), GDP per capita (GDP_pc) and the Gini index (INEQ). The point estimate of PMR shows that a more stringent regulation of electricity markets has a negative and significant influence on REPs. In line with previous evidence (Jenner et al., 2012), large utilities contrast the approval of ambitious REPs to retain their *raison d'etre*, which is intimately related to centralized energy production. Regarding the other variables of interest, INEQ, GDP_pc and CORR[17] have all the expected effects on REP, and only the coefficient of INEQ is not significant at the conventional level (p-value=0.170). If environmental quality is a normal good, policies that support it should be more ambitious in richer countries. In turn, conditional on a country's wealth, a lower inequality implies a more affluent median voter and thus increased support for REPs. Finally, the positive effect of corruption is in line with previous findings and implies that institutional quality has a positive effect on REPs (e.g., Fredriksson and Svensson, 2003).

[TABLE 3 ABOUT HERE]

In Model 2, we instrument PMR in electricity with the indexes of regulation in the telecommunication and railways sector. The chosen instruments have the expected signs, high explanatory power (the F-test for the first stage is 56.7, which is well above the usual cut-off level of 10), and appear exogenous, as is evident from the p-value of the Hansen tests

[16] All of the results presented in Section 3 are impressively robust to the use of an average of PMR in electricity and gas. The magnitude of the effect is approximately 20% larger in this case. The results remain available upon request by the authors.
[17] Recall that a higher Corruption Perception Index implies a less corrupted country.

presented in Tables 3, 4 and 5.[18] Since our exclusion restrictions pass standard specification tests in all of the models presented throughout the paper, we do not comment further on this issue.

When comparing the results of Model 1 and 2, the effect of liberalising the electricity market appears considerably larger in the IV specification. This finding suggests that PMR is positively correlated with an unobservable factor that dampers the public support for renewable energy policies. Such a large bias may be explained with a measurement error argument: an exogenous index of regulation understates the lobbying power of incumbents in highly concentrated sectors such as energy. As a result, we expect the effect of liberalization to be larger when the commitment of public authorities to liberalization is more credible and widespread across sectors. We observe that all of the effects are estimated more efficiently in Model 2 than in Model 1. By way of example, the size of the CORR coefficient is now smaller but significant at 99%, and the effect of INEQ is 1/3 larger and also significant at 99%.

Model 3 is our favourite specification, which augments Model 2 to account for two important features of a country's energy strategy, namely the share of energy produced from nuclear power (NUKE) and energy dependency (EN_DEP), i.e., the net energy imports in percentage of total energy use. Although endogeneity may in principle bias the estimates of these two effects, there are good reasons to believe that this is a minor issue. First, both variables display high persistency and either a flat (NUKE) or a decreasing trend, which is concentrated before the take-off in REPs (EN_DEP). Second, EN_DEP is only marginally affected by REPs. In fact, the share of energy produced using new renewable sources (i.e.,

[18] See Table A1 in the Appendix for detail on the first stage results.

wind and solar) is virtually negligible in all countries except Denmark,[19] but the share of hydropower remained unchanged since the 1980s, which reflects the relative maturity of this technology (Popp et al., 2011). Reassuringly, our results corroborate this conjecture about the exogeneity of the additional variables: although the estimated effects for our main variables of interest barely change from Model 2 to Model 3, energy dependency has the expected significant effect on REPs. In turn, the influence of nuclear share is far from being statistically significant but retains the expected sign.

We evaluate the magnitude of our effect of interest using coefficients estimated through Model 3, which -we contend- offers the most accurate representation of the factors that affect REPs. Because the two variables of interest, REP_fact and PMR, are indexes, we carry out the quantification with robust inter-quartile changes. First, the inter-quartile increase in REP_fact explained by an inter-quartile decrease in PMR is greater than 3/4. To provide a concrete example of this effect, France and Italy would have ranked just below Denmark in REP_fact with an electricity market, on average, regulated to the same extent as the German one. Second, the remaining variables also have a considerable influence on REP_fact and especially GDP_pc. The explained inter-quartile deviation is 1.6 for GDP_pc, 0.38 for INEQ, 0.32 for CORR and 0.18 for EN_DEP. Note that the good scores of Nordic countries in terms of INEQ and CORR explain a large fraction of their high scores in REPs.

To ensure that our estimated effects are not driven by other time-varying country characteristics, we enrich the favourite specification with controls for the influence of the green lobby, political institutions and other characteristics of the energy sector in Model 4. Recall that the additional variables in this extended specification are the share of green

[19] Also in Germany, the share of electricity generated from renewable sources increased substantially. However, our results are robust to the exclusion of Denmark and Germany.

deputies in the parliament,[20] a dummy that is equal to one since the year in which a solar association began, energy consumption per capita and the Polity 2 index, which captures the level of democracy. Qualitatively, the inclusion of these additional controls does not alter the results. Quantitatively, the effect of liberalization remains unaffected, similarly to that of INEQ. In turn, the effects of GDP_pc, CORR and EN_DEP are reduced by approximately 1/5 on average. Regarding the new variables, they all have the expected signs and are significant at the 99% level with the exception of Polity 2 and the dummy for the existence of a solar association. The result for electricity consumption per capita is interesting per se and indicates a complementary between energy efficiency and commitment to RE, but it should be taken with care due to unresolved concerns regarding endogeneity.[21]

4.2 Different Policy Indicators

Absent a widely accepted methodology to aggregate heterogeneous policies, one may argue that REP_fact imperfectly describes policy support for RE. We thus re-estimate our favourite specification using the alternative indicators described in Section 3.2. In Table 4, Models 3b and 3c are equivalent to Model 3 except for the policy indicator used, and Models 3p, 3q and 3i investigate the role of our variables of interest on specific groups of RE policies. More precisely, we conduct a PCA on three subsets of policies: price-based policies (i.e., tax

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[20] In doing so, we test the robustness of our results for the subset of most developed countries because data on green deputies are not available for the transition economies Mexico and Turkey. Note that, in general, our results are robust to the exclusion of one country at the time.

[21] In other robustness checks, which are available upon request by the authors, we show that our results are robust to a different measure of corruption, i.e., the one developed by the World Bank in the Worldwide Governance Indicator project. Also importantly, our results are robust to the inclusion of the share of capacity from independent power producers (IPPs) to address the issue raised by Schmalensee (2012) on the relationship between IPPs and RE penetration. He suggests that the cost of RE is higher if regulation prescribes a fair rate of return on the sunk costs afforded by utilities. In turn, the cost is lower in states with organized wholesale markets managed by independent system operators where returns of IPPs are not warranted. Controlling for the share of IPPs allows us to reduce the unobserved correlation between the willingness to adopt RE, proportional to its expected cost, and liberalization, which was positively correlated with the share of IPPs.

credits or FITs), quantity-based policies (i.e., RECs) and R&D policies. See the Appendix for details.

