Determinants of Renewable Energy Innovation: environmental policy vs. market regulation

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Outline

- Aim and motivation
- Theoretical background
- Empirical strategy
- Results
- Conclusions

Motivation

- Large dispersion in the capacity of reducing reduce GHG emissions among rich countries (e.g. Stern 2004)

- This seems related to different capacities of fostering environmental innovations:
  - E.g. leadership in key environmental technologies such as renewable energy in Northern Europe rather than in the US.

- Environmental technologies ≠ other technologies
  - E.g. mainly driven by policy interventions, importance of social conditions and demand (Beise and Rennings 2004)

Motivation

- Besides policy, various long-term trends in socio-economic and institutional factors may have affected green technologies

- Especially two:
  - Increase in income inequality
  - Liberalization in the energy markets
  - Possible interactions with policy

Research questions

- Besides policy, which are the other factors that enable to build up a comparative advantage in environmental technologies?

- Are environmental policy sufficient instrument to spur these innovations? To what extent environmental policies are endogenous and interact with these factors?

➢ *We address these issues in an international comparison covering 30 years, 28 countries and several technological sub-fields within the major field of renewable energy (Wind, PV, Solar-thermal, Geothermal, Hydro, Biofuel, etc.).*

Main contributions

- Assessing the effect of market regulation on renewable energy technology and possible synergetic effects with the policy

- Estimate the impact of environmental policy on renewable energy technology when policy is endogenous

Theory: policy inducement

- Double externality problem> direct policy interventions
  - Two policy instruments are usually recommended: one for each externality, e.g. R&D subsidy and carbon tax (Acemoglu et al. 2010, Newell et al. 2004, Jaffe et al. 2005)

- High initial costs and uncertainty for relatively less developed technologies require direct subsidies or price incentives (e.g. feed-in tariff) to encourage initial investments

- Energy prices are also important for a standard induced-innovation argument (e.g. Hicks 1932, Binswanger 1974)

Evidence: policy inducement

- Existing works on renewable energy (Johnstone et al. 2010, Popp et al. 2011) found that:
  1. Energy prices are generally not very important once controlling for specific renewable energy policies
  2. The effect of quantity-based policies (e.g. obligations, trade certificates) is stronger on relatively more developed technologies, i.e. wind
  3. The effect of price-based policies (e.g. feed-in, incentives) is stronger on relatively less developed and costly technologies, i.e. PV, Solar

➢ *However, problem of endogeneity of the policy support*

Theory: market structure

- Literature on the relationship between innovation and competition:
  - Tension between monopolistic rents and entry barriers: escaping competition effect usually stronger close to the technological frontier (e.g. Aghion et al. 2001, 2002)
  - Differences in innovation regimes (e.g. Winter 1984, Hall and Soskice 2001) and firm's life-cycle theory, i.e. young firms introduce more radical innovations than incumbents at least in growing industries (e.g. Klepper 1997)

- Cross-country evidence on the effect of competition is mixed:
  - Propensity to introduce radical innovation not higher in liberal countries w.r.t. regulated ones, but US outlier (Akkermanns et al. 2009)
  - Positive, but using time-invariant index of barriers (Bassanini and Ernst 2002); negative, but not robust especially to Scandinavian countries (Griffith and Harrison 2004)

Theory: market structure and renewable energy innovation

- For renewable energy technologies a positive effect of competition on innovation is likely to prevail because:
  - Lock-in of existing incumbents
  - Radical innovations <> new competences and business practices
  - Decentralization of production and smaller scale <> conflict with the existing monopolistic structure

- However, liberalization of the energy sector has led to a decrease in R&D expenditures in the US and in other Oecd countries (Dooley 1998, Jamasb and Pollitt 2008), whereas productivity of R&D seems to improve (Jamasb and Pollitt 2010)

Outline: empirical strategy

Goal: assessing the impact of these three factors, i.e. targeted policies, market structure, market size/inequality

- Baseline specification and technology FE
- Endogeneity of the policy
  - Digression on policy indicator (based on Nicolli and Vona 2012)
- Identification and interpretation of the effect of PMR
- Citations as dependent variable and quality of the knowledge stock

Basic Specifications

- Poisson FE model with cluster-robust standard errors to control for mild cases of overdisperion , i.e. small departures from the assumption E(y|x)=Var(y|x)

  (Wooldridge 1999, Cameron and Trivedi 2005)

- Also for sake of comparison with GMM Poisson where the policy is instrumented
- Remark: results are generally robust to neg-binomial estimates, but for inequality

Baseline Specifications

- Specification 1: Country FE

$$Pat_{it} = \exp(\alpha Pol_{it} + \beta Pmr_{it} + \gamma Ineq_{it} + \boldsymbol{\tau}\mathbf{X}_{it} + \mu_i + \mu_t + \varepsilon_{it})$$

where Pat=total ren. patents, Xs are basic controls (population plus logs of total patent, past and present R&D and energy prices)

- Specification 2: technology*country FE

$$Pat_{ist} = \exp(\boldsymbol{\tau}\mathbf{X} + \alpha Pol_{it} + \alpha_s Pol_{it} + \beta Pmr_{it} + \beta_s Pmr_{it} + \gamma Ineq_{it} + \mu_{is} + \mu_t + \varepsilon_{ist})$$

Remarks

- Including technology-specific effects is important as renewable technologies are highly heterogeneous
- In the matrix **X** only R&D is now field-specific
- Policies field-specific, i.e. Feed-in, are included in some specifications but we do not build field-specific indicators
- Interactions field-policy capture this aspect

Policy Endogeneity

- Policy and technology affected by common unobservable factors (i.e. omitted policy, citizens' preferences, measurement issues)
- Cross-country heterogeneity in the effect of the policy:
  - Regressing patent on policy the R2 range from 60% in Denmark, France and the US to 30% in other countries
- Feedback from innovation to policy through lower generation costs (Downing and White 1986) and reinforcing green players in the energy market (Nicolli and Vona 2012)

Policy Endogeneity: digression on policy indicators

- Need to build an indicator that summarizes policy intensity and can be instrumented
- Problem: intensity for certain policies (gov R&D, REC, Feed-in), only signal for others
- Two types of indicators: 1. using both intensity and signals (PCA: principal component anlysis), 2. only policy signal

Digression on policy indicators

- Using different methodologies to buid an aggregate indicator of renewable energy policy, Nicolli and Vona (2012) show that:
  - Past GDP good predictor for all indicators
  - Mkt. Reg. and Ineq. explain well indicators built using PCA, no effect on indicators based on policy signals

➢ *To minimize the indirect effect of Mkt. Reg. and Ineq. on the policy, we use an indicator based on policy signals and control for overall R&D per capita*

Endogeneity: IV-strategy

- Ideas:
  - Richer countries adopt pro-environmental policies
  - Ratification of international agreements, i.e. Kyoto, and the political context improve the effectiveness of the policies

- Main Instruments: past GDP per capita.

