Do Technology Standards Induce Innovation in Grid Modernization Technologies?

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1. Motivation

Accelerating decarbonization

- Half of tech. for 2050 net-zero goals: still in the lab (IEA, 2021)
- Policy successes: wind and solar cost competitive with fossil-fuel generation
- Next challenge: integrating more renewables
    - Grid pressures
        - Ageing grid
        - Compounded by climate change
- What is needed is not just more innovation, but different innovation (Popp et al, 2022)

The smart grid

- Grid flexibility, resilience, reliability
- Aspiration: transformative technologies for new model of the grid
  - Decentralized
  - Digitalized
  - Big data
  - Automated
- Linchpin for flexibility tools: demand-side management, V2G/G2V, distributed storage, microgrids/islanding (Martinot, 2016)

New sector of innovation, new challenges?

- Not just environmental externalities and knowledge spillovers (Popp, 2019)
- Coordination challenge: compatibility
  - Opportunities to generate network externalities (Katz and Shapiro, 1985).
- Cross-sectoral technologies
  - Pooling knowledge from several sectors of technology

2. Literature

Literature: environmental innovation

- Effects of technology-push and demand-pull policies
  - Higher energy prices induce innovation in clean tech (Popp, 2002; Crabb and Johnson, 2020)
  - Demand-pull instruments (e.g. prices) have a greater impact on innovation than technology-push instruments (e.g. subsidies) (Costantini et al, 2017)
  - Consumer subsidies for solar panels increase innovation through effect on demand and cost reductions. Effect outlasts subsidies (Gerarden, 2018).
  - Emissions trading: regulated firms patent more than unregulated firms (Calel and Dechezlepretre, 2016)

Literature: environmental innovation

- Firm-level studies:
  - Switching decisions of firms – dirty to clean - induced by prices (Aghion et al, 2016).
  - Knowledge stocks : path-dependency (Aghion et al, 2016).
    - Increase in clean patenting driven by entry of specialized renewable energy firms and exit of specialized fossil fuel firms (Noailly and Smeets, 2015).
    - Complementarities: firms with experience in storage technologies more likely to patent in renewables (Lazkano et al, 2017).

Policies for smart grid innovation

- Voluntary standards for interoperability
  - Mandates:
    - US: EISA (2007)
    - EU: EC mandates M/441 (2009), M/490 (2011)
  - Roadmaps:
    - Canada: The Canadian Smart Grid Standards Roadmap (2012)
    - Germany: The German Standardization Roadmap E-Energy/Smart Grid (2010)
    - Korea: Korea’s Smart Grid Roadmap 2030 (2010)

UNDERSTUDIED POLICY INSTRUMENT

Literature: standards and market failures

- Standards:
  - Codify knowledge (Contreras, 2017; Wiegmann et al, 2017)
  - Voluntary (not regulatory)
    - Proprietary
    - **Open standards (consensus-building at SSOs)** (Baron and Spulber, 2018)
- Typology of standards (Swann, 2000; Tassey, 1999; DeVries, 1999):
  - Quality standards: reduce transaction costs, redress information asymmetries
  - Information standards : reduce transaction costs, redress information asymmetries
  - Variety reduction standards: economies of scale
  - **Compatibility standards: coordination, network externalities**

Literature: standards and innovation

- Focus on how innovation ➡️ standards
  - Strategic interactions (Lerner and Tirole, 2006; Chiao et al, 2007, Kang and Bekker, 2015)
- Little empirical literature on how standards ➡️ innovation
  - Standards lead to high impact innovation by complementor firms (Wen et al, 2022)
  - Standards favor incremental innovation (Foucard and Li, 2021)

3. Questions and hypotheses

Research questions

- What is the effect of compatibility standards on inventive activity in smart grids?
  - Do these effects vary by type of firm?
    - age, size, expertise

