Environmental Policies, Competition and Innovation in Renewable Energy

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Aims and Motivation

Theoretical Insights

Data, Measurement and Econometric Strategy

Results

Conclusions

Appendix, Instruments

Motivation

- Empirical literature on environmental innovation focuses on the inducement effect of policies and energy prices (e.g. Popp 2002; Johnstone et al. 2010).
- Another strand examines the effects of liberalization on proxies of innovation in the energy sector (e.g. Jamasb & Pollitt 2008, 2010; Sanyal & Ghosh 2012).
- The interplay of these two factors on renewable energy innovation has not been assessed in a rigorous empirical setup.

Aims

- Fill this gap using a new dataset that combines information on renewable energy policies (REP index henceforth), product market regulation (PMR index henceforth) and high-quality renewable energy patents (families of inventions and triadic patents), varying over time (32 years) and across countries (27).
- Contribute to the empirical literature on the relationship between innovation and competition, and to the literature on the effectiveness of environmental policies.
- Testing the possible complementarity between REP and PMR policies.

Preview of the methodology and results

- Pre-sample mean Poisson model with linear feedback (Blundell *et al.* 1995, 2002), extended to account for endogeneity.
- Positive and strong synergetic effect between PMR and REP indexes, but essentially on high quality innovations.
- The effect of deregulation is positive, driven by entry barriers, much lower with endogeneity and for high quality patents; the opposite holds for public R&D and REP.

Plan of the talk

- Brief theoretical overview
- Empirical protocol
- Results
- Conclusions

Aims and Motivation

Theoretical Insights

Data, Measurement and Econometric Strategy

Results

Conclusions

Appendix, Instruments

Factors affecting environmental innovations

- Inducement hypothesis: key role for policies in presence of multiple externalities and low initial efficiency of new technologies (Fisher & Newell 2008, Acemoglu et al. 2011)
- Innovation and competition:
  1. Escaping competition effect counterbalances the classical Schumpeterian effect and generates an inversely U-shaped relationship (Aghion *et al.* 2001, 2005).
  2. Innovation regimes (Winter 1984, Baumol 2002): division of innovative labour between entrants (radical innovation) and incumbents (incremental innovation).
  3. Klepper (1996) industry's life cycle: product innovation is more beneficial to smaller and younger firms, while process innovation yields greater returns for large firms.
  4. As a whole, the positive effect of competition on innovation is expected to strongly dominate in the context of radically innovative technologies and emergent markets.

Factors affecting environmental innovations: policy complementarities

- Are targeted innovation policies more effective in liberalized markets? e.g. focus of R&D efforts in most promising sectors (Aghion et al. 2012) or relaxing financial constraints for new potential entrants.
- Our main hypothesis: only if entry barriers are low, REP policies may attract new players with appropriate skills and higher incentives to develop new technologies (not only to comply with regulation).
- With the exception of R&D subsidies, the primary goal of renewable energy policy is to generate a certain volume of demand for clean energy (Popp et al. 2009). The positive demand shock is expected to stimulate innovation, particularly when the entry of new players is facilitated.

Peculiarities of renewable energy technologies

- Radical innovations, decentralization of energy production and smaller scale tend to negatively affect profits of large utilities.
- Sanyal and Ghosh (2012) show that greater competition in wholesale markets increases the fraction of innovative rents obtained by upstream suppliers, as long as many non-utility generators (NUGs) enter the wholesale market. These NUGs (small cooperatives, municipalities, households) are generally specialized in decentralized production, i.e. combined generation, local heating systems, renewable sources.
- Rich case study evidence: key role of new players for innovation and opposition of existing incumbents against REP.

Aims and Motivation

Theoretical Insights

Data, Measurement and Econometric Strategy

Results

Conclusions

Appendix, Instruments

Case study evidence

- Substantial evidence of sustained entry of new firms producing clean energy or new electric equipments, such as wind turbines(Jacobsson et al. 2000, 2004, Nilsson et al. 2004, Lauber and Mez 2004).
- In Denmark, most wind turbines are owned by NUGs, whereas utility-owned wind capacity accounted for only 15% of the total wind capacity (Hadjilambrinos 2000).
- In the US, the Public Utility Regulatory Policies Act mandate that utilities purchase energy from small-scale power producers, essentially NUGs (Loiter and Norberg-Bohm 1999).
- Nicolli and Vona (2012) robustly show that market regulation negatively affects various indexes of REPs.