  Other good instruments for overidentified specifications are:
  - A dummy equals 1 when Kyoto has been signed (1997)
  - A dummy=1 if government changes to capture political context

- Note that: 1. all the effect of income on innovation passes through the policy; 2. energy prices and renewable energy policy are only partially co-determined, e.g. 3-6% in Denmark of higher retail prices, 3. results are robust using adoption year weighted by the 'expected' worldwide patents in renewable energy five years after as main instrument.

Endogeneity: determinants of the policy

Determinants of the Policy Index

Variable	Only best instrument	Only 2' best instrument	Both best instruments	Variables pol. Context
Adoption lead	14.7875		10.8762	9.5313
	0.4765		0.4831	0.6691
Lagged gdp_pc		0.00001	0.00001	0.00001
		0.000	0.000	0.000
gov. change				0.0107
				0.008
kyoto				0.21
				0.0157
constant	-0.0302	-0.1202	-0.1965	-0.0714
	0.01	0.0153	0.0128	0.0182
N	1008	943	943	756
R^2	**0.4886**	**0.4181**	0.6216	0.7041

Identification of the effect of Market Regulation

- The effect is driven by a general increase in the propensity to patents or by a true effect on renewable energy innovation?

- A diff-in-diff estimator allows to answer this issue:
  - *following liberalization in the energy sector the propensity to patents increases significantly more for renewable energy than for generic technology*

Interpretation of the effect of market deregulation

- Which aspects of deregulation matters more? E.g. privatization, vertical integration or entry barriers
- Does the policy is more effective in liberalized markets?
- Does the effect of deregulation is stronger in countries with initially more R&D or DG energy production?

➢ *We test these predictions augmenting our baseline specifications: interacting mkt. reg. with these variables*

Quality of patents

- Quality-adjusted measures of patents, knowledge diversity (# of patent classes in which the country is active) and knowledge stock, differentiated by green and non-green.
- For building these variables we use patents registered at the US Pat Off, which contain citations (*current working on it for EPO*).
- Which factors is more important for high quality patents?

- Problem: in USPTO very innovative countries such as Denmark and other Scandinavian have few patents registered.

Measurement issues and data sources

- Dependent Variable: Innovation <> EPO patents (Johnstone et al. 2010)
  > Good measure, highly correlated with export of energy-related equipment and installed renewable capacity

- Key variables:
  1. Product Market regulation, time-varying exogenous indicator of Product Market Regulation provided by the Oecd (for detail see refs in the paper)
  2. Inequality, Standardized World Income Inequality Database (SWIID)
  3. Synthetic indicator of environmental policy (IEA, and other sources)
  4. Knowledge stock weighted by citations (USPTO)
  5. Knowledge diversity –number of tech. field- conditioned to the number of patents (USPTO)

- Basic controls:
  1. Total patent activity (Oecd)
  2. Current and past electricity prices (IEA, International Energy Agency)
  3. Current and past R&D in renewable energy (IEA)
  4. Population <> basic proxy of local market size

- Additional controls:
  1. Index of country political stability <> uncertainty in regulation (Comparative Political Data Set I)
  2. Woman participation in parliament <> preference
  3. Share of tertiary educated <> preference/technology
  4. Share of people above 65 <> preference

Patent classes in Renewable Energy Technologies

Class	Brief Descriptions
Wind energy	Wind currents can be used to generate electricity by using wing-shaped rotors to convert kinetic energy from the wind into mechanical energy and a generator to convert the resulting mechanical energy into electricity.
Solar thermal energy	Heat captured from the sun is used for residential heating or industrial processes or for thermal power generation. Technologies involved in solar thermal energy production include solar heat collection, heat storage, systems control, and system design technologies
Solar photovoltaic (PV) energy	Specially adapted semiconductor devices are used to convert solar radiation into electrical current. Related technologies include solar cell design, storage battery, and power conversion technologies.
Geothermal energy	Thermal energy derived from magma heat and stored in soil, underground water, or surface water can be used for heating or cooling buildings by means of a ground coupled heat pump system. Such systems operate by having a heat exchange embedded in a borehole supply the energy for the evaporation and condensation of a refrigerant. Geothermal liquid can also be used to drive turbines and thus generate electricity.
Marine energy (excluding tidal)	Energy From waves.
Hydro energy - tidal, stream or damless	The energy from incoming and outgoing tides can be harnessed to generate electricity using, for instance, turbines.
Hydro energy – conventional	Electricity can be generated through the conversion of potential energy of water contained in a reservoir using a turbine and a generator.
Biofuels	Bioenergy generally refers to energy produced from biomass, that is to say organic matter including dedicated energy crops and trees, agricultural food and feed crops, agricultural crop wastes and residues, wood wastes and residues, aquatic plants, animal wastes, municipal wastes, and other waste materials.
Fuel from waste (e.g. methane)	Household and other waste can be processed into liquid or solid fuels or burned directly to produce heat that can then be used for power generation ("mass burn"). Refuse derived fuel (RDF) is a solid fuel obtained by shredding or treating municipal waste in an autoclave, removing non-combustible elements, drying, and finally shaping the product. It has high energy content and can be used as fuel for power generation or for boilers.