Hypotheses: effect of standards on patenting

- Information hypothesis:
  - Standards provide credible information about technical specifications, reduces uncertainty for inventors. ***Increases patenting activity***.
- Technology lock-in hypothesis:
  - Standards remove incentives to test out new ideas. ***Reduces patenting activity.***
- Endorsement hypothesis:
  - Standards formalize what the industry has already *de facto* adopted. ***No effect, or negative effect, on patenting activity.***

Channels work in opposing directions: net impact is ambiguous

4. Data and descriptive statistics

Data

- Patents:
  - European Patent Office: PATSTAT.
- Standards:
  - Searle Center on Law, Business and Economics, Northwestern University: Technology Standards and Standard Setting Organizations database (Baron and Spulber, 2018)
  - Lists of smart grids standards: SEPA, CEN/CENELEC/ETSI

IEC standard 61400: Wind energy generation systems

Standard part	First release
Part 1: Design Requirements	1994
Part 2: Small wind turbines	1996
Part 3-1: Design requirements for fixed offshore wind turbines	2019
Part 3-2: Design requirements for floating offshore wind turbines	2019
Part 4: Design requirements for wind turbine gearboxes	2012
…	
Part 25-1 Communications for monitoring and control of wind power plants - Overall description of principles and models	2006
Part 25-2 Communications for monitoring and control of wind power plants - Information models	2006
Part 25-3 Communications for monitoring and control of wind power plants - Information exchange models	2006
Part 25-4 Communications for monitoring and control of wind power plants - Mapping to communication profile	2008
Part 25-5 Communications for monitoring and control of wind power plants - Compliance testing	2006
Part 25-6 Communications for monitoring and control of wind power plants - Logical node classes and data classes for condition monitoring	2010

Accreditation of parts 25-2 and 25-3

Austria	61400-25-2	2007
	61400-25-3	2014
Germany	61400-25-2	2006
	61400-25-3	2006
Switzerland	61400-25-2	2007
	61400-25-3	2015

Sample

- 2,751 firms
- 10,312 patents (counted at the patent family level)
- 1,482 country-level standards adoptions
- 19 OECD countries
  - Austria, Australia, Canada, Switzerland, Czech Republic, Germany, Denmark, Spain, Finland, France, United Kingdom, Italy, Japan, Korea, Netherlands, Norway, Sweden, Turkey and the United States
- 2000-2016