[TABLE 4 ABOUT HERE]

For the sake of comparison, Model 3 presents the benchmark results for REP_fact, and we use REP_poly, which is the indicator that maximizes the share of the variance explained by the first PC, in Model 3b. The results are qualitatively unchanged for all of the variables. The size of the estimated effects is unchanged for PMR and slightly reduced for INEQ. In turn, the effects of GDP_pc and CORR decrease by more than half compared to Model 3. The largest differences are observed in Model 3c, where we use an indicator (REP_div) that rewards policy diversification. All of the effects are substantially reduced to the point of becoming insignificant for all of the variables except GDP_pc and PMR with a cut-off p-value of 0.124. Despite the large reduction of its effect, an interquartile change in PMR continues to account for slightly less than 1/5 of an interquartile change in REP_div. In summary, our results are qualitatively unchanged when using different indicators, especially for PMR and GDP_pc, but the effects are considerably smaller for REP_div.

The second part of Table 4 addresses the issue of specific RE policies. In what follows, we comment on the effect of PMR on REPs and report the other coefficients only for sake of completeness.[22] Model 3p shows that the effect of PMR is stronger on price-based policies than on other REPs. Because price-based policies have a strong effect on renewable energy innovations (Johnstone et al. 2010, Fisher and Newell 2008), this result lends support to the idea that the incumbents' opposition to REPs is linked to technological competition (e.g., Dosi, 1982). Model 3q indicates that the estimated coefficient of liberalization is slightly

[22] The effects of the other variables remain more or less unchanged for the price, quantity and innovation indicators. Only CORR is negative and significant for the indicator of price-based policy. However, the result is fully driven by Italy, which is a country with high corruption and substantial price-based support for RE.

smaller for quantity-based policies than for price-based ones.[23] On the contrary, Model 3i confirms previous findings on the negative effect of liberalization on public R&D expenditures (e.g., Jamasb and Pollitt, 2008). This result resonates with the classical appropriability effect of competition on innovation and suggests the existence of several trade-offs in the effect of liberalization on renewable energy innovation.[24]

4.3 Various Features of the Liberalization Process

The design of liberalizations varies substantially across countries (Pollitt, 2012) and is the result of three distinct processes: granting freedom of access and choice to producers and consumers, privatising public utilities and unbundling network services from power generation. Table 5 assesses which particular component of the liberalization process creates a friendlier environment for REPs. We use analogous components of the regulatory indexes in the transport and network industries as exclusion restrictions for PMR_ent, PMR_pub and PMR_unb. For instance, PMR_ent is instrumented with the index of entry barriers for transport and network industries.

[TABLE 5 ABOUT HERE]

Models 5, 5b, 5c, 5p, 5q and 5i consider the RE indicators used above. A clear picture emerges across indicators. The positive and significant effect of lowering entry barriers is offset by a negative and significant effect of privatization (i.e., lower PMR_pub). In turn, the effect of unbundling tends to be negative and significant, but it changes depending on the RE indicator used. We thus conclude that unbundling plays a secondary role in the process of REP determination and focus our comments on PMR_ent and PMR_pub.

[23] However, the effect is larger in terms of explained inter-quartile variation insofar as variation in quantity-based policies is significantly lower than variation in price-based ones.

[24] Two trade-offs have been emphasized by previous literature: one between applied and basic research (Jamasb and Pollitt, 2008) and one between exploitation of existing discoveries and path-breaking research driven by public R&D (Popp, 2006).

Observe that, conditional on PMR_pub (which captures large-scale privatization), a lower PMR_ent implies the entry of small players such as municipalities, independent power producers, cooperatives and households that should have favoured the emergence of lobbies supporting renewable energies (e.g., Canton, 2008). An important result is that the effect of PMR_ent is strong and significant for REP_div, which is the indicator on which the aggregate PMR effect was smaller. The effects are again economically meaningful: if Canada had the same level of entry regulation as Sweden, it would have climbed 12 positions in the REP_fact's ranking, reaching a level similar to that of Germany.[25] It is also worth noticing that PMR_ent has a considerably stronger effect on REP_price and REP_inno, which reinforces our claim that granting access to new, unconventional actors spurs the support to ambitious environmental policies. Finally, our result for PMR_pub clearly indicates that large private-owned firms care less about environmental problems compared with their public-owned counterparts. For example, the increase in public ownership at the level of Sweden would have ensured for the USA (resp. the UK) a level of REP_fact above that of Denmark (resp. Sweden).

To recap, a reduction in the monopolistic power of state-owned utilities has a positive effect on REPs when various types of actors are ensured access to the grid instead of it being provided to only a few large private firms. For instance, Sweden and, to a lesser extent, the Netherlands are well recognized as having low entry barriers, strong public ownership and ambitious REPs (Pollitt, 2012).

4.4 Persistency in Renewable Energy Policies

[25] More formally, a change from the 1^{st} to the 3^{rd} quartile in PMR_ent explains between 0.71 (for REP_fact) to 1.69 (for REP_price) of an interquartile change in REP.

Renewable energy policies are changing slowly over time and display high persistency with an estimated autoregressive coefficient of approximately 1. This finding does not come unexpectedly, as past decisions to implement REPs should affect the present behaviour of policy makers through learning and lobby formation. However, accounting for dynamics is not straightforward in our case because we must address the endogeneity of both the lagged dependent variable (Nickell, 1981) and our main variable of interest.

We propose two methodologies to address these issues. First, we include the lagged REP among the covariates. To fix endogeneity for the lagged dependent variable, we use its own lags and lagged differences as instruments, and PMR is instrumented as above. However, our external instruments for PMR become weaker in this dynamic setting.[26] We thus propose a second, preferred approach to consider dynamics. In particular, we take the five-year average, take the first difference of our variables of interest and then re-estimate our main specification using a 2SLS where the differenced-PMR is instrumented as usual. This second choice is validated by the fact that the 5-year averaged REP index, conditioned to time effects, does not display serial correlation.

Model 6 of Table 6 presents the first approach. Individual effects are modelled using a standard within-transformation. The point estimates are qualitatively similar to those of the static specification. For instance, the effects of CORR and INEQ are very near statistical significance. Note that in this case, the point estimates should be interpreted as short-term effects; therefore, one should not be surprised by the fact that they are remarkably smaller than the point estimates of Model 3 in Table 3. The long-term effects are instead nine times larger, and a persistent interquartile decrease in PMR triggers a considerable interquartile increase of 2.3 in REP_fact.