Expected effect of competition

- Positive effect likely to prevail also because the energy sector starts from low level of competition (i.e. Griffith et al. 2010) and renewable technologies are radical and destructive for incumbents (Makard & Truffer 2006)
- However, the literature found a negative effect of liberalization on energy innovation for the US and the UK (Dooley 1998; Jamasb & Pollitt 2008, 2010; Sanyal & Ghosh 2012) and for electric utilities worldwide (Salies 2010; Sterlacchini 2012)
- But these works do not focus on renewable energy innovation and do not exploit cross-country variation in competition

Data

- REP Policies: IEA dataset contains fact sheets on several REPs (tax credits, incentives, obligations, tradable certificate etc.) plus other data sources for feed-in tariff and tradable certificates (RECs)
- Index of Product Market Regulation developed at the OECD for several sectors. Average of three sub-indices: entry barriers, vertical integration and privatization
- Patents extracted from PATSTAT, containing patents registered in all offices over the last 2 centuries.

Aims and Motivation

Theoretical Insights

Data, Measurement and Econometric Strategy

Data

Measurement Issues

Econometric Strategy

Results

Conclusions

Appendix, Instruments

Measurement: the dependent variable

- Issue of quality: generic green patents extracted from PATSTAT very imprecise measure, e.g. include patents claiming protection in marginal markets, dirty data with unassigned patents.
- Citations are reliable only for USPTO patents, but under-representation of key countries like Scandinavian ones. EPO: home bias.
- Our choice:
  1. Large families of inventions: priority claim in at least two patent offices, usually the 2^{nd} is USPTO or EPO.
  2. The royal family is the triadic one: patents jointly filed in USPTO, EPO and Japanese PO.
  3. We use large family as baseline because triadic displays many zeros and severe overdispersion so quasi-Poisson models are less reliable (Cameron & Trivedi 2005).

Aims and Motivation

Theoretical Insights

Data, Measurement and Econometric Strategy

Data

Measurement Issues

Econometric Strategy

Results

Conclusions

Appendix, Instruments

Measurement: the REP index

- Each country diversifies its energy strategy by adopting different REPs, and estimating the effect of a specific policy conditioned to the regime of competition is exceedingly difficult. For these reasons, we build a single REP index combining information about several types of renewable energy policies.
  - A single indicator for REP policy stringency consent to address the issue of policy endogeneity.
- REP policies mainly available as dummies, but for public R&D, feed-in tariff and RECs.
- We choose an index that is the sum of policy dummies.
  - Note that feed-in tariffs have been reduced in earlier-adopter countries (learning), while RECs adopted only recently.
  - Results are robust to different indicators and to the inclusion of RECs and Feed-in continuous.

