# Environmental Policies, Product Market Regulation and Innovation in Renewable Energy

Francesco Vona[a] Lionel Nesta[a] Francesco Nicolli[b]

[a] OFCE-DRIC Sciences-Po

[b] University of Ferrara

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# 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 where dynamic feedbacks and endogeneity issues are taken into account.

# 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, recently emphasized by Schumpeterian growth models (Aghion et al. 2012).

# 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.
- Reducing PMR from $3^{rd}$ to $1^{st}$ quartile when REP is at $3^{rd}$ quartile increases the expected number of high quality patents by 13% of the median number of patents
- 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

# Factors affecting environmental innovations

- Inducement hypothesis: key role for policies in presence of multiple externalities, uncertainty 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)
- Policy Complementarity Hypothesis: 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

# Peculiarities of renewable energy technologies





- Radical innovations, decentralization of energy production and smaller scale tend to negatively affect profits of large utilities.
- Rich case study evidence: key role of new players and opposition of existing incumbents against REP.
- Policy complementarity: subsidies and policies fostering demand for clean capacity attract new players with appropriate skills and higher incentives to develop new technologies (not only to comply with regulation) only if entry barriers are low.
  - Note that REP policies are crucial to favour the entry of non-utility generators, like municipalities, households, cooperatives, farmers etc. that tend to be more environmentally friendly
  - Liberalization increases the bargaining power of specialized suppliers, key for energy tech., especially when the share of non-utilities generators is high (Sanyal & Ghosh 2012)

# 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
  1. Pros: objective, exogenous and direct measure for energy
  2. Cons: indirect measure of profitability and concentration
- Patents extracted from PATSTAT, containing patents registered in all offices over the last 2 centuries.

# 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 registered in USPTO, EPO and Japanese PO
  3. We use family as baseline because triadic displays many zeros and severe overdispersion so quasi-Poisson models are less reliable (Cameron & Trivedi 2005)

# Measurement: the REP index

- Need to build a single indicator for REP policy stringency to endogeneize and interact it with PMR
- REP policies mainly available as dummies, but for public R&D, feed-in tariff and RECs
- Note that feed-in tariffs have been reduced in earlier-adopter countries (learning), while RECs adopted only recently
- Hence, we choose an index that is the sum of policy dummies
  - Results are robust to different indicators and to the inclusion of RECs and Feed-in continuous. Our simpler indicator of policy stringency is the one that explains the greatest fraction of patents.

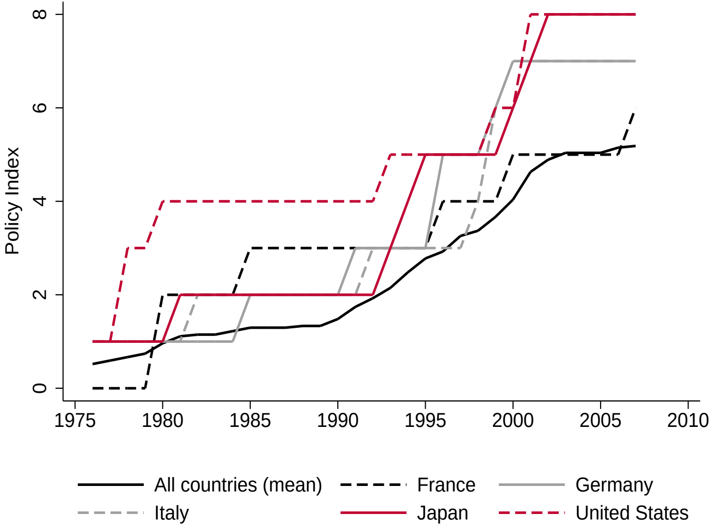


Figure: Evolution of policy index between 1976 and 2007 (big countries)

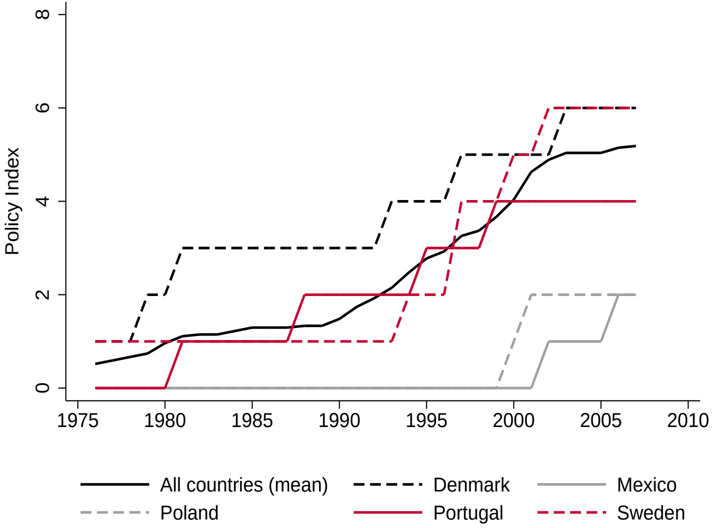


Figure: Evolution of policy index between 1976 and 2007 (small countries)