[26] In model 7, the F-statistics of excluded instruments is only 3.4 for PMR.

Model 7 presents the results for the alternative first-difference 2SLS estimator. Observe first that the main results are qualitatively unchanged and that the magnitude of the effects is the same for PMR, GDP_pc and EN_DEP as in the FE specification of Model 3 in Table 3. Obtaining this result in a first-difference specification further corroborates our causal interpretation of the effect of PMR on REP. Among the other effects, INEQ is far from being statistically significant, but CORR is nearly significant with a p-value of 0.183. To summarize, we may conclude that PMR, GDP_pc and EN_DEP are the three variables that remain significant determinants of REPs in these demanding dynamic specifications.

[Table 6 ABOUT HERE]

5. Conclusions

This paper investigates the effect of liberalization in the electricity market on renewable energy policy indicators that measure a country's commitment to RE. We draw inspiration from political economy models of environmental policies and adapt the predictions of these models to the case of REP. Our main result is that energy market liberalization has a positive and perhaps unintended impact on REPs. Although this result is in line with anecdotal evidence and previous empirical work, our IV strategy highlights a substantial downward bias in the OLS estimate of this effect. We argue that the difference between the IV and OLS estimator is due to the mismeasurement of electricity regulation and reverse causality, i.e., endogenous lobby formation. Remarkably, the effect of PMR is the second largest after that of GDP_pc, with an interquartile decrease in PMR explaining roughly 3/4 of an interquartile increase in our favourite REP indicator. Considering the effects of inequality, corruption and green lobbying, our results suggest that a hybrid politico-economic model, where both citizens' preferences and lobbying power are important, offers the most accurate explanation of REP determinants.

To provide a more transparent interpretation of the effect of liberalization, we split the PMR index into its three components and find that a reduction in entry barriers fully captures the effect of PMR on REP. This finding suggests that a reduction in the monopolistic power of state-owned utilities has a positive effect on REPs when various types of actors are ensured access to the grid instead of it being provided to only a few large private firms. Because reducing entry barriers has a stronger effect on the two policy types that have stronger effects on innovation (i.e., price-based and innovation-based policies), we are inclined to explain this finding with the competition between two rival technological paradigms. The development of RE will increase decentralized and small-scale energy production and thus reduce the profits of large-scale generators, which fuels their opposition to REPs.

Our results are important for future and on-going research on energy markets. First, assessments of the effect of liberalization on energy prices may be incomplete and misleading when not accounting for REPs as long as the cost of these policies are, at least partially, passed to consumers and REPs are affected by the liberalization. Second, the welfare consequences of both liberalizations and REPs should be jointly assessed by accounting for the interaction highlighted by our paper. The explicit inclusion of these effects in energy modelling seems a promising avenue for illustrating the trade-offs between various objectives, i.e., energy security vs. price reductions, and the full consequences of specific market reforms.

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Table 1. Summary of the individual REP policies.

Instrument	Brief explanation	Variable Construction	Source
Investment incentives	Capital grants and all other measures aimed at reducing the capital cost of adopting renewables. May also take the form of third party financial arrangements, where governments assume part of the risk or provide low interest rates on loans. They are generally provided by State budgets.	Dummy Variable	International Energy Agency
Tax Measure	Economic instruments used either to encourage production or discourage consumption. They may take the form of investment tax credits or property tax exemptions, to reduce tax payments for the project owner. Excises are not directly accounted for here unless they were explicitly created to promote renewables (for example excise tax exemptions).	Dummy Variable	International Energy Agency
Incentive tariff	Through guaranteed price schemes, the energy authority obliges energy distributors to feed in the production of renewable energy at fixed prices varying according to the various sources. Some countries (UK, Ireland) developed so-called bidding system schemes in which the most cost-effective offer is selected to receive a subsidy. This last case is also accounted for in the dummy, due to its similarity to the feed-in systems.	Level of price guaranteed (USD, 2006 prices and PPP)	International Energy Agency Cerveny and Resch (1998) Country specific sources REN21 Database (www.ren21.net)
Voluntary program	These programs generally operate through agreements between the government, public utilities and energy suppliers, where they agree to buy energy generated from renewable sources. One of the first voluntary programs was in Denmark in 1984, when utilities agreed to buy 100 MW of wind power.	Dummy Variable	International Energy Agency
Obligations	Obligations and targets generally take the form of quota systems that place an obligation on producers to provide a share of their energy supply from renewable energy. These quotas are not necessarily covered by a tradable certificate.	Dummy Variable	International Energy Agency
Tradable Certificate	Renewable energy Certificates (REC) are used to track or document compliance with the quota system and consist of financial assets, issued by the regulating authority, which certify the production of renewable energy and can be traded among the actors involved. Along with the creation of a certificate scheme, more generally a separate market is established where producers can trade the certificates, creating certificate "supply", while the demand depends on political choices. The price of the certificate is determined through relative trading between the retailers.	Share of electricity that must be generated by renewables or covered with a REC.	Data made available by Nick Johnstone, OECD Environment Directorate REN21 Database (www.ren21.net) Country Specific sources
Public Research and Development	Public financed R&D program disaggregated by type of renewable energy.	Public sector per capita expenditures on energy R&D (USD, 2006 prices and PPP).	International Energy Agency
EU directive *2001*/77/EC	Established the first shared framework for the promotion of electricity from renewable sources at the European level.	Dummy Variable	European Commission

Table 2. Descriptive statistics and sources.