Aims and Motivation

Theoretical Insights

Data, Measurement and Econometric Strategy

Data

Measurement Issues

Econometric Strategy

Results

Conclusions

Appendix, Instruments

Aims and Motivation

Theoretical Insights

Data, Measurement and Econometric Strategy

Data

Measurement Issues

Econometric Strategy

Results

Conclusions

Appendix, Instruments

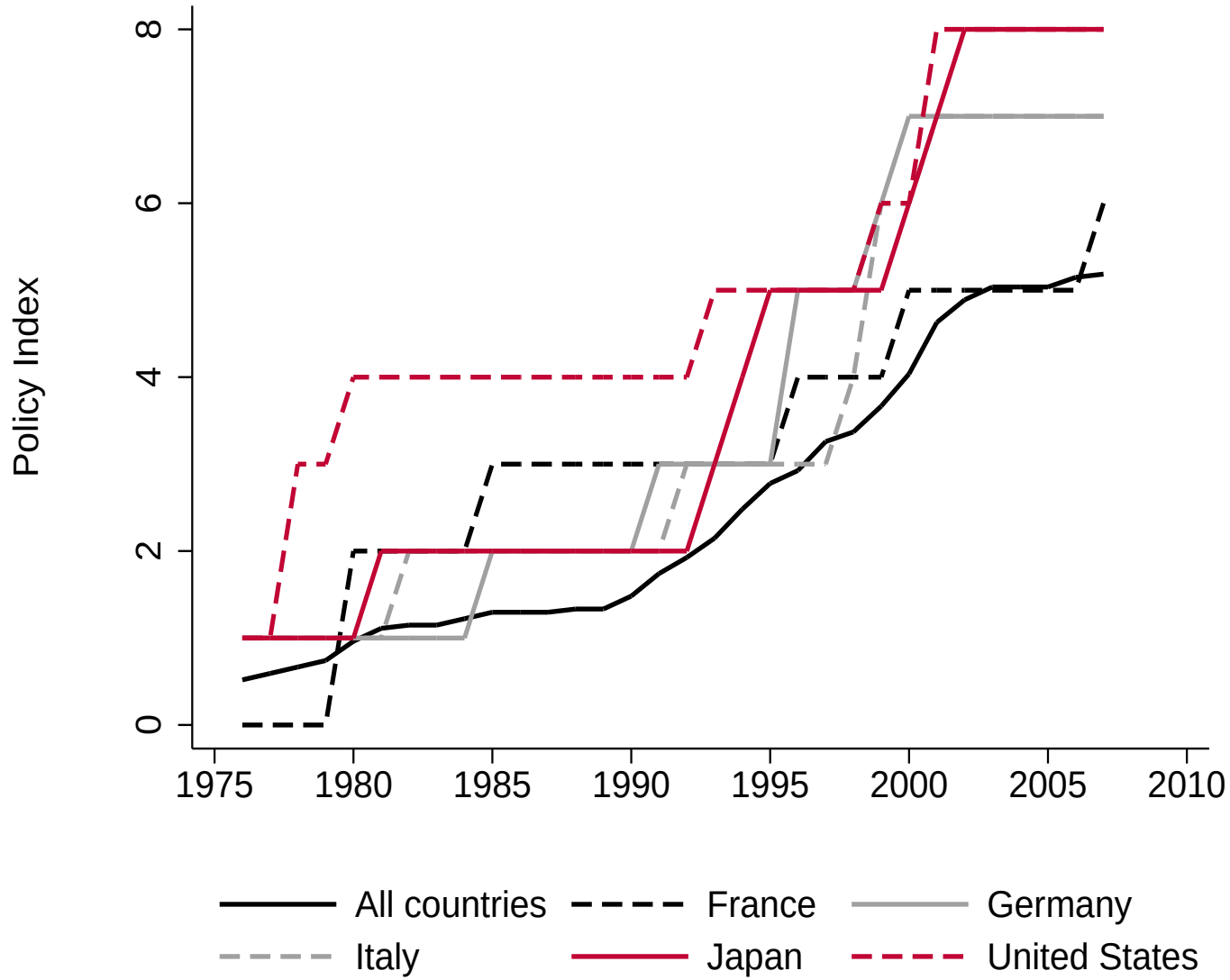

Figure: Evolution of policy index between 1976 and 2007 (big countries)