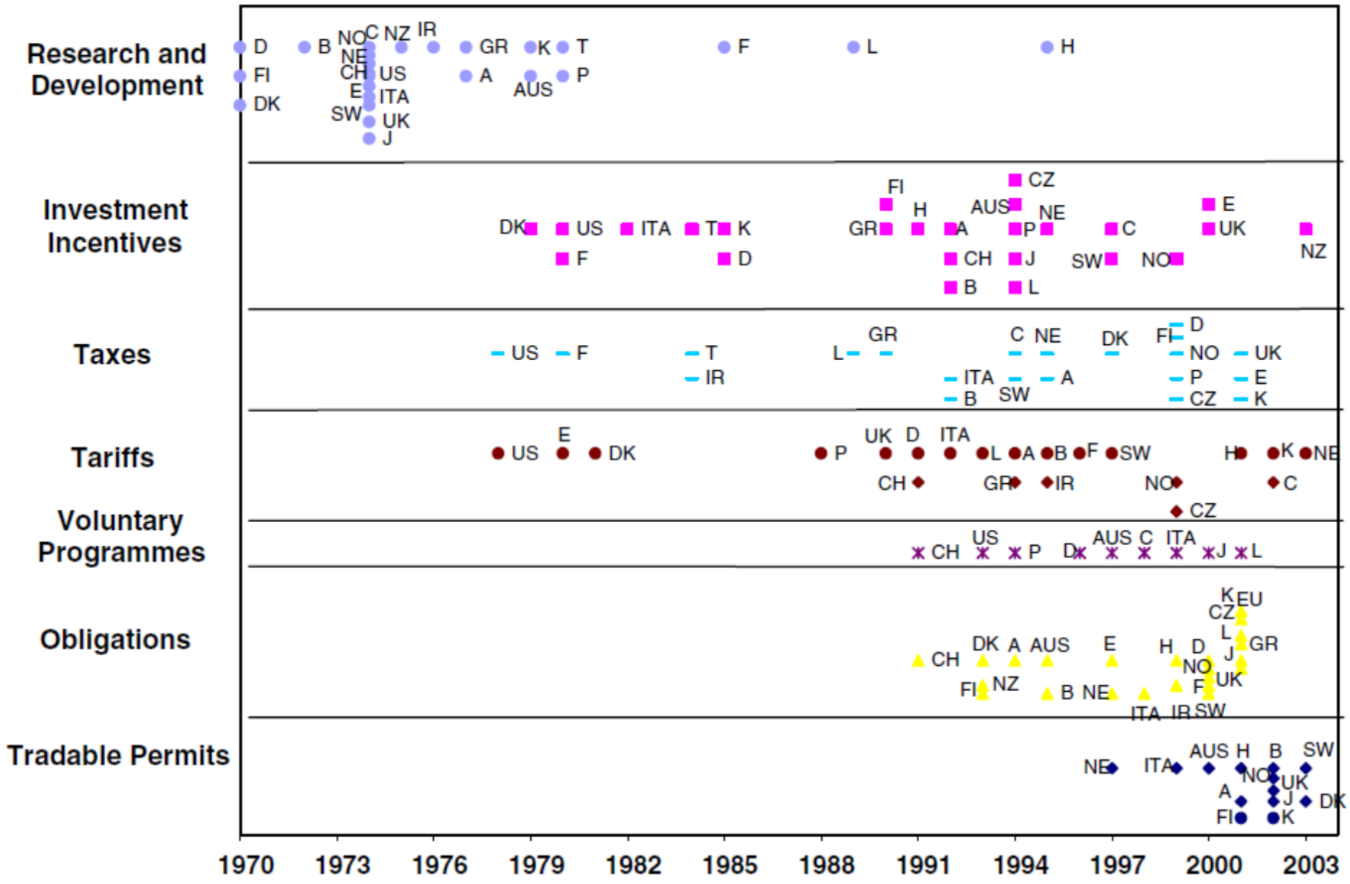
Source: WIPO. Patent Based Technology analysis Report.

Environmental policies composing the index: the sum of dummies capturing the fact that a policy has been adopted

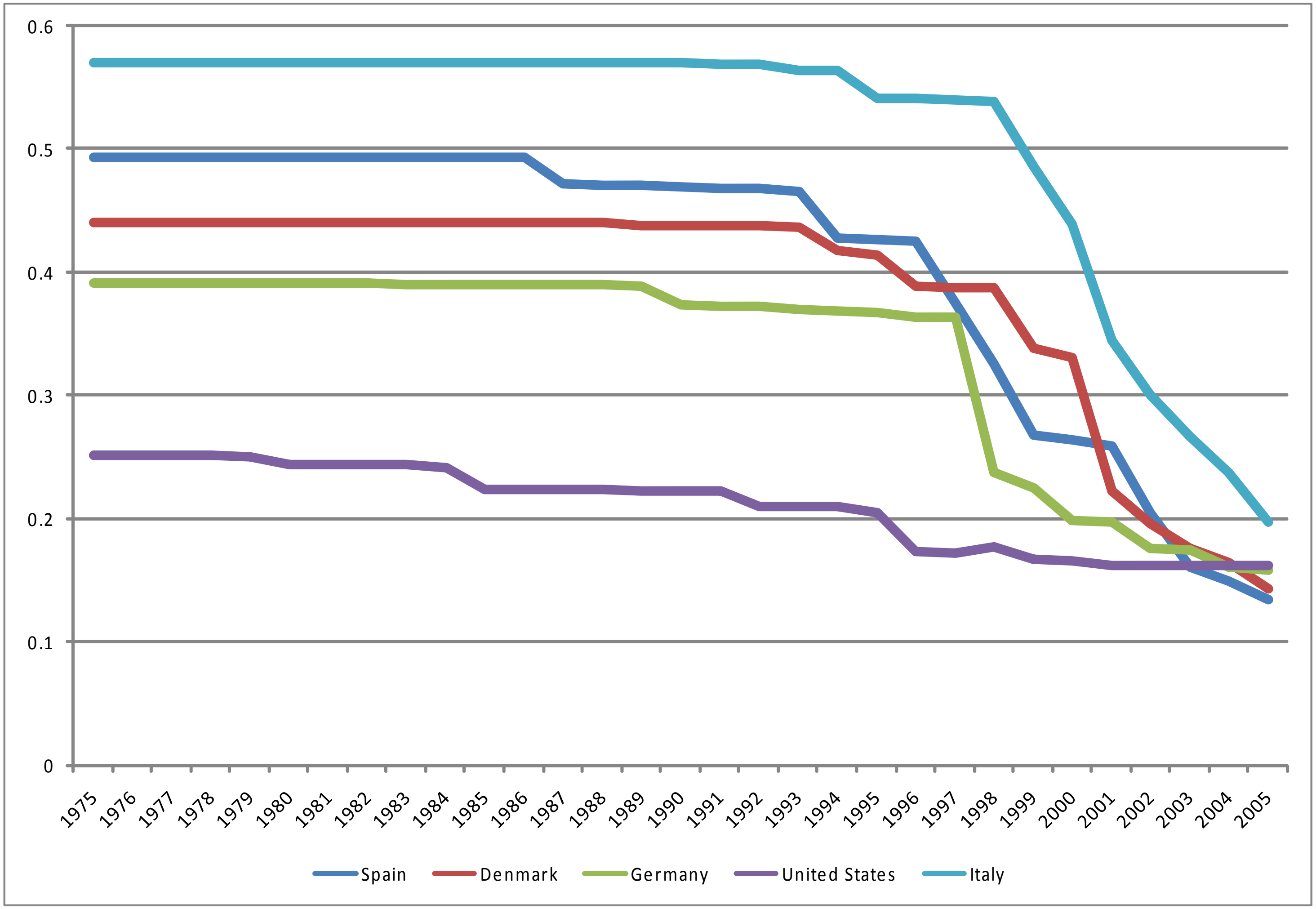
Table 1. Summary of the main Policies.