Acronym	Description	Obs.	Mean	St. Dev.	Min	Max	Source
REP_fact	Policy index based on principal component analysis (standardized in the analysis)	784	0.11	0.63	-0.33	7.5	
REP_poly	Policy index based on polychoric principal component analysis (standardized in the analysis)	784	0.36	1.52	-1.04	6.45	
REP_div	Policy index based on dummy variables (standardized in the analysis)	784	2.65	2.08	0	8	
REP_price	Market-based policy Indicator - based on PCA (standardized in the analysis)	784	0.26	1.04	-0.75	3.39	
REP_quan	Quota-based policy Indicator - based on PCA (standardized in the analysis)	784	0.11	1.14	-0.96	7.46	
REP_inno	Innovation-based policy Indicator - based on PCA (standardized in the analysis)	784	0.22	1.03	-2.56	2.91	
GDP_pc	GDP per capita, thousands US 1990 Dollars, ppp. (Missing data for Czech and Slovak republic before 1990)	767	24.67	10.51	5.41	86.05	OECD
INEQ	Gini Coefficient	783	29.31	6.32	15.06	50.41	Standardized World Income Inequality Database (SWIID)
CORR	Corruption index that ranges from 0 (highly corrupt) to 10 (highly clean).	784	6.96	2.04	1.49	9.95	World Resource Institute dataset
PMR_{elec}	Product Market regulation in the energy sector	784	4.35	1.74	0	6	OECD
$PMR_{elec\ entry}$	Product Market regulation in the energy sector sub-index: Entry barriers	784	4.25	2.41	0	6	OECD
$PRM_{elec\ public\ own}$	Product Market regulation in the energy sector sub-index: Public ownership	784	4.45	1.83	0	6	OECD
$PMR_{elec\ vertical\ int}$	Product Market regulation in the energy sector sub-index: Vertical integration	784	4.36	2.16	0	6	OECD
EN_DEP	Energy imports, net (% of energy use)	784	16.86	124.52	-842.43	99.17	IEA
NUKE	Electricity production from nuclear sources (% of total)	784	17.07	20.61	0	79.07	World bank
ELEC_CONS	Average value of industrial and residential consumption per capita (Gxh)	784	4.93	3.72	0.34	19.18	IEA
GREEN	Share of green deputies in parliament	616	1.92	3.04	0	13.33	World bank
POLITY 2	Political regime characteristics (from -10 (hereditary monarchy) to +10 (consolidated democracy)	784	8.62	3.99	-8	10	Polity IV Project (Centre for Systemic Peace)
SOLAR_ASS	Existence of a state chapter of the international Solar Energy association (ISES)	784	0.88	0.31	0	1	National ISES web sites

PMR_{rail}	Product Market regulation in the Rail sector	784	5.08	1.22	0.37	6	OECD
PMR_{tel}	Product market regulation in Telecommunications	784	1.22	2.02	0.13	6	OECD
$PMR_{entry\ net}$	Average value of PMR entry Postal service and PMR entry Telecommunication. sub-index: Entry barriers	784	3.41	2.10	0	6	OECD
$PMR_{entry\ air}$	Product Market regulation in the Airlines sector sub-index: Entry barriers	784	3.69	2.33	0	6	OECD
$PMR_{vert\ int\ rail}$	Product Market regulation in the Rail sector sub-index: Vertical integration	784	4.96	1.59	0	6	OECD
$PMR_{public\ own\ tel}$	Product market regulation in Telecommunications sub-index: Public ownership	784	3.83	2.45	0	6	OECD
$PMR_{market\ struct\ tel}$	Product Market regulation in the Airlines sector sub-index: Market Structure	784	4.80	1.49	0.40	6	OECD
$PMR_{public\ own\ air}$	Product Market regulation in the Airlines sector sub-index: Public ownership	784	3.73	2.38	0	6	OECD

Table 3. Effect of Product Market Regulation on Renewable Energy Policies, dependent variable: REP_fact.

Model	Model 1	Model 2	Model 3	Model 4
$PMR_{elec\ -1}$	-0.0939*	-0.2427***	-0.2353***	-0.2646***
	[0.0518]	[0.0610]	[0.0620]	[0.0728]
GDP_pc_{-1}	0.1186***	0.1150***	0.1308***	0.1084***
	[0.0366]	[0.0256]	[0.0264]	[0.0297]
$INEQ_{-1}$	-0.0337	-0.0480***	-0.0512***	-0.0565***
	[0.0239]	[0.0125]	[0.0130]	[0.0178]
$CORR_{-1}$	0.0910**	0.0675***	0.0906***	0.0779*
	[0.0414]	[0.0230]	[0.0229]	[0.0426]
EN_DEP_{-1}			0.0031***	0.0024***
			[0.0005]	[0.0004]
$NUKE_{-1}$			-0.0009	-0.001
			[0.0023]	[0.0033]
$ELEC\_CONS_{-1}$				-0.1128***
				[0.0396]
$GREEN_{-1}$				0.0515***
				[0.0133]
POLITY 2_{-1}				0.0562
				[0.0922]
SOLAR_ASS				0.0206
				[0.1063]
N	760	760	760	611
Number of countries	28	28	28	22
Hansen J		0.0078	0.4989	0.1909
Hansen crit- prob.		0.9294	0.48	0.6622

Notes: In Models 2, 3 and 4, we use PMR in telecommunication and railways as instrument for PMR in electricity. Details on the first-stage results are available in the Appendix. All regressions include year and country effects. Standard errors are clustered by country. Significant levels: * 10%, ** 5%, *** 1%.

Tabel 4. Effect of Product Market Regulation on Renewable Energy Policies for different policy indicators. All columns present results estimated using Model 3 of Table 3.

Dep. Variable	**REP_fact**	**REP_poly**	**REP_div**	**REP_price**	**REP_quan**	**REP_inno**
$PMR_{elec\ -1}$	-0.2353***	-0.2433***	-0.0746	-0.7907***	-0.6626***	0.1990***
	[0.0620]	[0.0573]	[0.0486]	[0.1747]	[0.1046]	[0.0729]
GDP_pc_{-1}	0.1308***	0.0559***	0.0387***	0.0206**	0.0048	-0.0035
	[0.0264]	[0.0060]	[0.0057]	[0.0101]	[0.0115]	[0.0107]
$INEQ_{-1}$	-0.0512***	-0.0455***	-0.0088	-0.0870***	-0.0959***	0.0265**
	[0.0130]	[0.0101]	[0.0096]	[0.0212]	[0.0191]	[0.0135]
$CORR_{-1}$	0.0906***	0.0371*	0.024	-0.0836*	0.0676**	0.0665**
	[0.0229]	[0.0206]	[0.0194]	[0.0445]	[0.0327]	[0.0287]
EN_DEP_{-1}	0.0031***	0.0018***	0.0006	0.0024***	0.0007	0.0008***
	[0.0005]	[0.0003]	[0.0004]	[0.0009]	[0.0006]	[0.0003]
$NUKE_{-1}$	-0.0009	-0.0011	-0.0016	0.0018	-0.0033	0.0009
	[0.0023]	[0.0023]	[0.0020]	[0.0041]	[0.0039]	[0.0039]
N	760	760	760	760	760	760
Number of countries	28	28	28	28	28	28
Hansen J	0.4989	0.0613	2.5669	0.5643	0.1374	0.0009
Hansen crit- prob.	0.48	0.8044	0.1091	0.4525	0.7109	0.9765

Notes: We use PMR in telecommunication and railways as instrument for PMR in electricity. In the case of REP_price, the Hansen test rejects the null hypothesis that instruments are uncorrelated with the error term, hence we use PMR in airplane and post industries as instruments. All regressions include year and country effects. Standard errors clustered by country. Significant levels: * 10%, ** 5%, *** 1%.

