Fondazione Eni Enrico Mattei

At Home and Abroad: An Empirical Analysis of Innovation in Energy-Efficient Technologies

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Outline

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2. ***Innovative Activity:***
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   - ***Patents as Proxy for Innovation***
3. ***Knowledge flows:***
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   - ***Diffusions parameters estimates***
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   - ***Internal vs External Knowledge Stock (17 countries)***
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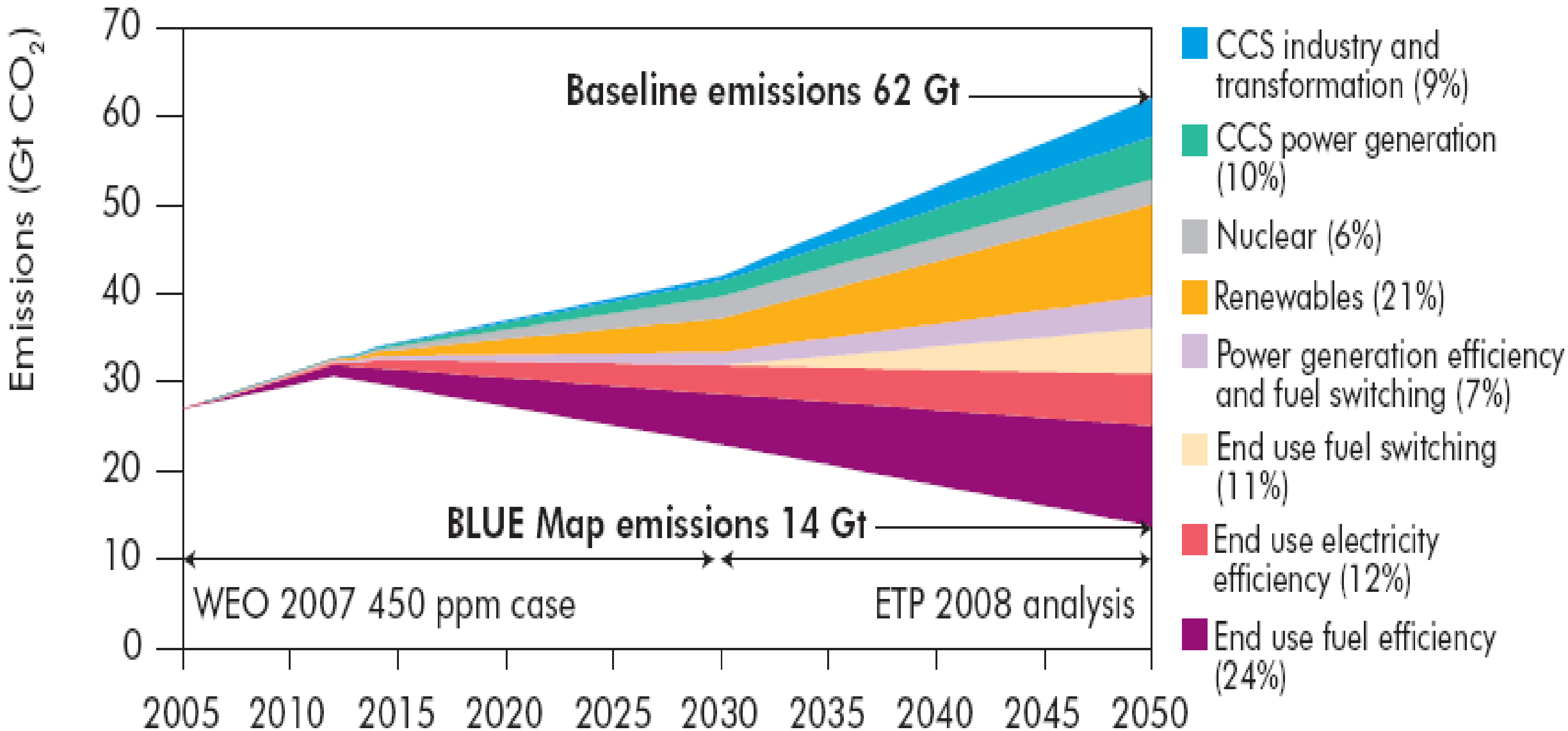
1. Technical Change, Energy and the Environment