Aims and Motivation

Theoretical Insights

Data, Measurement and Econometric Strategy

Data

Measurement Issues

Econometric Strategy

Results

Conclusions

Appendix, Instruments

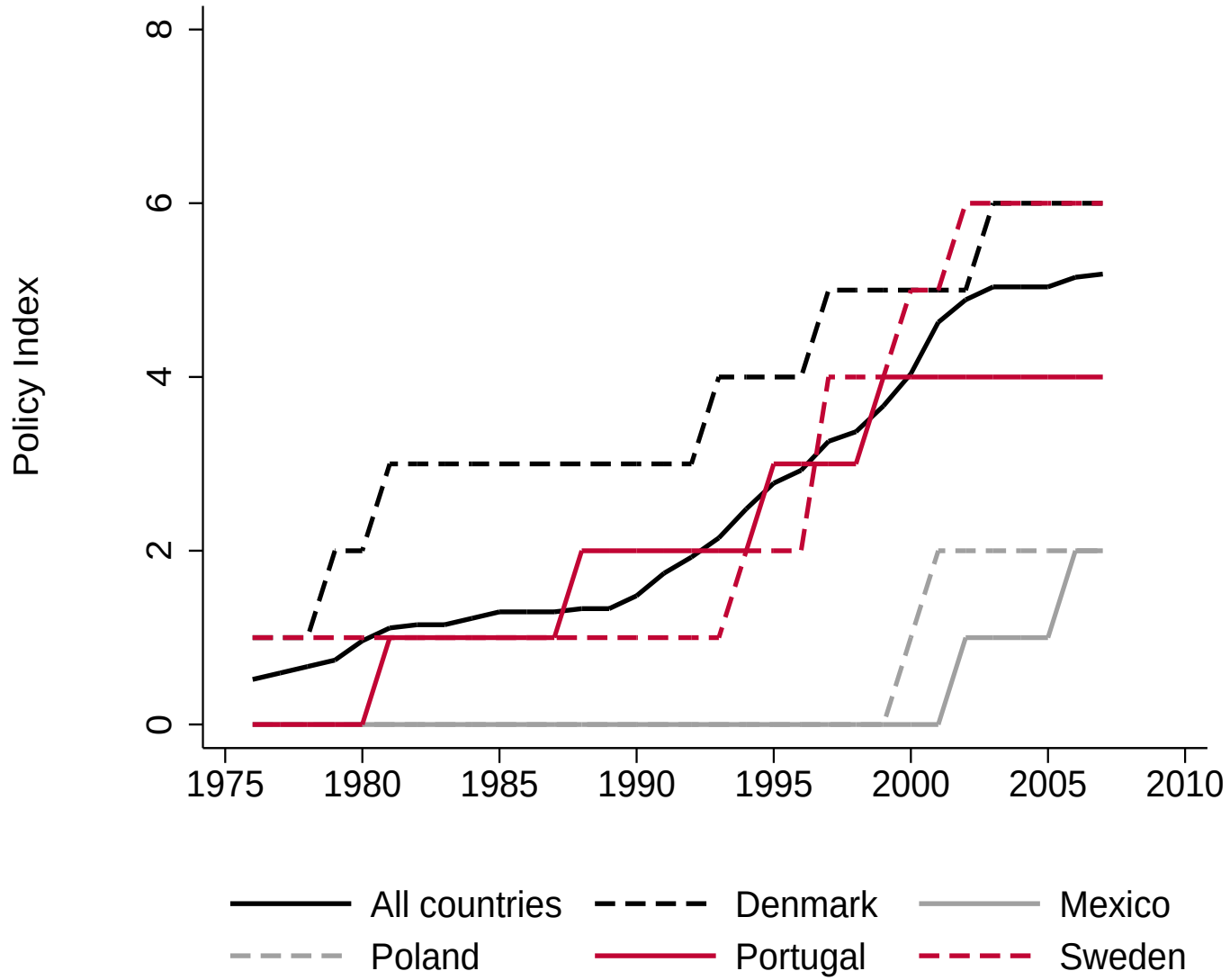

Figure: Evolution of policy index between 1976 and 2007 (small countries)