Instrument	Brief explanation	Variable Construction	Source
Investment incentives	Capital Grants and all other measures aimed at reducing the capital cost of adopting renewable energy technologies. May also take the form of third party financial arrangements, where central governments assume part of the risk or provide low interest rate 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 have the form of investment tax credit or property tax exemptions, in order to reduce tax payments for project owner. An example is the US production Tax credit for wind (1992). Excises are not directly accounted here unless they were explicitly created to promote renewables (for example excise tax exemptions).	Dummy Variable	International Energy Agency
Incentive tariff	Price systems that guarantee above market tariff rates. In such cases, the Environmental authority generally sets a premium price to be paid for power generated from renewables.Some countries (UK, Ireland) developed a so called bidding system schemes in whichthe most cost effective offer is selected to receive a subsidy. This last specific case is also accounted in the dummy, due to its similarity to the feed-in systems.	Dummy Variable	International Energy Agency
Feed-in Tariff	Guaranteed price that may vary by technology. (Wind, Solar, Ocean, Geothermal, Biomass, Waste, Hydro).	Level of price guaranteed (USD, 2006 prices and PPP) (Dummy Variable also available)	International Energy Agency Cerveny and Resch (1998) Country specific sources
Voluntary program	These programs generally operate through agreement between government, public utilities and energy suppliers, that agree to buy energy generated from renewable sources. One of the first voluntary program was in Denmark in 1984, when utilities agreed to buy 100MW of wind power.	Dummy Variable	International Energy Agency
Obligations	Obligation and targetstake generally the form of quota systems that place an obligation on producers to provide a share of their energy supply from renewable energy. These quota 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 quota system and can generally be traded in specific markets. As a result, at national level part of the total electricity produced generally must either be generated by renewables or covered with a renewable energy certificate.	Share of electricity that must be generated by renewables or coveredwith a REC. Dummy Variable also available.	Data made available by Nick Johnstone, OECD Environment Directorate
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). (Dummy Variable also available)	International Energy Agency
EU directive *2001*/77/EC	Established the first shared framework for the promotion of electricity from renewable sources at European level.	Dummy Variable	European Commission

Timing of Adoption of different policies



Process of liberalization



Results

- For sake of space, we present only results on main coefficients of interest.
- R&D has the expected sign and elasticity .3-.5, but less strong when including also lags.
- Energy price has also similar insignificant effects as in Johnstone et al. (2010), i.e. large std. errors.
- Number of patents has elastictiy between .5 and .8.
- Political instability has also the expected negative influence on innovation.

All technologies

All Renewables

Specification	I	II	III	IV	V	VI
Policy Index (Std)	0.3986***	0.3355***	0.2307***		0.2473***	0.2348***
PMR Electr. (Std)		-0.351***	-0.252***		-0.2888***	-0.336***
Gini coeff. (Std)		-0.3152	-0.2029*	-0.332***	-0.2322	-0.5629**
Policy Index$_{t-1}$				0.3175***		
PMR Electr.$_{t-1}$				-0.398***		
Kyoto Dummy					0.3310***	0.2922***
Basic Controls	Yes	Yes	Yes	Yes	Yes	Yes
Political Controls	No	No	No	No	No	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	No	No	Yes	No	No	No
Observation	567	543	543	542	543	490
Log likelihood	-1679.76	-1568.43	-1411.41	-1561.16	-1542.66	-1427.55
χ^2	1.30E+05	52040.21	1.80E+05	48870.93	44801.81	2.20E+06

Dependent variable: Total Renewable patents at EPO (EPO 3)

Basic Controls: past-present R&D, tot Pat, past-present Energy prices, Population

Political Controls: political instability, gov_change, tert. education, elderly, gov_type

Poisson Estimations, cluster-robust standard error in parenthesis. Cluster unit: Country

*,**,*** indicate significance at respectively 10%, 5% and 1% level.

Quantifying the results

- The effect of a one standard deviation increase of the policy ranges between 0.23% and 0.39% per-year increase in the patent propensity.
  - A country with a policy one-std. deviation persistently below the average accumulate a 30-years disadvantage of around 10%

- The effect of PMR is of similar size ranging between 0.22% and 0.35%.

  Also in this case, lagged effects tend to be slightly larger.
  - Italy/France PMR is ¾ of one standard deviation higher than Denmark/Finland PMR.