- ***Technical change affects economic growth***
- ***Why focusing on TC, knowledge flows and spillovers related to energy-efficient innovation?***
  - ***Environmental concern:*** TC is a possible way to mitigate GHG emissions without compromising economic growth. Differences in predicted costs of policies driven by assumptions about technological change. Need for better empirical understanding: *Can TC resolve otherwise conflicting policy objectives?*
  - ***Energy security concern:*** Security of supply of energy sources and lessening dependence from fossil fuels are major concerns for all nations (i.e. importance of renewable sources): *Should prospect of TC affect energy policy?*
  - ***Complexity of energy systems:*** Significant investments - long time frames - greater concern for lock-in effects, spillovers, externalities– *What is the scope for TC in energy systems?*

1.

GHGs Stabilization Options

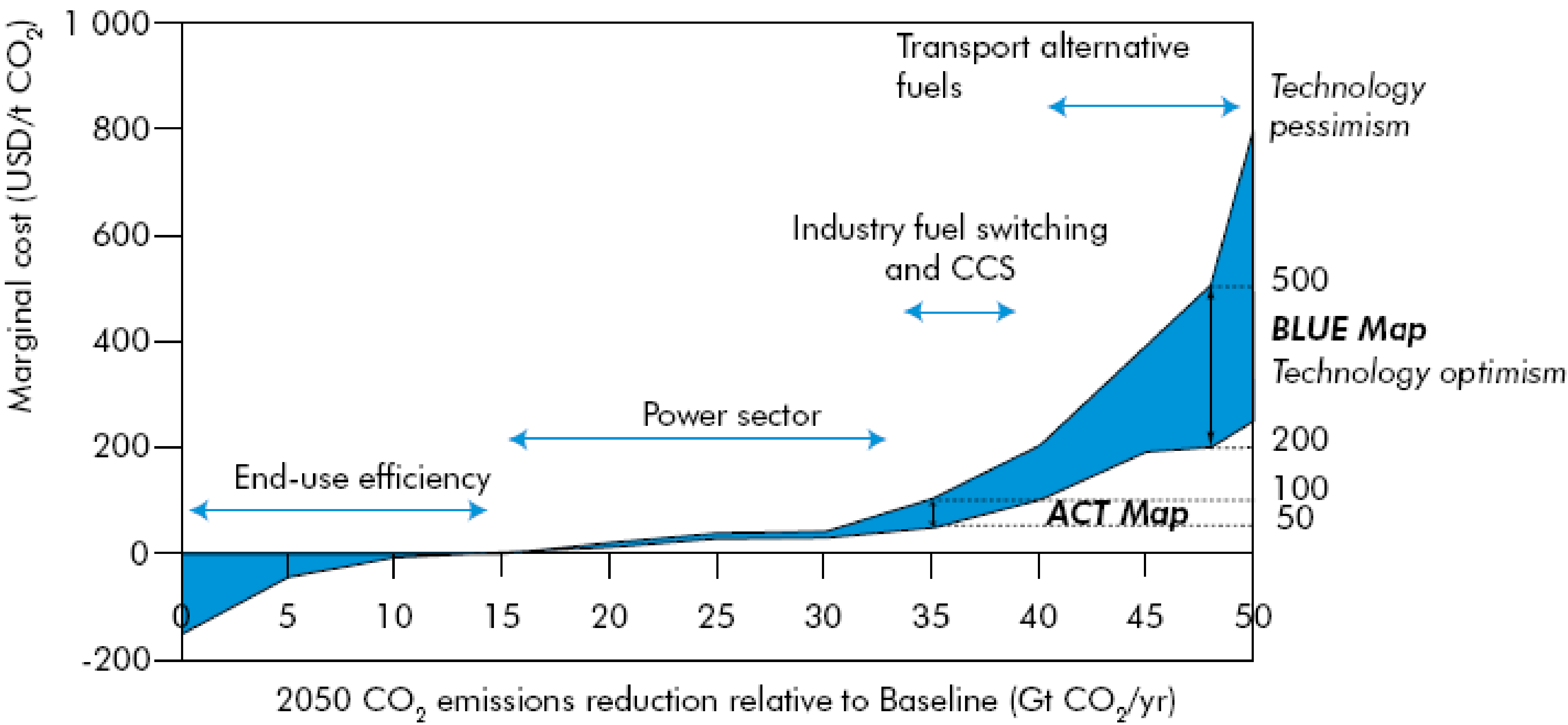
Figure 1: Technologies for reducing energy related CO_2 emissions