Aims and Motivation

Theoretical Insights

Data, Measurement and Econometric Strategy

Data

Measurement Issues

Econometric Strategy

Results

Conclusions

Appendix, Instruments

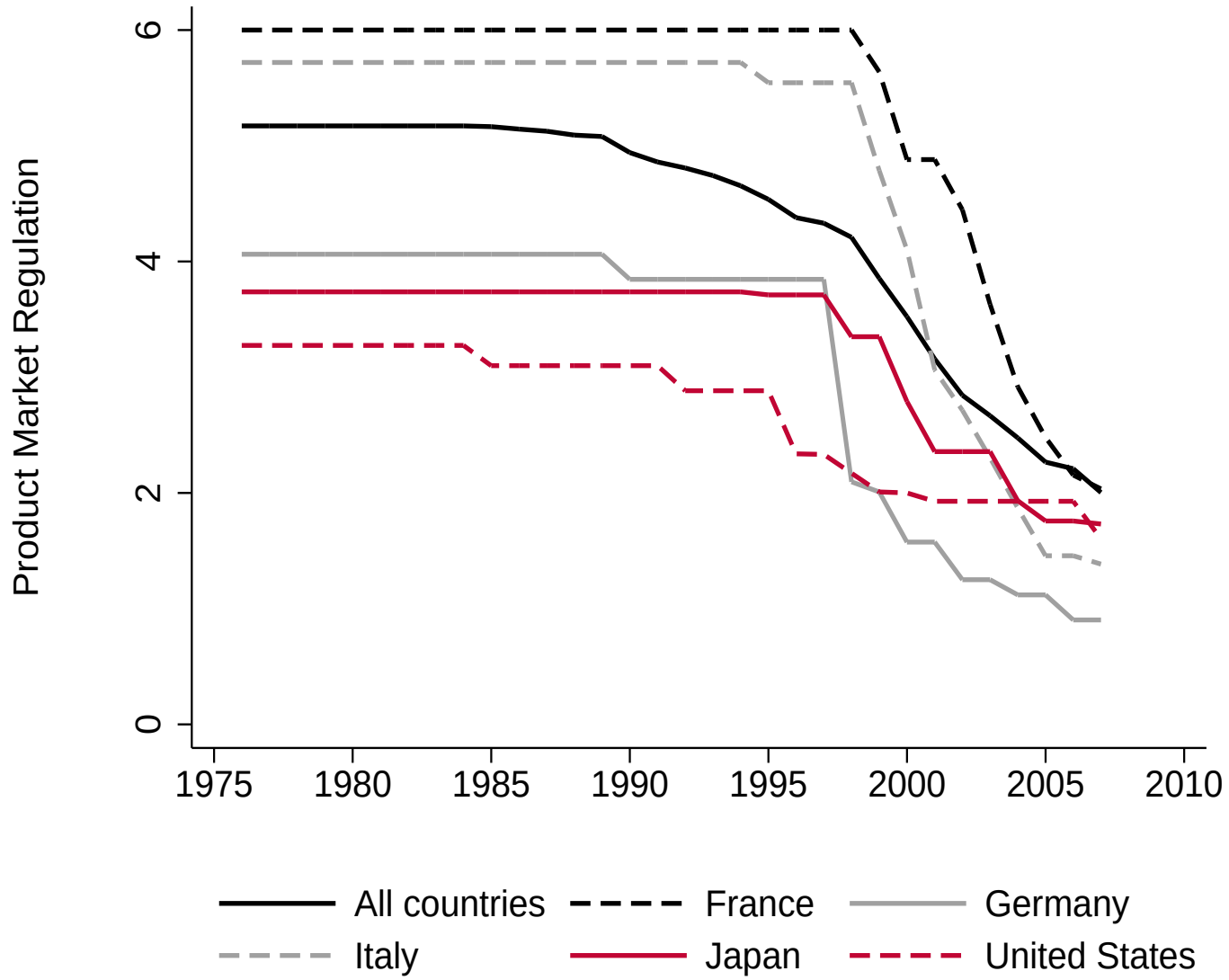

Figure: Evolution of Product Market Regulation between 1976 and 2007 (big countries)