Figure 1. Trends in smart grids patenting

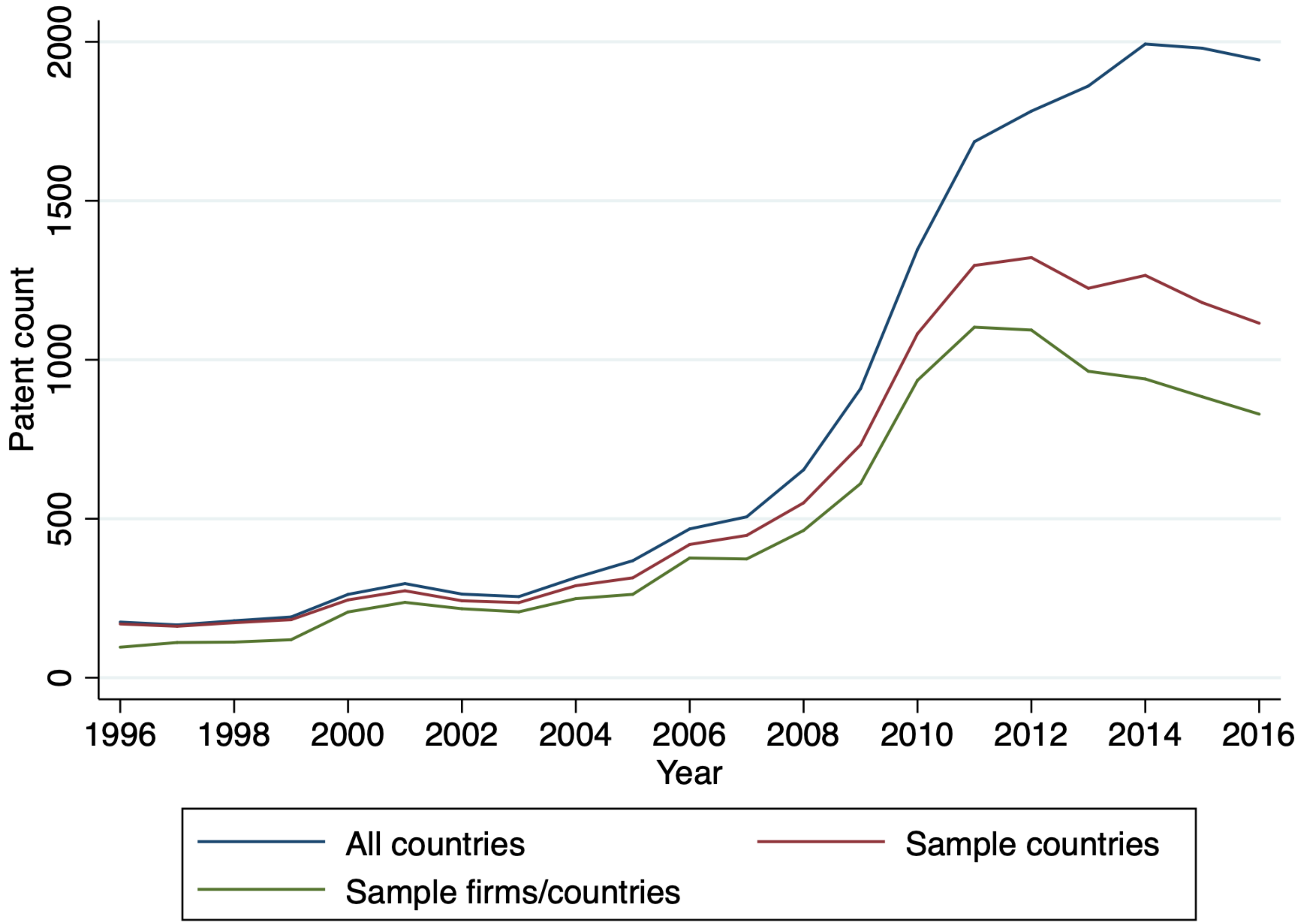
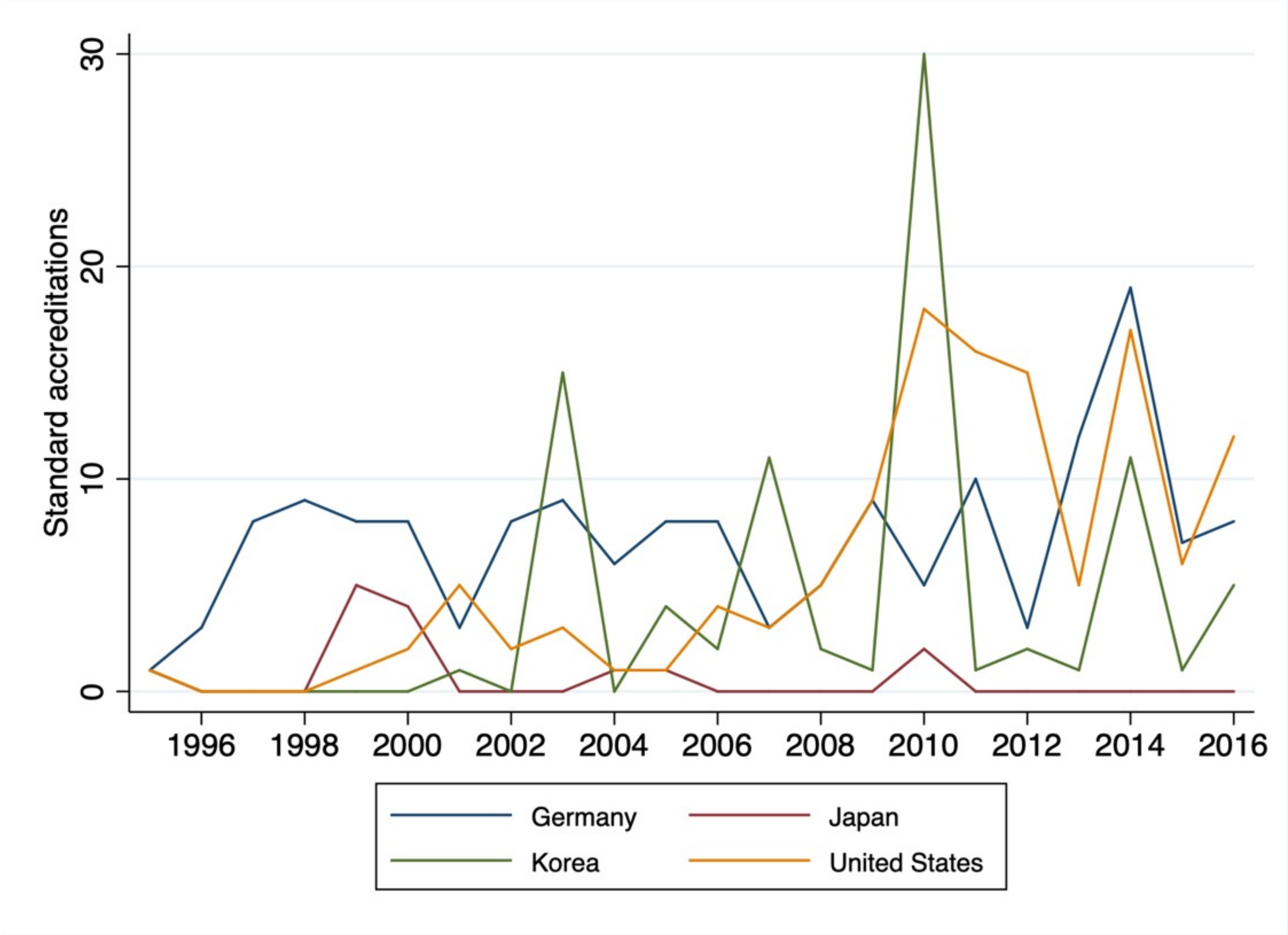