Source: IEA (2008), *Energy Technology Perspectives 2008.*

1. Marginal Cost Abatement Curve

Figure ES.1 ▶ Marginal emission reduction costs for the global energy system, 2050



Source: IEA, Energy Technology Perspectives, 2008

1.

Review of the literature

Induced technical change *vs* endogenous technical change: Hicks and relative factor prices [1932] - Schumpeter's "creative destruction" [1962]. Ahmad [1966], Binswanger [1974] on ITC. Griliches [1984], Scherer [1986] on ETC.

Endogenous growth model: i.e. Romer [1990, 1994], Grossman & Helpman [1994] on contribution of technical change to growth. Little on micro-foundation of technical innovation and diffusion - Caballero & Jaffe [1993]

Demand and supply determinants of innovation: debate spurred by Schmookler [1966]. Rosenberg and Mowery [1979], Scherer [1981]

TC, knowledge flow and spillovers: micro-level studies on diffusion in geographical and technological space – Jaffe [1986], Jaffe & Trajtenberg [1996]. Macro-level studies of trade-growth literature – Riviera-Batiz & Romer [1991] Feenstra [1996] – but little attention to channels of knowledge flow

ITC applied to climate models: i.e. Nordhaus [1999], Buonanno *et al.* [2001]

Empirical studies testing induced innovation hp: Lanjouw & Mody [1996], Jaffe & Palmer [1997], Newel *et al*. [1999]

Recent focus on differential impact of specific policy instruments: command-and-control vs market-based: Klaassen *et al.* [2005], Popp [2006]

1. The Starting Point: Popp [2002]

- ***Demand-pull:*** market demand increases the value of new innovation and spurs innovative activity
- ***Technology-push (supply):*** scientific advancements increase technological opportunities and make new innovation possible

Popp [2002]: (1) studies the relationship between energy prices and innovative activity (induced innovation) and (2) looks at effect of knowledge stock on innovation (debate on demand-pull *vs* supply-push determinants of innovative activity – Schmookler [1966]). Confirms the importance of considering both effects when analyzing induced innovation in energy-efficient technologies in the USA. Widely influential. However:

- ***Results for a single top-innovator country:*** Can we generalize them?
- ***No international diffusion/spillover effects analyzed:*** Innovation economics demonstrates that
    - ✓ there are important spillovers between countries and that
    - ✓ technology flows through different channels (trade, FDI)
    - ✓ diffusion is affected by geographic and technological vicinity

2. A Framework For Analysis

Innovation can be driven by

- Z_t^D demand-side factors
- Z_t^S supply-side factors

$$IA_t = h(Z_t^D, Z_t^S)$$

Z_t^S usually taken to be represented by TO_t

- accumulates over time
- subject to obsolescence
- likely to come from different countries

$$TO_t = g(K_{t-1}^{own}, K_{t-1}^{ext})$$

Z_t^D affected by:

- Expected price of energy
- State of the economy
- Energy-Efficiency Policies

$$IA_t = h(P_t^E, VA_{t-1}, EEPol_{t-1}, K_{t-1}^{own}, K_{t-1}^{ext})$$

2.

A Framework For Analysis

$$IA_t = h(P_t^E, VA_{t-1}, EEPol_{t-1}, K_{t-1}^{own}, K_{t-1}^{ext})$$

Any given country has easier access to the knowledge produced inside the national border than to the knowledge produced abroad:

- **Knowledge diffusion:** indicates that idea produced in a firm, region or country is learned by other firms, regions, countries
- **Knowledge spillovers:** indicate that the ideas that have diffused have an impact on the production of ideas/productivity of the receiving firm, region, country.