Aims and Motivation

Theoretical Insights

Data, Measurement and Econometric Strategy

Data

Measurement Issues

Econometric Strategy

Results

Conclusions

Appendix, Instruments

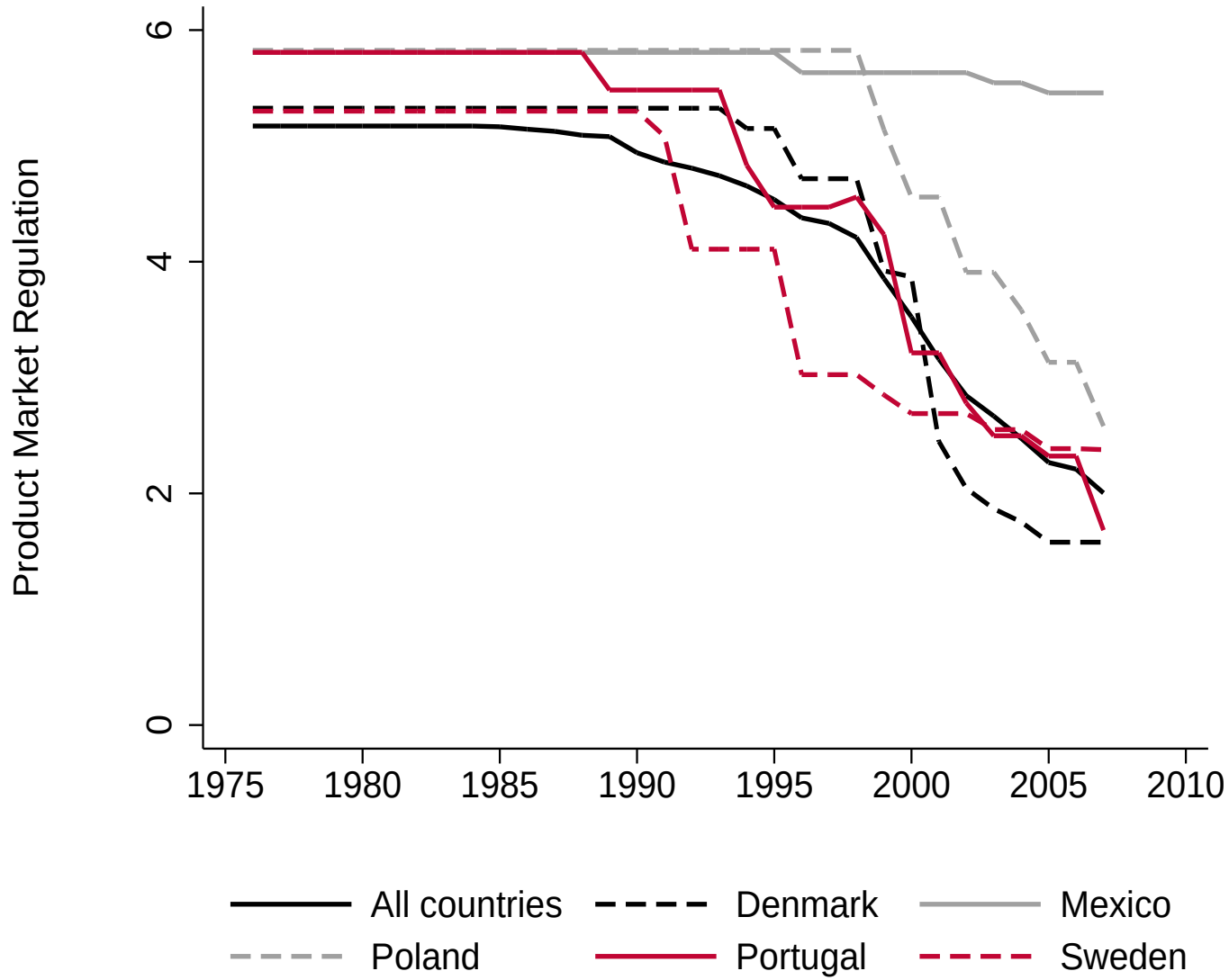

Figure: Evolution of Product Market Regulation between 1976 and 2007 (small countries)

Econometric Issues

- Existing papers on environmental innovation use count models, but do not address the issue of policy endogeneity (an exception being Popp 2002)
- Endogeneity is an issue since:
  1. Omitted variable bias: unobservable factors affecting patent propensity and the policy
  2. Mutual self-reinforcement policy-technology (Downing and White 1986) and PMR-policy-technology, i.e. lobbying opposition to REP (Nicolli and Vona 2012).
- Dynamic specification: our variables of interest are highly persistent
- Pre-sample observations on dependent variable to control for unobservable heterogeneity playing the same role as standard individual effects (Blundell *et al.* 1995, 2002). Results are robust if we use a Within Estimator in the same context.

PSM Poisson estimator with dynamics

The Pre-Sample Mean GMM Poisson model with linear feedback proposed by Blundell et al. (2002) is the best estimator to address all these issues.

We estimate:

$$y_{it} = \rho y_{it-1} + \exp(\mathbf{X}_{it}\beta + \phi \bar{y}_{ip}) + \varepsilon_{it}$$

Moment conditions read:

$$\frac{1}{N}\sum_{i=1}^{N}\sum_{t=1}^{T}\mathbf{Z}_{it}\left(y_{it} - \rho y_{it-1} - \exp(\mathbf{X}_{it}\beta + \phi \bar{y}_{ip})\right) = 0$$

where we define additional exclusion restrictions in the case of endogeneity of the regressors:

$$\mathbf{Z}_{it} = (\mathbf{1}, \widetilde{\mathbf{X}}_{it}, \bar{\mathbf{y}}_{ip}, \mathbf{PMR}_{it-\tau}, \mathbf{REP}_{it-\tau}, (\mathbf{REP} * \mathbf{PMR})_{it-\tau}, \mathbf{IV}_{it-\tau})$$

Aims and Motivation

Theoretical Insights

Data, Measurement and Econometric Strategy

Data

Measurement Issues

Econometric Strategy

Results

Conclusions

Appendix, Instruments

Controls and Instruments

- All regressions include standard controls: PSM computed over 15 years, time trend, electricity consumption, energy prices, public R&D pc, Kyoto dummy, number of generic patents, y_{t-1} and a constant
- Instruments affecting both PMR and REP: time the country has been democratic and years in office of the government (Clague et al. 1996), proxy for share of energy from distributed generation, GDP per capita.
  - durable democracies implement key reforms earlier, mitigate the influence of lobbies and pursue long-term goals.
- Unlike Popp (2002) and Aghion et al. (2011), our dependent variable is patent count rather than log(green/all or dirty) in order not to constrain to unit-proportionality their relationship.

Aims and Motivation

Theoretical Insights

Data, Measurement and Econometric Strategy

Data

Measurement Issues

Econometric Strategy

Results

Conclusions

Appendix, Instruments

Baseline Results

PSM Poisson Model with Linear Feedback, GMM with exogenous regressors
Family Weighted Number of Green Patents (fam>1), Years 1976-2007

	Model 2	Model 3	Model 4	Model 5
Linear ρ	0.783***	0.740***	0.675***	0.730***
Families (log)	0.762***	0.793***	0.792***	0.803***
Energy Price(log)	4.152*	2.849	2.701	3.082
Public R&D Ren. (log)	0.029	-0.001	0.054	-0.038
Kyoto	0.272*	0.130	0.153	0.153
Policy Index	0.090***	0.090***	0.143***	-0.050
PMR competition		-0.234***	-0.135**	-0.164**
Policy $\times$ PMR			-0.024*	
Policy $\times$ medium PMR				0.078
Policy $\times$ low PMR				0.148**
Observ.	843	843	843	843
Moments	10	11	12	13