- The effect of inequality has greater variability: one std. dev. effect is 0.22%-0.53% per-year.
  - NB: the gap between US and Swedish inequality is almost 2 standard deviations.

All technologies, interactions

All Renewables. PMR & Interactions

Specification	I	II	III	IV	V
Policy Index (Std)	0.2968***	0.276***	0.2693***	0.011	0.2867***
PMR Electr. (Std)	-0.3323***	-0.271***	0.114	-0.2007***	
DG *(1-PMR)		0.133**			
R&D *(1-PMR)			0.2209**		
Policy*(1-PMR)				0.1383***	
PMR entry					-0.0416*
PMR public owned					-0.0389
PMR vertical integration					-0.0565
Country FE	Yes	Yes	Yes	Yes	Yes
Year FE	No	No	No	No	No
Observation	550	550	550	550	567
Log likelihood	-1610.74	-1596.1	-1595.17	-1575.36	-1620.65
χ^2	54924.62	1.00E+05	1.20E+05	2.10E+05	77238.11

Dependent variable: Total Renewable patents at EPO (EPO 3)

Basic Controls: past-present R&D, tot Pat, past-present Energy prices, Population

Poisson Estimations, cluster-robust standard error in parenthesis. Cluster unit: Country

*,**,*** indicate significance at respectively 10%, 5% and 1% level.

Comments

- Of the components of the PMR index, entry barrier is the one that explains the results the most (less public ownership and vertical integration).

- The effect of the policy is much stronger in combination with market deregulation and low entry barriers.
  - Important remark: *liberalization of the energy sector long-term commitment while environmental policy short-term commitment risky combination*?
    1. No, positive political economy feedback (Nicolli and Vona 2012)
    2. Yes, EU market integration is leading to concentration in the energy market that fuels opposition against Decentr. Generation (DG), see what is happening in Nordpool

- Much stronger effect of liberalization if initial DG share high and initial R&D high

Robustness with PCA policy indicators and other models (e.g. negative binomial, generalized linear models)

- Interactions: the only important one is policy*PMR.
- Of the components of PMR, the effect of entry barriers almost doubles.
- Inequality not significant.
  - inequality is strongly correlated with PCA indicators, so its effect is fully mediated by the policy (Nicolli and Vona 2012)
  - However, inequality also not significant in neg-binomial

Technology-country fixed effects

Table 9: Technology Fixed Effect Model. Renewable EPO Patents

Specification	I	V	VI	VII
Policy Index (Std)	0.3623***	0.1142		-0.1351*
	(0.0748)	(0.088)		(0.074)
PMR electr. (Std)	-0.3827***	-0.1939**	-0.3233***	-0.3127***
	(0.0972)	(0.079)	(0.092)	(0.079)
Gini coeff. (Std)	-0.4552**		-0.2503	-0.4223***
	(0.1863)		(0.189)	(0.119)
Policy*(1-PMR)		0.1239***		
		(0.029)		
Feed in Level (Field)			0.8468**	
			(0.366)	
Share of REC			-0.0023	
			(0.021)	
Tax			0.5129***	
			(0.187)	
Incentive Investment			-0.0360	
			(0.101)	
Voluntary Program			-0.0467	
			(0.158)	
Obligation			0.4061***	
			(0.131)	
Kyoto				0.3971***
				(0.088)
Wind*policy				0.7448***
				(0.086)
Solar*policy				0.4749***
				(0.046)
Geothermal*policy				0.1914***
				(0.060)
Hydro*policy				0.3289***
				(0.106)
Marine*policy				0.3769**
				(0.154)
Biofuel*policy				0.4011***
				(0.102)
Techn*Cnt FE	Yes	Yes	Yes	Yes
Area trend	Yes	Yes	Yes	Yes
Basic Controls	Yes	Yes	Yes	Yes
Observation	3563	3608	3563	3563
Log likelihood	-4414.05	-4488.51	-4386.21	-4154.66
χ^2	712.03	626.83	944.75	3322.97

Dependent variable: Total Renewable Patents at EPO. Pooling of all the available technologies.
Basic Controls: past-pres. technology-specific R&D, past R&D, total Pat, Energy prices, Pop.
Poisson Estimations, cluster-robust standard error in parenthesis. Cluster unit: Country*technology
*,**,*** indicate significance at respectively 10%, 5% and 1% level.

Comments

- Note that this specification allows to control for many unobservable factors: technology-country FE plus area-specific time trends
- Again a strong synergetic effect emerges between policy and PMR
- The effect of the policy is stronger on wind and to less extent biofuel and solar
- The effect of PMR is preserved even when policies are considered separately as in previous studies

Endogenous Policy: GMM and dynamic panel

Endogenous Policy Index, FE GMM Poisson. Dependent Variable: Renewable EPO Patents

Specification	IV	V	VI	VII	VIII
Policy Index	0.4942**	0.2190***	0.1360**	0.2153***	0.2233***
	(0.227)	(0.075)	(0.071)	(0.078)	(0.086)
PMR Electr.	-0.2599*	-0.6108***	-0.4432***	-0.462***	0.3607
	(0.156)	(0.133)	(0.081)	(0.101)	(0.2086)
Gini coef.	-0.4240*	-0.5940***	-0.4958***	-0.445***	-0.3695**
	(0.250)	(0.191)	(0.155)	(0.165)	(0.151)
Lag dep. Var.			0.0030***		
			(0.0009)		
DG *(1-PMR)				0.1478***	
				(0.064)	
R&D *(1-PMR)					0.4213***
					(0.105)
Country FE	Yes	Yes	Yes	Yes	Yes
Basic controls	Yes	Yes	Yes	Yes	Yes
Observation	544	524	524	524	524
GMM criterion	4.737e-26	0.01417	0.0107	0.0135	0.0122
Hansen test	1.00	0.1150	0.2297	0.1318	0.1696
Instruments	one year lag GDP	Kyoto, one year lag GDP, two year lag GDP, Gov. Change	Kyoto, one year lag GDP, two year lag GDP, Gov. Change	Kyoto, one year lag GDP, two year lag GDP, Gov. Change	Kyoto, one year lag GDP, two year lag GDP, Gov. Change

Dependent variable: Columns I, II, III, IV: Total Renewable patents at EPO (EPO 3)
Basic Controls: past-pres. R&D, total Pat, past-pres. energy prices, population
Poisson Estimations, cluster-robust standard error in parenthesis. Cluster unit: Country.
*,**,*** indicate significance at respectively 10%, 5% and 1% level.