Research questions:

- ***What are the relevant dimensions to understand the diffusion of knowledge in energy-efficient innovations?***
- ***Do knowledge spillovers affect innovative activity?***
- ***What is the role of demand-side determinants of innovation other than energy price?***

2. Patents and Citations: Proxies for Innovation and Diffusion

Patents:

- ❖ A set of exclusionary territorial rights granted by a state to a patentee
- ❖ For a fixed period of time (usually 20 years)
- ❖ In exchange for the disclosure of the details of the invention

Innovation and patents:

- ❖ Patents are an imperfect but useful indicator of inventive activity - Griliches [1990]. Main limitations:
  - ✓ *Not all innovations are patented*
  - ✓ *Not all patented innovations have the same economic value*
  - ✓ *Propensity to patent varies across countries and technologies*

Knowledge diffusion and citations:

- ❖ (US) Citations are the "paper trail" left by the flow of knowledge

In this paper, we follow both established approaches :
we use patent citations as proxy for diffusion
and patent statistics as proxy for innovation

3. Data and Estimation Method

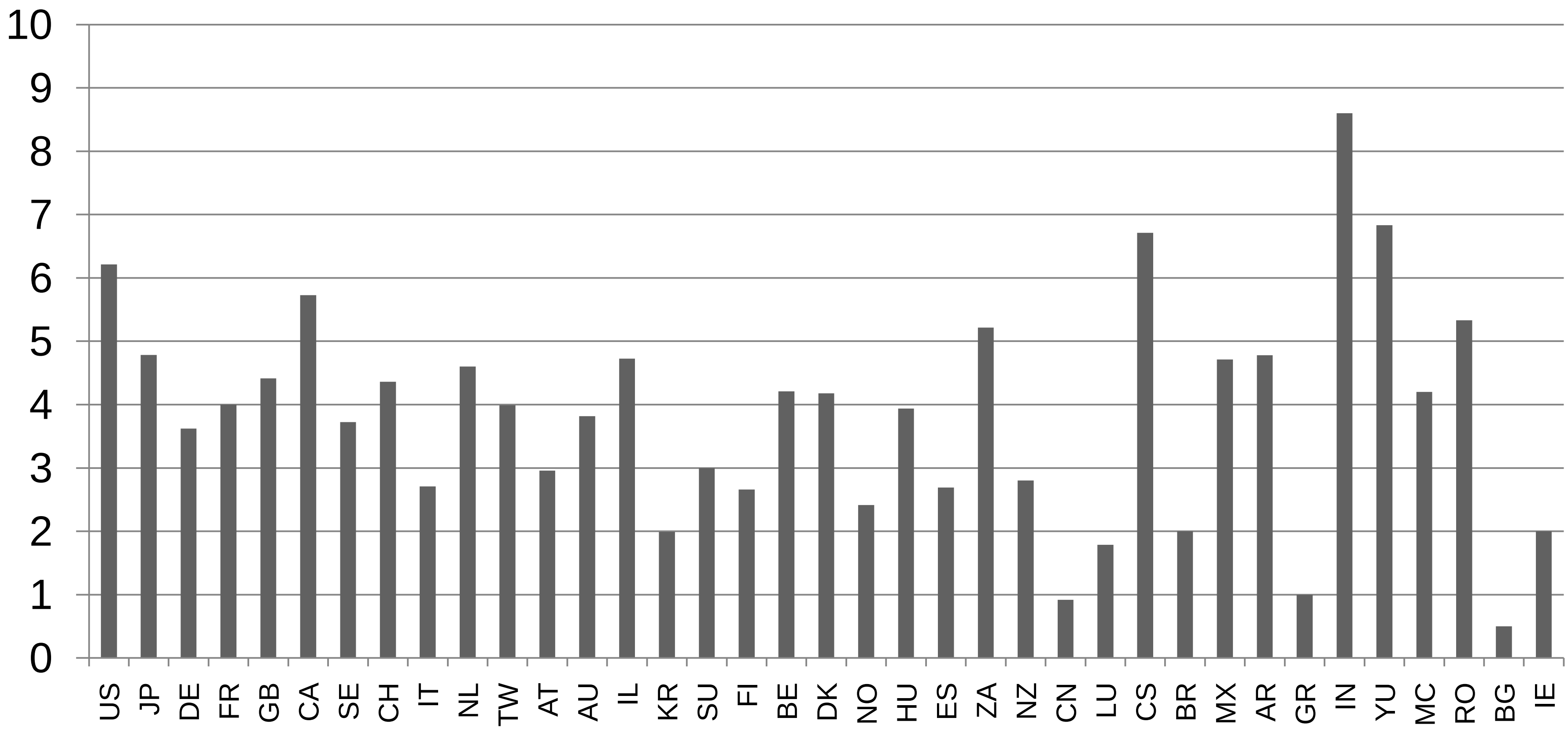
- NBER Patent Dataset: select 22,274 patents:
  - 6 energy supply groups (coal liquefaction, coal gasification, solar energy batteries for storing solar energy, fuel cells, using waste as fuel)
  - 5 demand technologies (recovery of waste heat for energy, heat exchange, heat pumps, stirling engines, continuous casting for metal)
- Patents granted between 1975 to 2000 to 38 countries (38x38 obs)
- Excluding self-citations
- CEPII (*Centre d'etudes prospectives e d'informations internationales*): information on geographical distance
- Negative Binomial model due to count data nature of the dependent variable
- Sensitivity Analysis