Aims and Motivation
Theoretical Insights
Data, Measurement and Econometric Strategy
Results
Baseline Results and Policies
Endogeneity and full quantification
Conclusions
Appendix, Instruments

Results: Beyond PMR and Policies

PSM Poisson Model with Linear Feedback, GMM with exogenous regressors
Family Weighted Number of Green Patents (fam>1), Years 1976-2007

	Model 6	Model 7	Model 8	Model 9
Policy Index	0.149***	0.069*	0.130***	0.105*
Agregate PMR	-0.122*			-0.095*
Policy Index × PMR	-0.025*		-0.025**	-0.014
R&D in Renew. × PMR				-0.142**
RECs	0.001			
Average Feedin	1.817			
PMR: barriers to entry		-0.166***	-0.110**	
PMR: public ownership		-0.065*	-0.031	
PMR: vertical integration		0.010	0.018	
Observations	843	843	843	843

Aims and Motivation
Theoretical Insights
Data, Measurement and Econometric Strategy
Results
Baseline Results and Policies
Endogeneity and full quantification
Conclusions
Appendix, Instruments

Remarks

- The interaction PMR*R&D is not robust for triadic patents and the effect of public R&D not significant alone.
- The effect of RECs is low as they were implemented quite recently, early 00s.
- The effect of feed-in tariff may be low for learning effects, i.e. early adopters adjusted feed-in downward.
- For a long-term cross-country study, policy signals seem better than continuous policies.

Endogeneity

PSM Poisson Model with Linear Feedback, GMM with endogenous regressors
Family Weighted Number of Green Patents (fam>1), Years 1976-2007

	Model 14	Model 15	Model 16	Model 18
Policy Index	0.121**	0.121***	0.134***	0.130**
	[0.052]	[0.054]	[0.047]	[0.038]
PMR	-0.135	-0.129	-0.095	-0.116**
	[0.086]	[0.076]	[0.077]	[0.058]
Policy × PMR	-0.021	-0.033**	-0.029*	-0.023*
	[0.017]	[0.016]	[0.015]	[0.013]
Observations	819	811	819	814
Hansen J	4.461	8.324	8.598	5.082
Deg. of freedom	3	5	5	6
Hansen crit. prob.	0.216	0.139	0.126	0.533
Excl. Restrictions	lags	*GDPpc* *DG*	+ time dem *DG*	+ time dem years office

Lags: 1^{st} and 2^{nd} for the three variables of interest

Remarks

- Much lower effect of PMR when controlling for endogeneity
- Almost all the effect of liberalization is now captured by the synergetic effect REP-PMR
- Properly accounting of endogeneity leads to a slight but relevant change in the interpretation of the results:
  - with exogeneous regressors, the effect of REP is significant only in liberalized energy sectors;
  - with endogenous regressors, liberalization appears to have a positive effect on clean innovation mostly when combined with ambitious policies.
  - Best sequence of reforms: first ambitious environmental policies so to reinforce green players, then liberalization, i.e. the case of the two leaders Germany and Demark.

Aims and Motivation

Theoretical Insights

Data, Measurement and Econometric Strategy

Results

Baseline Results and Policies

Endogeneity and full quantification

Conclusions

Appendix, Instruments

Patent quality: generic versus triadic

	Generic	Generic End.	Triadic	Triadic End.
Energy Price	3.877**	3.505**	-0.897	-1.314
	[1.789]	[1.749]	[1.448]	[1.348]
R&D in Renew.	0.086	0.055	0.177**	0.240***
	[0.117]	[0.162]	[0.082]	[0.108]
Kyoto	0.492***	0.577***	0.255*	0.124
	[0.136]	[0.126]	[0.148]	[0.170]
Policy Index	0.085**	-0.016	0.232***	0.233***
	[0.038]	[0.047]	[0.052]	[0.042]
PMR	-0.174**	-0.337**	-0.076	-0.103
	[0.079]	[0.091]	[0.047]	[0.069]
Policy × PMR	-0.021	0.006	-0.027**	-0.023*
	[0.017]	[0.024]	[0.014]	[0.011]
Observations	843	819	843	819
Hansen d.f.	0	5	0	6
Hansen prob.	.	0.366	.	0.331
Excl. Restr., lags		time dem		time dem
		years off		years off