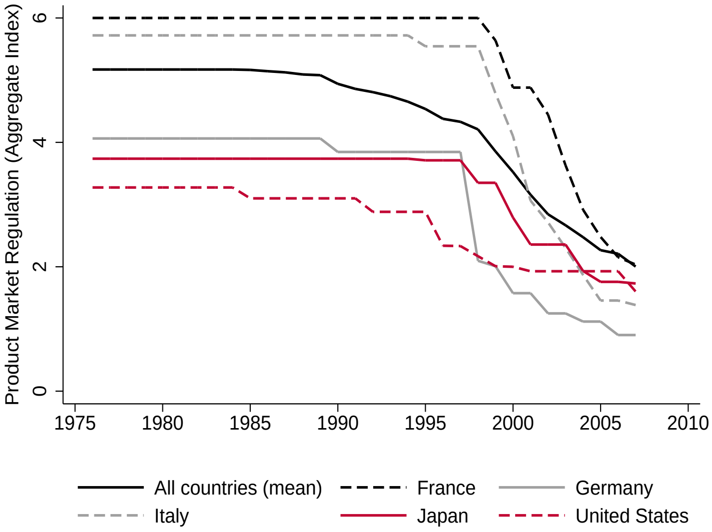


Figure: Evolution of Product Market Regulation between 1976 and 2007 (big countries)

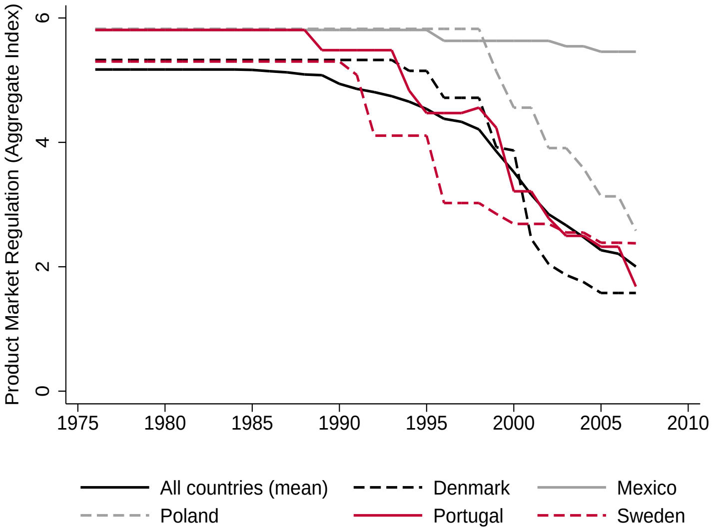


Figure: Evolution of Product Market Regulation between 1976 and 2007 (small countries)

# 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: i.e. income affects 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:

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

# Controls and Instruments

- PSM information computed over 15 years. Long PSM information reduces biases in the estimated coefficients.
- All regressions include standard controls for these studies: time trend, electricity consumption, energy prices, public R&D pc, Kyoto dummy, number of generic patents, $y_{t-1}$ and a constant
- Good and intuitive exclusion restrictions that affect both PMR and REP: share of energy from distributed generation before liberalization (IEA, Glanchant & Finon, 2003), GDP per capita, % tertiary education
- Unlike Popp (2002) and Aghion et al. (2011), our dependent variable is patent counts rather than log(green/all or dirty) in order not to constrain to unit-proportionality their relationship.

# 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 $\rho$ | 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 |

# 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 |

# 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 | 0.123** | 0.140*** | 0.137*** | 0.126** |
| | [0.054] | [0.051] | [0.051] | [0.054] |
| PMR | -0.135 | -0.108 | -0.098 | -0.09 |
| | [0.083] | [0.077] | [0.072] | [0.074] |
| Policy $\times$ PMR | -0.020 | -0.029* | -0.032** | -0.032** |
| | [0.017] | [0.015] | [0.015] | [0.016] |
| Observations | 819 | 819 | 811 | 811 |
| Hansen J | 4.312 | 7.338 | 8.481 | 8.903 |
| Deg. of freedom | 3 | 4 | 5 | 6 |
| Hansen crit. prob. | 0.23 | 0.119 | 0.132 | 0.179 |
| Excl. Restrictions | lags | $+DG$ | $+GDPpc$ | $+\%GRAD$ |

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 only when combined with ambitious policies.