2. Descriptives

Country	Number of Patents	Percentage
United States	12,229	55.36
Japan	3,662	16.58
Germany	1,952	8.84
France	862	3.90
Canada	503	2.28
Sweden	426	1.93
United Kingdom	376	1.70
Switzerland	370	1.67
Italy	213	0.96
Netherlands	185	0.84
Israel	179	0.81
Austria	171	0.77
Taiwan	169	0.77
Australia	169	0.77
South Korea	130	0.59
USSR/Russian Federation	81	0.37
Finland	76	0.34
Belgium	56	0.25
Denmark	51	0.23

Total Patents	22,091
Non-assigned/Individuals	4,591
Assigned	17,500
Number of assignees	4,003
Assignees with:	
1 patent	60.52%
2 patents	14.16%
3-10 patents	18.14%
11-20 patents	3.17%
21-50 patents	2.65%
51-100 patents	0.87%
more than 100 patents	0.48%
Patents receiving:	
1 citation or none	53.40%
2-10 citations	41.83%
11-40 citations	4.69%
more than 40 citations	0.08%

Average Forward Citation



3. Knowledge Diffusion

Knowledge diffusion and citations: Citations widely used as proxy for what Krugman [1991] calls the "*paper trail*" for knowledge flows [*note: limitations of citations as proxy*]

Common approach: Likelihood that a patent k (with given characteristics) will cite patent K (with given characteristics) is assumed to be determined by the combination of two different exponential processes: one through which knowledge diffuses, and one through which knowledge becomes obsolete.

$$p_{(k,K)} \equiv \frac{c_{(k,K)}}{(n_K)(n_k)} = \alpha_{(k,K)} e^{g(x)} (1 - e^{-\beta_{2(k,K)}(\tau)})$$

Caballero & Jaffe [1993]: $x = N$

Jaffe & Trajtenberg [1996], Popp[2002]: $x = \tau$

3.

Channels of Knowledge Diffusion

$$K^{ext}_{i,t-1} = \sum_{j \neq i} \hat{\phi}_{ij} K_{j,t-1}$$

External available knowledge stock for country i is a portion of the knowledge produced by other innovating countries (Peri [2003])

$$\phi_{ij}(l) = \zeta e^{f(i,j)}(1 - e^{-\kappa(l)})$$

Process of diffusion depends on a series of "resistance factors", a set of bilateral characteristics of the sending and receiving countries

- ✓ Diffusion is geographically localized – JTH [1993], JT [1996]
- ✓ Trade influences technology transfer – Coe & Helpman [1993],Keller[2000]
- ✓ Language is a barrier – Keller [2002] , Peri [2003]
- ✓ Technological specialization of countries affects diffusion – Branstetter [2000]
- ✓ Citing and cited countries fixed-effects

$$\phi_{ij} = \exp\left[a + b_1(x_1)_{ij} + b_2(x_2)_{ij} + \ldots + b_n(x_n)_{ij}\right]$$