Figure 2. Smart grids standards accreditations in select markets



5. Model

Estimation

- Zero-inflated Poisson:
  - Two-stage model: whether to patent, how much to patent
    - Excess zeros generated by separate process
- Pre-sample mean estimator: weak exogeneity (Blundel et al, 1995; Noailly and Smeets, 2015; Rozendaal and Vollebergh, 2021)
  - Controls for unobserved attributes of the firms (confounding)
  - Knowledge stocks violate strict exogeneity assumptions of fixed effects model

Model

$$patents_{it} = f(standards_{it-2}, gov.R\&D_{it-2}, int.knowledge_{it-2}, ext.knowlege_{it-2}, controls_{it-2})$$

<u>Policy variables:</u>

- Count of standards
- Government RD&D budgets in grid-related technologies
- Government RD&D budgets in renewables

<u>Internal and external knowledge stocks</u>

- Smart grid
- Green tech
- Electricity
- Information and communication technologies

<u>Control variables:</u>

- Share of renewables in electricity generation
- Growth in electricity consumption
- Household electricity prices
- GDP per capita
- New firm dummy
- 4 zero stocks dummies
- Yearly average of patents in pre-sample
- Year dummies

Policy weights

- Weight country-level variables: markets where firm operated in pre-sample period in relevant CPC classes (Noailly and Smeets, 2016; Aghion et al, 2016; Lazkano et al, 2017; Rosendaal and Vollebergh, 2021).
  - Relative importance of each market to the firm: exposure to policy variables