# Patent quality: generic versus triadic

| | Generic | Generic End. | Triadic | Triadic End. |
|---|---|---|---|---|
| Energy Price | 3.877** | 3.802** | -0.897 | -1.477 |
| | [1.789] | [1.899] | [1.448] | [1.316] |
| R&D in Renew. | 0.086 | 0.055 | 0.177** | 0.236*** |
| | [0.117] | [0.120] | [0.082] | [0.063] |
| Kyoto | 0.492*** | 0.778*** | 0.255* | 0.303*** |
| | [0.136] | [0.175] | [0.148] | [0.057] |
| Policy Index | 0.085** | -0.014 | 0.232*** | 0.194*** |
| | [0.038] | [0.069] | [0.052] | [0.032] |
| PMR | -0.174** | -0.234** | -0.076 | -0.022 |
| | [0.079] | [0.094] | [0.047] | [0.036] |
| Policy $\times$ PMR | -0.021 | -0.020 | -0.027** | -0.036*** |
| | [0.017] | [0.025] | [0.014] | [0.008] |
| Observations | 843 | 811 | 843 | 811 |
| Hansen d.f. | 0 | 5 | 0 | 7 |
| Hansen prob. | . | 0.154 | . | 0.161 |
| Excl. Restr. | | $DG$,lags,$GDP$ | | $DG$,lags,$GDP$ |

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 | 1.458 | 0.776 | -0.340 |
| | 3.470 | 3.103 | -4.279 |
| Public R&D in Renew. (log) | 0.892 | -0.0510 | 0.693 |
| | 2.123 | -0.2040 | 8.720 |
| Kyoto | 0.768 | 3.144 | 1.143 |
| | 1.828 | 12.58 | 14.40 |
| Policy Index | 4.203 | -0.516 | 1.877 |
| | 10.01 | -2.063 | 23.64 |
| PMR | 2.591 | 2.986 | 0.185 |
| | 6.168 | 11.94 | 2.327 |

# 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* |
| $\Delta$Policy, PMR=mean | -0.072 | -0.399 | 0.348 |
| | -0.170 | -1.594 | 4.377 |
| $\Delta$Policy, PMR=$25^{th}$ percentile | 1.238 | -0.620 | 0.822 |
| | 2.948 | -2.479 | 10.35 |
| $\Delta$Policy, PMR=$75^{th}$ percentile | -1.166 | -0.234 | -0.124 |
| | -2.775 | -0.935 | -1.562 |
| $\Delta$PMR, Policy=mean | 4.174 | 2.949 | 0.791 |
| | 9.939 | 11.79 | 9.964 |
| $\Delta$PMR, Policy=$25^{th}$ percentile | 2.535 | 3.217 | 0.167 |
| | 6.036 | 12.87 | 2.105 |
| $\Delta$PMR, Policy=$75^{th}$ percentile | 4.939 | 2.830 | 1.114 |
| | 11.76 | 11.32 | 14.02 |

# 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 Popp (2003) 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.
- The synergetic effect of policy and liberalization is another source of path-breaking innovations.

# Other Results

- Changing either REP or PMR is not able to revert previous innovative patterns, but is effective only if the green stock is high. Regulated energy markets may be good for innovation when the green stock is high.
- Demand Pull or Supply Push: R&D very important on high quality patents, but demand policy generally more important in terms of magnitude
- 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

# Results: Policies and Path Dependency





Quasi-Poisson Maximum Likelihood Estimator

Family Weighted Number of Green Patents (fam>1), Years 1976-2007

| | Model 10 | Model 11 | Model 12 | Model 13 |
|---|---|---|---|---|
| Green Stock (log) | 0.277*** | 0.274*** | 0.138 | 0.111 |
| Families (log) | 0.827*** | 0.810*** | 0.749*** | 0.785*** |
| Public R&D Renew. | 0.282*** | 0.494*** | 0.252*** | 0.474*** |
| Policy Index | 0.108*** | 0.095*** | -0.103 | 0.009 |
| PMR | -0.097*** | -0.070** | -0.399*** | -0.314*** |
| Policy Index $\times$ PMR | -0.015* | -0.011 | | -0.016 |
| R&D Renew. $\times$ PMR | | -0.065** | | -0.062** |
| Green Stock $\times$ PMR | | | 0.034*** | 0.037*** |
| Green Stock $\times$ Policy | | | 0.023** | 0.013 |
| Observations | 843 | 843 | 843 | 843 |
| LL | -11854 | -11782 | -11807 | -11646 |