Table 5: Effect of different component of PMR on different REP indicators

Dep. Variable/ Model	**REP_fact/ 5**	**REP_poly/ 5b**	**REP_div/ 5c**	**REP_price/ 5p**	**REP_quan/ 5q**	**REP_inno/ 5i**
$PMR_{elec\ entry\ -1}$	-0.3245***	-0.2480**	-0.4012***	-0.8993***	-0.3460**	-0.6253***
	[0.1019]	[0.1134]	[0.1062]	[0.2969]	[0.1572]	[0.1122]
$PRM_{elec\ public\ own\ -1}$	0.4958***	0.6956***	0.6116***	0.4051*	0.7297***	0.4220**
	[0.1758]	[0.1846]	[0.1693]	[0.2239]	[0.1976]	[0.2037]
$PMR_{elec\ vertical\ int\ -1}$	-0.1624	-0.3172**	-0.0274	0.4867**	-0.5359***	0.3901**
	[0.1189]	[0.1332]	[0.1185]	[0.2179]	[0.1820]	[0.1570]
GDP_pc_{-1}	0.1196***	0.0706***	0.0410***	0.0249**	0.0197	-0.012
	[0.0188]	[0.0117]	[0.0085]	[0.0115]	[0.0124]	[0.0113]
$INEQ_{-1}$	-0.0411***	-0.0281*	-0.0024	-0.0262	-0.0674***	0.0083
	[0.0156]	[0.0165]	[0.0152]	[0.0281]	[0.0216]	[0.0177]
$CORR_{-1}$	0.1309***	0.0913***	0.0634**	0.0342	0.1205***	0.0735*
	[0.0364]	[0.0338]	[0.0301]	[0.0479]	[0.0453]	[0.0380]
EN_DEP_{-1}	0.0058***	0.0052***	0.0044***	0.0064***	0.0045***	0.0053***
	[0.0008]	[0.0009]	[0.0010]	[0.0019]	[0.0010]	[0.0010]
$NUKE_{-1}$	0.0036	0.0048	0.0045	0.0078	0.0034	0.0068
	[0.0035]	[0.0039]	[0.0037]	[0.0066]	[0.0048]	[0.0047]
N	760	760	760	760	760	760
Number of countries	28	28	28	28	28	28
Hansen J	4.8233	2.5335	2.5092	1.9029	4.215	0.8795
Hansen crit- prob.	0.1852	0.4693	0.4736	0.5928	0.2392	0.8304

Notes: We use PMR in telecommunication and railways as instrument for PMR in electricity. In the case of REP_price, the Hansen test rejects the null hypothesis that instruments are uncorrelated with the error term, hence we use PMR in airplane and post industries as instruments. All regressions include year and country effects. Standard errors clustered by country.

Table 6: Effect of PMR on REP_fact, dynamic specifications

Model/ dep. var.	**Model 6/ REP_fact**	**Model 7/ *ΔREP_fact***
REP_fact $_{-1}$	0.8996***	
	[0.0389]	
PMR_{elec} ($\Delta\ PMR_{elec}$)	-0.1042*	*-0.2396**
	[0.0606]	*[0.1361]*
GDP_pc (*Δ GDP_pc)*	-0.0113	*0.0970****
	[0.0100]	*[0.0332]*
INEQ (*Δ INEQ)*	0.0410**	*-0.0103*
	[0.0172]	*[0.0151]*
CORR (*Δ CORR)*	0.0444***	*0.0235*
	[0.0126]	*[0.0177]*
EN_DEP (*Δ EN_DEP)*	0.0009**	*0.0019**
	[0.0004]	*[0.0010]*
NUKE (*Δ NUKE)*	0.0006	*-0.0042*
	[0.0018]	*[0.0042]*
N	760	162
Number of countries	28	28
Hansen J	11.797	0.361
Hansen crit- prob.	0.2989	0.5479

Notes: Standard errors are clustered by country. Significant levels: * 10%, ** 5%, *** 1%. Notes Model 6: we use ΔREP_fact from t-2 to t-5 and the average REP_fact from t-5 until t-1979 (the initial year of our analysis) as instruments for REP_fact (t-1). We instrument PMR in electricity using PMR in telecommunications and railways lagged 0, 1 and 2 years to increase goodness of fit of the first stage. All variables are detrended to eliminate year effects, while country effects are explicitly added. Notes Model 7: we take the 5-year average of all the variables and then take the long-difference; this explains the lower sample size. The instruments for ΔPMR elec. are ΔPMR tel. and ΔPMR rail. All variables are detrended to eliminate year effects.