Comments

- The effect of the policy is substantially under-estimated in OLS
  - Taking the just-identified estimate as unbiased benchmark, a policy one-standard deviation below the average for 30 years leads to a 18-20% decrease in the green patents (NB: policy effect in FE Poisson 10%).
- Including a feed-back from past patents (no matter if linear or exponential), decrease only the effect of the policy.
- PS: results are only provisional as R&D should be instrumented too

High-quality patents (USPTO)

Quality of Patents. Dependent Variable: Renewable USPTO Patents

Specification	I	II	III	IV	V	VI	VII	VIII
Dependent Variable	Green Patent Counts	Green Citations	Green P. Counts (Without outliers & Denmark)	Green Citations (Without outliers & Denmark)	Green P. Counts (Without outliers & Denmark)	Green Citations (Without outliers & Denmark)	Green P. Counts (Without outliers & Denmark)	Green Citations (Without outliers & Denmark)
Know. Stock	0.0858***	0.1265***	0.0874***	0.1293***	0.0905***	0.1411***	0.1415***	0.1750***
(std)	(0.020)	(0.048)	(0.020)	(0.049)	(0.023)	(0.0405)	(0.041)	(0.055)
Green Know.	0.2890***	0.4676***	0.2916***	0.4629***	0.3358***	0.6173***	0.0290	0.3579
(std)	(0.0790)	(0.170)	(0.074)	(0.171)	(0.076)	(0.156)	(0.109)	(0.267)
Know. Diver.	0.0790***	0.1644***	0.0837***	0.1613***	0.1308***	0.3167***	0.0437	0.2235***
(std)	(0.023)	(0.048)	(0.024)	(0.049)	(0.031)	(0.053)	(0.032)	(0.072)
L. R&D	0.0881	0.2893***	0.0746	0.2848***	0.0892	0.3339***	0.1551	0.4405***
(Ren.)	(0.086)	(0.093)	(0.090)	(0.092)	(0.110)	(0.119)	(0.107)	(0.111)
PMR Electr.	-0.1243	-0.6544***	-0.1093	-0.648***	-0.1032	-0.630***	-0.287***	-0.807***
(Std)	(0.114)	(0.207)	(0.115)	(0.2094)	(0.107)	(0.184)	(0.071)	(0.178)
Gini coeff.	0.2566	-0.5984	0.3224	-0.6143	0.3726	-0.3495	0.0456	-0.7955**
(Std)	(0.315)	(0.423)	(0.313)	(0.429)	(0.304)	(0.357)	(0.232)	(0.364)
Dummy R&D	0.5005***	0.4933**	0.5314***	0.4850**	0.5115***	0.4275**	0.3488***	0.2936*
Grant	(0.121)	(0.240)	(0.132)	(0.241)	(0.127)	(0.211)	(0.085)	(0.176)
Trade	**0.4054***	**1.1735****	0.5370**	1.1702**	0.4467**	0.9188**	0.7195***	1.2808***
Certificate	**(0.228)**	**(0.490)**	(0.222)	(0.519)	(0.234)	(0.387)	(0.239)	(0.452)
Investment	0.1280**	0.1672***	0.1486**	0.1683***	0.1493**	0.1882**	0.0826	0.1112
Incentive	(0.064)	(0.055)	(0.063)	(0.056)	(0.067)	(0.086)	(0.057)	(0.086)
Economic	0.1426	**0.5163*****	0.1665	**0.5371*****	0.1299	0.3435**	0.0935	0.3550***
incentive	(0.134)	(0.157)	(0.133)	(0.152)	(0.117)	(0.135)	(0.082)	(0.122)
Obbligation	**0.2584**	**-0.6728***	0.1778	-0.6740*	0.1464	-0.726**	0.2077	-0.6518*
	(0.165)	**(0.385)**	(0.160)	(0.404)	(0.155)	(0.371)	(0.172)	(0.367)
Log GDP					-0.1511	-0.1656	-0.8053	-0.6627
					(0.919)	(1.590)	(0.978)	(1.800)
Kyoto					0.2509***	0.7899***	0.1466*	0.6756***
					(0.091)	(0.1808)	(0.087)	(0.175)
Controls Political Context							Yes	Yes
Other controls: Pop., Energy Prices, past R&D, other policies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	No	No	No	No	No	No	No	No
Observation	434	361	351	338	351	338	347	
Log likelihood	-640.865	-703.30	-597.70	-691.84	-595.27	-669.12	-566.64	
χ^2	4.2e+09	7.6e+15	1.5e+16	-1.0e+17	3.5e+16	1.0e+18	-2.7e+16	

Dependent variable: Patent count at USPTO, Citations in green patent
Poisson Estimations, cluster-robust standar error in parenthesis. Cluster unit: Country
*,**,*** indicate significance at respectively 10%, 5% and 1% level

Comments

- Certain policies have a much larger effect on high value patents (Kyoto, RECs and Feed-in)
- R&D is significantly more effective on high-quality patents
- The effects of inequality and PMR hold only for high value patents:
  - Especially the effect of PMR reaches around 1.2 if only top 20% patents are considered
- The knowledge stock has the expected positive effect on patents:
  - Knowledge diversity has a much larger effect on citations

Concluding remarks

- Effect of the Policy underestimated if endogeneity not accounted for
- Effect of PMR mainly captured by entry barriers
- Synergetic effect PMR-Policy: the effect of the policy is much stronger in systems with low entry barriers
- R&D, knowledge diversity, PMR and certain policies appear stronger on high quality patents.
  - However, these results should be checked for EPO or PCT patents that seem more representative of green knowledge than USPTO (working on it!!)