6. Results

Standards reduce both entry (decision to patent) and the intensity of patenting

Table 1. Regression results from Zero-Inflated Poisson Regressions

Variables	Level of patenting	Prob. zero patents
Standards	-0.038***	0.016*
	(0.012)	(0.008)
Marginal effect, standards	-0.076***	
	(0.021)	
Observations	30,628	30,628
Log-likelihood	-47022	-47022

Internal knowledge stocks matter: prior experience in smart grids, green technology, electricity associated with more patents

Table 1. Regression results from Zero-Inflated Poisson Regressions

Variables	Level of patenting	Prob. zero patents
Int. knowledge stocks - smart grids	0.598***	-1.436***
	(0.032)	(0.050)
Int. knowledge stocks - green tech	0.075**	-0.180***
	(0.032)	(0.022)
Int. knowledge stocks - electricity	0.137***	-0.147***
	(0.034)	(0.029)
Int. knowledge stocks - ICTs	-0.165***	-0.012
	(0.029)	(0.025)
Observations	30,628	30,628
Log-likelihood	-47022	-47022

Knowledge spillovers from other smart grid innovators

Table 1. Regression results from Zero-Inflated Poisson Regressions

Variables	Level of patenting	Prob. zero patents
Ext. knowledge stocks - smart grids	0.454**	-0.414***
	(0.185)	(0.098)
Ext. knowledge stocks - green tech	-0.565***	0.078
	(0.151)	(0.096)
Ext. knowledge stocks - electricity	-0.010	0.013
	(0.177)	(0.094)
Ext. knowledge stocks - ICTs	0.108	0.290***
	(0.151)	(0.101)
Observations	30,628	30,628
Log-likelihood	-47022	-47022

Tradeoffs between smart grid innovation and other green technology innovation

Standards reduce patenting in large firms
Government incentives affect the R&D decisions of small firms

Table 3. Regression results by firm size

	Large firms		Small firms	
Variables	Level of patenting	Prob. zero patents	Level of patenting	Prob. zero patents
Standards	-0.051***	0.043***	-0.001	-0.001
	(0.015)	(0.016)	(0.015)	(0.011)
RD&D smart grid	-0.015	0.085	0.236***	0.062
	(0.117)	(0.067)	(0.081)	(0.050)
RD&D renewables	0.013	0.021	-0.445***	-0.116*
	(0.127)	(0.081)	(0.101)	(0.069)
Marginal effect, standards (combined)	-0.238***		-0.001	
	(0.062)		(0.011)	
Numer of firms	597	597	2,154	2,154
Observations	9,523	9,523	21,105	21,105
Log-likelihood	-23768	-23768	-21228	-21228

Standards increase entry by firms with no prior smart grid innovation experience

Table 4. Effect of standards on new entrants

Variables	Level of patenting	Prob. zero patents
Standards	-0.033**	0.120***
	(0.015)	(0.013)
Interaction standards and zero stock dummy	-0.014	-0.165***
	(0.015)	(0.011)
Joint significance	-0.047***	-0.044***
	(0.011)	(0.009)
Observations	30,628	30,628
Log-likelihood	-46872	-46872

Technology maturity matters: standards encourage patenting early but reduces patenting in later years

Table 5. Regression results for early-stage versus mature technology

Variables	**2010**
Intensive margin of standards	
Prior to 2010	0.105***
	(0.033)
After 2010	-0.049***
	(0.013)
Extensive margin of standards	
Prior to 2010	-0.063**
	(0.025)
After 2010	0.019**
	(0.008)
Observations	32,068
Log-likelihood	-50556

Note: These regressions use the same specification and control variables as the main model, but add an interaction between the count of standards and the cut-off year. Robust standard errors are included in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Takeaways

Main results

- Standards decrease innovation
  - Effect driven by large firms
  - Standards increase entry by new entrants
  - Standards increase innovation when technology is in early stages and reduce innovation when technology is more mature

Policy implications

- Timing?
- Quantity versus quality? Tech development versus tech diffusion?

Thank you!

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