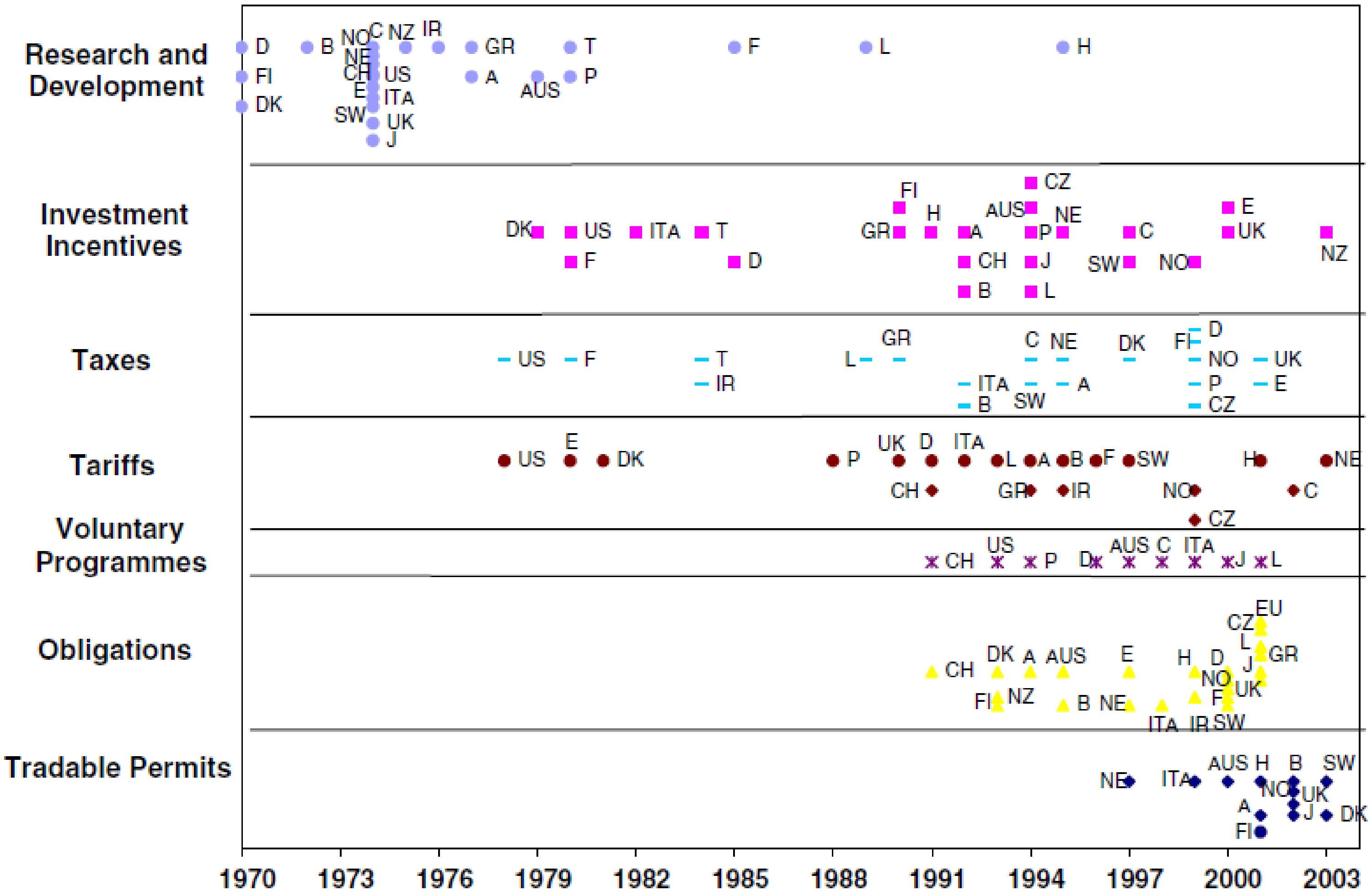

Figure 1. Patterns of policy adoption in selected OECD countries.

Source: IEA (2004), as in Johnstone et al. (2009). *AUS* Australia, *C* Canada, *FI* Finland, *GR* Greece, *ITA* Italy, *L* Luxembourg, *NO* Norway, *SW* Sweden, *UK* United Kingdom, *A* Austria, *CZ* Czech Rep., *F* France, *H* Hungary, *J* Japan, *NE* Netherlands, *P* Portugal, *CH* Switzerland, *US* United States, *B* Belgium, *DK* Denmark, *DE* Germany, *IR* Ireland, *NZ* New Zealand, *E* Spain, *T* Turkey

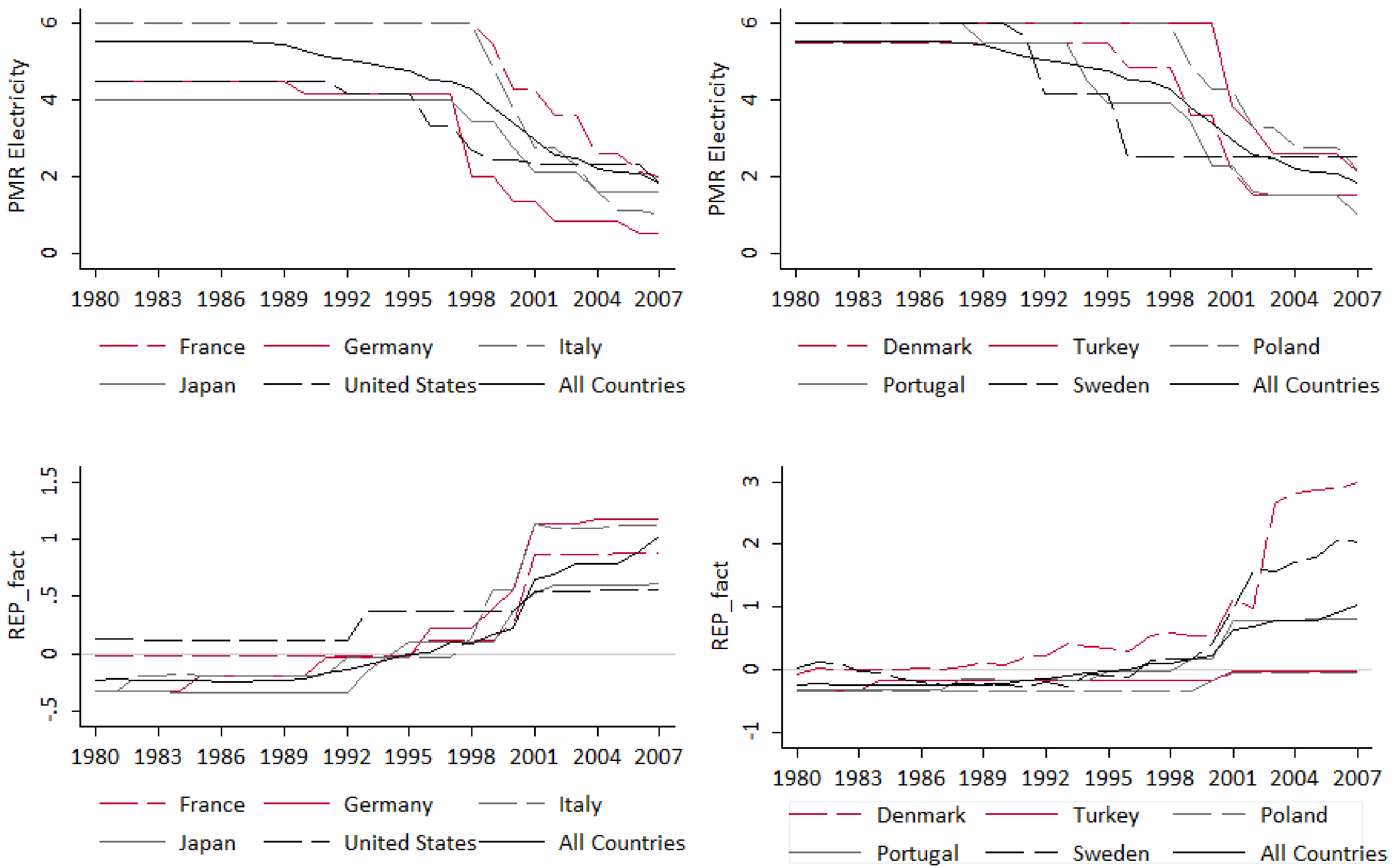

Figure 2. Evolution of Product Market Regulation in the Electricity sector and the main renewable energy policy indicator (REP_fact) between 1980 and 2007 in Large Countries (left panel) and Small Countries (right panel).