Conclusions on Entry Barriers

- Of the components of PMR, entry barriers is a very strong predictor of both the policy (Nicolli, Vona 2012) and technology

- However, the integration of the EU energy market is increasing market concentration possibly bringing about a policy bias against DG of energy (i.e. RECs raher than Feed-in) and technological bias against radical innovations and new infrastructures (e.g. smart grids)

Open research questions

- Does PMR fully capture the degree of market concentration and entry barriers? Endogenous part of entry barriers, i.e. market shares, markups in an integrated market

- Is the policy index reliable? How does the choice of the index change the results?

- How results change on high-quality patents, defined as the one registered in many countries & highly cited?

More Results: Policy, country ranking for different indicators(from Nicolli and Vona 2012)

Ranking	FACT_AV_FEEDIN		COM_POL		COUNT_POL	
1	Denmark	6.427	Japan	3.185	Denmark	8.448
2	Sweden	3.636	Germany	2.668	Austria	5.436
3	Austria	3.551	United States	2.668	Sweden	3.634
4	Netherlands	2.507	Italy	2.668	Portugal	3.402
5	United Kingdom	2.447	Austria	2.150	Belgium	2.465
6	Germany	2.179	Belgium	2.150	Netherlands	1.999
7	Italy	2.150	Canada	2.150	Spain	1.774
8	Belgium	2.125	Denmark	2.150	Germany	1.745
9	Finland	1.775	Finland	2.150	Switzerland	1.571
10	Spain	1.640	Netherlands	2.150	United Kingdom	1.485
11	Japan	1.590	Norway	2.150	Hungary	1.359
12	France	1.538	Sweden	2.150	Czech Republic	1.250
13	Switzerland	1.486	United Kingdom	2.150	Italy	0.550
14	Luxembourg	1.409	Australia	1.633	Greece	0.437
15	United States	1.274	France	1.633	Luxembourg	0.418
16	Australia	1.120	Luxembourg	1.633	France	0.364
17	Ireland	1.113	Spain	1.633	Australia	0.311
18	Portugal	0.990	Switzerland	1.633	Japan	0.166
19	Norway	0.827	Ireland	1.116	Finland	0.138
20	Czech Republic	0.757	Czech Republic	0.598	United States	0.083
21	Canada	0.751	Hungary	0.598	Canada	-0.214
22	Greece	0.425	New Zealand	0.598	Norway	-0.341
23	New Zealand	0.300	Portugal	0.598	New Zealand	-0.389
24	Poland	0.022	Greece	0.081	Ireland	-0.463
25	Hungary	-0.152	Poland	0.081	Slovak Republic	-0.600
26	Slovak Republic	-0.193	Slovak Republic	-0.436	Poland	-0.600

More Results: Policy, PCA indicator (from Nicolli and Vona 2012)

Table11.Dependent variable: FACT_AV_FEEDIN.

Specification	I	II (RE)	III (RE)	V	VI	VI'
one year lag GDP	0.0461**	0.0451**	0.0292	0.0301**	0.0198*	0.0226
	(0.0194)	(0.0209)	(0.0216)	(0.0157)	(0.0120)	(0.0235)
Ginicoeff.	-0.0458*	-0.0844**	-0.0799**	-0.0703**	-0.0699**	-0.0436**
	(0.0263)	(0.0344)	(0.0325)	(0.0309)	(0.0287)	(0.0199)
Kyoto Dummy	0.9771***	0.6058***	0.6097***	0.5289***	0.5216***	0.5890***
	(0.2074)	(0.1723)	(0.1593)	(0.1996)	(0.1884)	(0.1378)
Green	0.0349	0.0471	0.0358	0.0402	0.0304	-0.0378
	(0.0369)	(0.0377)	(0.0390)	(0.0378)	(0.0383)	(0.0333)
PMR Electr. (Std)		-0.4768***	-0.4340***			
		(0.1670)	(0.1629)			
Energy Prices			5.2821*		5.3322**	6.0683
			(2.8469)		(2.3563)	(3.9402)
DG			0.1416	0.2971**	0.2081	0.1836
beforeLiberalization			(0.1783)	(0.1325)	(0.1422)	(0.1374)
Kyoto*PMR						
DG bef Lib*PMR						
PMR Entry				-0.1510***	-0.149***	-0.1395***
				(0.0536)	(0.0534)	(0.0534)
PRM Public				-0.0009	0.0008	-0.0003
Ownership				(0.0549)	(0.0591)	(0.0481)
PMR Vertical				-0.0076	0.0119	-0.0424
Integration				(0.0784)	(0.0773)	(0.0743)
Country FE	No	No	No	No	No	No
Area FE	Yes	Yes	Yes	Yes	Yes	Yes
Area Trend	No	No	No	No	No	Yes
Observation	726	634	617	660	643	643
Hausman test						

Cluster Robust standard error, cluster unit country. *,**,*** indicate significance at respectively 10%, 5% and 1% level.

More Results: Policy, Signal Indicator (from Nicolli and Vona 2012)

Table 13. Dependent variable: COM_POL.

Specification	I (RE)	II	III	IV	V	VI
one year lag GDP	0.0715***	0.0819***	0.0633***	0.0506***	0.03397**	-0.0006
	(0.0213)	(0.021)	(0.0207)	(0.0186)	(0.0148)	(0.0104)
Ginicoeff.	0.0196	0.0181	0.0199	0.0238	0.0264	0.0107
	(0.0201)	(0.027)	(0.0279)	(0.0257)	(0.0267)	(0.0178)
Kyoto Dummy	0.9196***	0.7587***	0.7553***	0.7677***	0.7735***	0.5191***
	(0.1678)	(0.135)	(0.1272)	(0.1544)	(0.1320)	(0.1567)
Green	0.0379	0.0501**	0.0429*	0.0533**	0.0436**	0.0009
	(0.0245)	(0.024)	(0.0232)	(0.0219)	(0.0209)	(0.0195)
PMR Electr. (Std)		-0.0730	-0.0565			
		(0.094)	(0.0858)			
Energy Prices			5.6178***		7.5481***	0.8310
			(1.3486)		(1.397)	(2.314)
DG before			0.0410	0.2282**	0.0868	0.0535
Liberalization			(0.0821)	(0.1033)	(0.0976)	(0.0896)
PMR Entry				-0.1036**	-0.1010**	-0.0806**
				(0.0491)	(0.0460)	(0.0351)
PRM Public				-0.0242	-0.0304	-0.0404
Ownership				(0.0455)	(0.0440)	(0.0333)
PMR Vertical				0.0641	0.0927*	0.0761*
Integration				(0.0519)	(0.0491)	(0.0388)
Corruption						
Higher Education						
Political instability						
Woman partecipation						
Country FE	No	No	No	No	No	No
Area FE	Yes	Yes	Yes	Yes	Yes	Yes
Area Trend	No	No	No	No	No	Yes
Observation	726	634	617	660	643	643
Hausman test						