Lags: 1^{st} and 2^{nd} for the three variables of interest, for triadic also R&D

Marginal Effects with Endogenous Regressors

Mrg. eff. computed as discrete change in expected num. of patents.
Exp. pat. computed at the *mean* of all vars, but the one of interest

Variable	Gfam>1	Ggen	Gtri
Unconditional median and *mean*	42	25	*7.942*
Energy Price	1.577	0.910	-0.256
	3.756	3.641	-3.225
Public R&D in Renew. (log)	0.900	-0.0304	0.595
	2.143	-0.122	7.497
Kyoto	2.510	2.692	0.381
	5.976	10.51	4.79

Marginal Effects with End. Reg. (cont.)

Mrg. effects computed as discrete change in expected num. of patents.
Exp. pat. computed at the *mean* of all vars, but the one of interest

Variable	Gfam>1	Ggen	Gtri
Unconditional median and *mean*	42	25	*7.942*
ΔPolicy, PMR=mean	1.236	0.0634	1.070
	2.944	0.254	13.47
ΔPolicy, PMR=25^{th} percentile	2.631	-0.0116	1.501
	6.263	-0.0463	18.90
ΔPolicy, PMR=75^{th} percentile	0.0469	0.0935	0.677
	0.112	0.374	8.519
ΔPMR, Policy=mean	5.233	3.757	1.065
	12.46	15.03	13.41
ΔPMR, Policy=25^{th} percentile	3.524	3.828	0.559
	8.390	15.31	7.044
ΔPMR, Policy=75^{th} percentile	6.107	3.723	1.384
	14.54	14.89	17.43

Main Results

- Reconsidering the effect of market liberalization on innovation in the energy sector: strong evidence in favour of the policy complementarity hypothesis.
- REP policies must be consistent with the institutional context, notably with low PMR, to be effective.
- In line with Norberg-Bohm (2000), Popp (2006) and Jamasb & Pollitt (2008), the effect of public policies is much stronger on high quality patents while, when properly accounting of endogeneity, the autonomous effect of PMR is mainly on low quality ones.
- Our conclusion is that part of the effect of deregulation should be to encourage strategic decision making by large incumbents: they accumulate industrial property rights to deter potential entrants.

Other Results

- From the quantification exercise, the synergetic effect of policy and liberalization turns out being the main source of path-breaking innovations.
- Demand Pull or Supply Push: although our results are inconclusive in shedding light on the demand-pull versus supply-push debate, they do suggest that both scientific input and demand factors are crucial for frontier innovation.
- Energy prices play a relatively minor role but this also depends on the time frame considered, i.e. inclusion of the early 70s and the first oil shock would change the results.

Further justifications of the instruments 1

- The recent liberalization of energy markets should have reduced the incumbents' lobbying capacity, favoring the adoption of ambitious REPs and facilitating the emergence of new players in renewable energy innovation.
- The close interplay between competition and innovation policies points to the existence of a latent factor affecting both the liberalization process and the adoption of REPs.
- Moreover, because of the strong persistence of our two policy indicators, the timing of reforms is of paramount importance in establishing comparative advantages in renewable energy technologies.
- Accordingly, we chose an instrument that jointly influences the two policy indicators and, in particular, their time of adoption.

Further justifications of the instruments 2

- Our strategy is to use both within-sample and out-of-sample instruments. First, we use lags in the policy variables (REP, PMR).
- Second, we included a series of out-of-sample instruments, predictors of policy implementation. Main: a proxy accounting for the time length for which a country has had consolidated and durable democratic institutions (WB Data on Political Institutions).
- A growing literature shows that democratic countries tend to approve stricter environmental policies and to foster product market liberalizations.
- With respect to younger democracies, durable democracies ensure a longer time horizon for decision making and should be more responsive to citizens' preferences.

Validity of the Instruments

	polind dem1	*polind dem2*	*polind gdp1*	*polind gdp2*
tensys	0.040***	0.038***		
yrsoffc		-0.046***		
yrcurnt		-0.019		
rgdpl			0.000***	0.000***
dg bef lib				0.242***
cons	0.812***	1.124***	-0.437***	-0.573***
R square	0.23	0.22	0.37	0.38
	pmr dem1	*pmr dem2*	*pmr gdp1*	*pmr gdp2*
tensys	-0.026***	-0.025***		
yrsoffc		0.013		
yrcurnt		0.044		
rgdpl			-0.000***	-0.000***
dg bef lib				-0.155***
cons	5.405***	5.225***	6.105***	6.193***
R square	0.18	0.17	0.27	0.28