Appendix (for on-line publication only)

A1. First Stage Results

Table A1 below presents results for the first stage of Model 2 in Table 3 for the PMR and Model 1 in Table 5, for the three sub-components of the PMR (PMR_ent, PMR_pub, PMR_vert). The excluded instruments are statistically significant and all have the expected sign, being a higher PMR in network and transport industries positively associated with a higher PMR in electricity. Observe that the F-statistic for the excluded instruments is always well-above the threshold of 10. In general, instruments appear slightly weaker when we split PMR reflecting the fact that it is difficult to find suitable instruments to each particular feature of the liberalization process. Note also that, compared to the aggregate PMR, the excluded instruments are different when we consider the PMR split. The reason is that in this case we have to slightly adapt the external instrument to pass the Hansen test. For the aggregate PMR, results are instead very robust to the use of different external instruments, i.e. PMR in several other sectors.

[TABLE A1 HERE]

A2. Data Sources

Renewable energy policies data. The dataset made available by the IEA contains detailed country fact sheets that allow to construct dummy variables reflecting the adoption time of selected REPs for most OECD countries. Where possible, we integrated this data with information on the stringency of the single policies. To the best of our knowledge, this is possible for the following three policy instruments: public renewable R&D expenditures, feed-in tariff schemes and renewable energy certificates (see Table 1 for a full description of the policies). Information on the first is also available in the joint IEA-OECD dataset, whereas the main references for feed-in tariffs are two reports compiled by the IEA (2004) and Cerveny and Resch (1998), plus the REN21 website. Our measure of the stringency of renewable energy certificates (RECs) is the variable constructed by Johnstone et al. (2010) that reflects the share of electricity that must be generated by renewables.

Market Liberalization. To account for the degree of liberalization in the energy market we choose the index of Product Market Regulation (PMR) in the electricity sector provided by the OECD. This index is constructed using common factor analysis by combining objective sector-specific policies and regulations from different data sources (see Conway et al., 2005 for details). The PMR index for electricity aggregates three sub-indexes, which takes on values from 0 to 6:

- Ownership, ranging from public (6) to private (0)
- Entry barriers, which synthesizes information on: third party access to the grid (regulated (0), negotiated (3), no access (6)) and minimum consumer size to freely choose suppliers (no threshold (0) - no choice (6));
- Vertical integration, ranging from unbundling (0) to full integration (6).

The other indexes of Product Market Regulation used in the analysis (Rail, Telecommunications, Airlines and Postal Services) are constructed following the same procedure and always refer to the degree entry barriers, public ownership and vertical integration in their respective markets. The only exception is the index of market structure in the telecommunications, which refers to the number of firms competing in the market and their relative market share. For other variables detailed data sources are reported in Table 1.

A3. Policy Indicators

REP_FACT. PCA is interesting because of its ability to extract a small number of uncorrelated sub-indexes (called principal components) from a wide set of variables. The first principal component is the linear combination of the original variables that explains the greatest amount of the overall variance (obtained finding the eigenvalues and eigenvectors of the covariance matrix of the initial set). With sequential application of PCA, it is possible to identify a second linear combination of the original variables that explains a greater share of the residual variance, and so on. The components obtained in the analysis are generally rotated to produce more readily interpretable results. To construct aggregate indicators, the general rule of thumb is to use only those components that account for a sufficient amount of variance, i.e., generally those associated with eigenvalues greater than one.

Table A.2 provides an in-depth summary of the main variables that 'load' each relevant component entering the indicator REP_fact. This step is important to clearly interpret each principal component, as it is usually desirable for variables exhibiting greater similarity to be clustered together. Supporting our methodological choice, similar original policies are typically clustered together in the same component. For instance, the component with the greatest explanatory power (35%) is primarily a combination of price-based policies, while the second is a combination of quantity-based instruments. The last principal component in terms of explanatory power is strongly correlated with innovation policies (i.e., R&D intensity). Starting from PCA analysis we constructed our favourite indicator REP_fact taking the simple average of the three components.

[TABLE A2 HERE]

Finally, we apply three distinct PCA on thematic subset of policies derived from the previous analysis. A first one synthesizes in a single index all the available price based instruments (Feed-in, Tax, Investment incentive and Incentive tariff), the second one summarizes quantity based policy (Voluntary Programms, Obbligations, RECs and EU/2001 dummy) and the third one is applied to policies in support of innovation (R&D Plan adoption dummy and R&D per Capita). In all the three cases a single factor has been derived, accounting respectively for the 62, 46 and 40 per cent of the total variance of the original set of variables, and has been employed as alternative indicators in the analysis (FACT_price, FACT_quantity and FACT_inno).

REP_POLY: Further details on the methodology used to build this indicator can be found in Kolenikov and Angeles (2009). For sake of space, we provide here just the main intuition. In presence of discrete data, the normality assumption that underlines the PCA method is violated as the skewness and kurtosis in the distribution of, i.e., dummy variable is much larger. This is likely to bias downward the pairwise correlations used to build principal components. A maximum likelihood estimator can overcome this issue and allows to obtain the unobserved, normally distributed, continuous variable from their observed discrete counterpart, i.e. the so-called polychroric correlations. Practically, the likelihood function is maximized with respect to both the thresholds of a multivariate Probit model and the matrix correlations among the underlined, but unobservable, variables. This allows to obtain such correlation matrix as if each variable was draw from a normal distribution. More important for us, this method can be easily extended to obtain correlations between continuous and discrete variables, i.e. so-called polyserial correlations. Finally, the derived correlation matrix is used to carry out a PCA in the usual way.

As documented by the large simulation study analysis of Kolenikov and Angeles (2009), the main advantage of using this polyserial correlation method is that the proportion of variance explained by each component is larger than with PCA. Our comparison of indicators confirms this finding. The first component alone explain 58% when using polyserial correlation, while only 40% is explain by the first PC when not correcting for such discrete variable bias. The downside is that the first principal component has a less clear interpretation in this case as several policies load on it. For this reason and to be consistent with previous works on environmental policy indicators, we choose to use the PCA indicator as our favorite one.

A4. Comparison of the Policy Indicators

As show by the correlation matrix presented in Table A3, the differences between the three indicators are small. In fact, the cross-correlations are statistically significant and range between 0.75 and 0.91. This similarity is also confirmed by the country ranking presented in Table A4, which is fairly consistent across indicators. Transition economies are generally those with lower policy levels, together with Greece, Mexico and New Zealand. Denmark, Switzerland, the Netherlands, Sweden and the US have higher REP levels. In last 15 years, policy support in Austria, Germany, Finland and Italy approached the levels of the best performing countries, while Sweden and the US experienced substantial declines in their rankings. There are, however, some discrepancies. In particular, the absence of feed-in tariff schemes in certain countries altered the ranking between REP_div and the other two indicators. For instance, Japan ranks second in REP_div and only 17th in REP_fact. Similarly, countries like Luxembourgh and Sweden have much better rankings in indicators employing information from continuous variables because of their higher than average levels of feed-in, REC targets and public R&D expenditures.