More results PMR. Diff-in-Diff

following liberalization in the energy sector the propensity to patents increases significantly more for renewable energy than for generic technologies

Identification of the PMR effect. Dependent variable: D(tot EPO patents)-D(Ren. Energy patetns)

Specification	**I**	**II**	**III**	**IV**	**V**
Der. Electr. Shock	-120.8644***	-108.4538**	-163.35**	-122.023**	-142.0623**
	(42.371)	(42.338)	(62.621)	(48.279)	(59.218)
Time Trend		0.7738			
		(0.665)			
Der. Shock*Time			6.6986		
			(4.302)		
Trend Scand				-0.6722	-1.0792
				(1.0808)	(1.288)
Trend Med				-.3990	-.8087
				(1.1722)	(1.374)
Trend Centr				2.0065	1.6735
				(1.3095)	(1.057)
Trend anglo				1.6408	1.2526
				(3.439)	(3.594)
Trend East				-2.5042**	-2.9252**
				(1.017)	(1.246)
Trend Poor				-2.5783**	-3.0638**
				(1.174)	(1.443)
Country FE	Yes	Yes	Yes	Yes	No
Area dummy	No	No	No	No	Yes
Observation	980	980	980	508	980

Difference in Difference model, cluster-robust standard error in parenthesis. Cluster unit: Country.
*,**,*** indicate significance at respectively 10%, 5% and 1% level.

Why inequality is important besides policy: Inequality and Innovation

- Literature on demand, innovation and income inequality (Murphy et al. 1989, Bertola et al. 2006):
  - tension between a market size effect and pioneer consumer effects, i.e. early adopter triggers positive technological and consumption externalities for all.

- With non-homothetic preferences:
  1. lower inequality increases the market size for new products
  2. lower inequality reduces the pioneer consumer effect

Evidence: inequality and environmental innovations

- For various green technologies, Vona and Patriarca (2011) show that the 'market size' effect is stronger the higher the level of development of a country.
  - For rich countries, lowering income inequality positively affects green innovations.
  - This effect appears mediated by a politico-economy channel and the effect is much stronger in rich countries (Nicolli and Vona 2012).

- On renewable energy, inequality might have an influence through:
  1. The willingness to pay higher energy tariff
  2. Financial constraint to buy and install Photovoltaic cells
  3. Local willingness to build infrastructures and invest in public goods, i.e. unobservable micro aspects of policy (see, e.g., works of Kotchen)

More results: Inequality

- Inequality: market size vs. quality of the policy vs. unobservable individual and social preferences.
  - With the indicator based on policy signals, the effect of inequality appears not driven by political factors

- The effect of inequality is stronger for solar energy where demand effect and financial constraint are probably stronger.

More results: inequality by technology

Renewable Energy Technologies Separated. Dependent variable: Renewable EPO Patents

Specification	Solar Photovoltaic	Solar thermal	PV	Wind	Hydro energy Conventional
Log Total Patent	0.9810***	0.18481	-.4728	0.5463	0.5717***
	(0.328)	(0.119)	.633	(0.372)	(0.187)
Log R&D (Field specific)	0.2817***	0.5378***	.9224***	0.0975	0.3584**
	(0.067)	(0.108)	.262	(0.140)	(0.179)
Policy Index (Std)	0.2460***	0.1054	.4277***	0.7099***	0.1767
	(0.081)	(0.072)	.15	(0.156)	(0.119)
PMR Electr. (Std)	-0.2027**	-0.6483***	.0044	-0.4664*	-0.2654**
	(0.103)	(0.139)	.417	(0.278)	(0.137)
Gini coefficient (Std)	-0.277**	-0.6020***	-1.190**	-0.9924*	-0.3091
	(0.143)	(0.190)	.607	(0.567)	(0.488)
Policy No Denmark	0.246***	0.1345*	0.4277***	0.8264***	0.1915
	(0.082)	(0.071)	(0.150)	(0.139)	(0.117)
PMR No Denmark	-0.2007**	-0.5963***	0.0044	-0.1868	-0.2338*
	(0.103)	(0.132)	(0.417)	(0.202)	(0.140)
Gini No Denmark	-0.2771**	-0.5156***	-1.190**	-0.3620	-0.2566
	(0.143)	(0.184)	(0.607)	(0.465)	(0.505)
Other controls: Pop., Energy Prices, past R&D	Yes	Yes	Yes	Yes	Yes
Year FE	No	No	No	No	No
Observation	419	525	319	477	508
Log likelihood	-653.44	-741.80	-115.82	-730.21	-499.66
χ^2	62976.03	1184.69	7052.43	32009.18	6376.08

Poisson Estimations, cluster-robust standard error in parenthesis. Cluster unit: Country
*,**,*** indicate significance at respectively 10%, 5% and 1% level.

Further references on inequality and policy

- Vona, F., Patriarca, F. (2011). Income Inequality and the Development of Environmental Technologies. *Ecological Economics.*
- Patriarca, F., Vona, F. (2012). Environmental Taxes, Inequality and Technical Change. *Revue de l'OFCE, special issue on agent-based models (forthcoming).*
- Nicolli, F., Vona, F. (2012). The Evolution of Renewable Energy Policy in Oecd countries: aggregate indicators and determinants. *OFCE documents de travail*.