[TABLE A3 HERE]

As an external validation, in Table A4 we compute the correlation of our three indicators with a widely used indicator of environmental policy, i.e. the Environmental Sustainability Index (ESI). [27] We restrict the analysis to the 2005 as it is the only year for which we have the ESI. Among the three indicators considered in our analysis, our preferred indicator REP_fact

[27] The ESI is an indicator developed by developed by the Yale Center for Environmental Law and Policy and the Center for International Earth Science Information Network - Columbia University (WEF, 2001).

is the only one that displays a statistically significant correlation of 0.47 with the ESI. This further validates our choice of using it as main policy indicator.

[TABLE A4 HERE]

Table A1. First stage estimations of Model 2 Table 3 and Model 1 Table 5 (results for exclusion restrictions only).

Model **Instrumented Var**	**Mod 2 tab 3** $PMR_{elec\ -1}$	**Mod 1 Tab 5** $PMR_{elec\ entry\ -1}$	**Mod 1 Tab 5** $PRM_{elec\ public\ own\ -1}$	**Mod 1 Tab 5** $PMR_{elec\ vertical\ int\ -1}$
$PMR_{rail\ -1}$	0.2462***			
	[0.0653]			
$PMR_{tel\ -1}$	0.2934***			
	[0.0435]			
$PMR_{entry\ net\ -1}$		0.0810	0.0636*	0.2076***
		[0.0512]	[0.0348]	[0.0518]
$PMR_{public\ own\ tel\ -1}$		-0.0347	0.0838***	0.0792**
		[0.0406]	[0.0247]	[0.0400]
$PMR_{market\ struct\ tel\ -1}$		0.4654***	-0.0039	-0.0001
		[0.0911]	[0.0460]	[0.0816]
$PMR_{entry\ air\ -1}$		0.0808**	-0.0281	0.0914**
		[0.0407]	[0.0238]	[0.0396]
$PMR_{public\ own\ air\ -1}$		0.0139	-0.0567**	0.0383
		[0.0349]	[0.0225]	[0.0348]
$PMR_{vert\ int\ rail\ -1}$		0.2850***	0.2227***	0.3518***
		[0.0588]	[0.0469]	[0.0585]
N	760	760	760	760
Number of countries	28	28	28	28
first-stage F	(2, 700) 56.67	(6, 694) 18.69	(6, 694) 17.25	(6, 694) 35.73

Notes: Model 2 Tab 3 includes the following regressors: PMR_{elec}, GDP_pc, INEQ and CORR, while Model 1 of Tab 5 includes $PMR_{elec\ entry}$, $PRM_{elec\ public\ own}$, $PMR_{elec\ vertical\ int}$, GDP_pc, INEQ and CORR, EN_DEP and NUKE. $PMR_{entry\ net}$ is the average value of PMR entry Postal service and PMR entry Telecommunication. Standard errors are clustered by country. Significant levels: * 10%, ** 5%, *** 1%.

Table A2. Principal Component Analysis results.

	Variables included	**Eigenvalue**	**Share of variance Explained**
First	Average Feed-in tariff (Value) Tax Measure (Dummy) Investment incentive (Dummy) Voluntary program (Dummy) Incentive tariff (Dummy)	3.72	0.35
Second	Obligation (Dummy) EU Directive 2001 (Dummy) REC target (Value)	1.15	0.18
Third	Public R&D (Value)	1.01	0.12

Note: The above results were obtained applying an orthogonal (VERIMAX) rotation, but an oblique rotation, not presented in the paper, yields very similar outcomes.

Table A3. Country ranking according to the different indicators (std. values). Average value 1980-07.

Rank	REP_fact		REP_poly		REP_div	
1	Luxembourg	1.21	Denmark	0.95	United States	1.30
2	Denmark	0.98	United States	0.78	Japan	0.75
3	Sweden	0.42	Austria	0.50	Denmark	0.68
4	Austria	0.39	Germany	0.45	Germany	0.59
5	Switzerland	0.31	Switzerland	0.44	Italy	0.53
6	United States	0.29	France	0.43	France	0.44
7	Netherlands	0.29	Belgium	0.37	Finland	0.41
8	Germany	0.20	Spain	0.35	Switzerland	0.35
9	France	0.19	Italy	0.33	Netherlands	0.32
10	Belgium	0.18	Luxembourg	0.30	Austria	0.30
11	Italy	0.18	Portugal	0.30	Belgium	0.30
12	Finland	0.12	Netherlands	0.21	Spain	0.13
13	Ireland	0.02	Sweden	0.15	Canada	0.08
14	Spain	0.02	Finland	-0.03	Sweden	0.06
15	Portugal	-0.06	Japan	-0.04	United Kingdom	0.05
16	United Kingdom	-0.06	Ireland	-0.09	Ireland	-0.02
17	Japan	-0.15	United Kingdom	-0.10	Australia	-0.02
18	Norway	-0.20	Czech Republic	-0.10	Norway	-0.09
19	Australia	-0.26	Canada	-0.27	Portugal	-0.09
20	Canada	-0.26	Australia	-0.31	Luxembourg	-0.25
21	Greece	-0.30	Norway	-0.33	Turkey	-0.26
22	Czech Republic	-0.31	Greece	-0.42	New Zealand	-0.45
23	New Zealand	-0.38	Turkey	-0.47	Czech Republic	-0.52
24	Turkey	-0.42	Hungary	-0.48	Greece	-0.55
25	Hungary	-0.54	New Zealand	-0.57	Hungary	-0.67
26	Poland	-0.59	Poland	-0.68	Poland	-1.02
27	Mexico	-0.61	Mexico	-0.81	Mexico	-1.14
28	Slovak Republic	-0.68	Slovak Republic	-0.86	Slovak Republic	-1.21

Table A4. Correlations among the policy indicators. Years 1970-2005.

	REP_fact	REP_poly	REP_div	ESI (Only year 05)
REP_fact	-			0.47*
REP_poly	0.89*	-		0.26
REP_div	0.75*	0.91*	-	0.37

*p<0.05

2011

2011/1, Oppedisano, V; Turati, G.: "What are the causes of educational inequalities and of their evolution over time in Europe? Evidence from PISA"
2011/2, Dahlberg, M; Edmark, K; Lundqvist, H.: "Ethnic diversity and preferences for redistribution "
2011/3, Canova, L.; Vaglio, A.: "Why do educated mothers matter? A model of parental help"
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