- Observable citations c_{ij} proxy for unobservable diffusion parameter ϕ_{ij}

$$c_{ij} = \exp\left[\rho_i + \vartheta_j + b_1(x_1)_{ij} + b_2(x_2)_{ij} + \ldots + b_n(x_n)_{ij} + \varepsilon_{ij}\right]$$

Measures of Technological Specialization

Technological difference

$$Tdiff = 1 - Tcorr = 1 - \frac{(Sh'_i\, Sh_j)}{[\sum_s (sh_{is})^2 \sum_s (sh_{js})^2]^{1/2}}$$

Leaders or followers

$$Leader = \frac{\sum_s (\overline{f_{is}} / \overline{f_s})}{S_i} > 1$$

Distance of citing country

from frontier of cited country

$$Vicinity = \frac{\sum_s (\overline{f_{js}} / \overline{f_{is}})}{S_j} - 1$$

3.

Results: Diffusion of Knowledge

Specification	I	II	III	IV
Country Border	-1.851***	-1.399***	-1.326***	-1.340***
	(0.244)	(0.247)	(0.247)	(0.248)
1,000 Km Further	-0.016	-0.013	-0.011	-0.011
	(0.014)	(0.013)	(0.013)	(0.013)
Trade Border	-0.272*	-0.288**	-0.289**	-0.290**
	(0.139)	(0.131)	(0.130)	(0.130)
Linguistic Border	-0.302***	-0.189**	-0.202**	-0.202**
	(0.093)	(0.085)	(0.083)	(0.082)
Technological Distance	-	-2.008***	-2.042***	-2.045***
	-	(0.366)	(0.362)	(0.363)
Vicinity of Citing	-	-	-0.209**	-0.215**
to Frontier of Cited	-	-	(0.085)	(0.087)
Technological Leaders	-	-	-	5.280***
	-	-	-	(0.368)
Technological Followers	-	-	-	-5.348***
	-	-	-	(0.352)
Cited Country FE	yes	yes	yes	yes
Citing Country FE	yes	yes	yes	yes
Observations	1444	1444	1444	1444
Log-Likelihood	-1375	-1351	-1348	-1348
Chi-Squared	8712.29	10039.17	9536.03	10298.28

3. Results: Diffusion of Knowledge – sensitivity analysis

Specification	5 Years	10 Years	15 Years	20 Years
Crossing Country Border	-1.209***	-1.340***	-1.337***	-1.309***
	(0.252)	(0.248)	(0.241)	(0.239)
1,000 Km Further	-0.016	-0.011	-0.009	-0.009
	(0.014)	(0.013)	(0.013)	(0.012)
Trade Border	-0.242*	-0.290**	-0.292**	-0.280**
	(0.133)	(0.130)	(0.124)	(0.122)
Linguistic Border	-0.229***	-0.202**	-0.186**	-0.168**
	(0.087)	(0.082)	(0.079)	(0.077)
Technological Distance	-2.128***	-2.045***	-2.101***	-2.113***
	(0.365)	(0.363)	(0.349)	(0.338)
Vicinity of Citing	-0.222**	-0.215**	-0.248***	-0.236***
to Frontier of Cited	(0.092)	(0.087)	(0.083)	(0.081)
Technological Leaders	4.977***	5.280***	5.242***	5.318***
	(0.383)	(0.368)	(0.353)	(0.347)
Technological Followes	-5.026***	-5.348***	-5.309***	-5.360***
	(0.366)	(0.352)	(0.341)	(0.336)
Cited Country FE	yes	yes	yes	yes
Cited Country FE	yes	yes	yes	yes
Observations	1444	1444	1444	1444
Log-Likelihood	-1163.13	-1348	-1407.45	-1429.11
Chi-Squared	9663.53	10298.28	12907.47	10958.67

3.

Comments on Results

- Results are robust to a series of modifications in the definition of the dependent variable
- Assumption that diffusion happens at same rate across time, though restrictive, is confirmed by sensitivity analysis
- Effect of linguistic border very close to previous estimates
- Result are comparable with previous studies if measure of technological distance is excluded from estimation
- Technological distance is very important variable in assessing knowledge flow: not considering it would overestimate the impact of geographical distance
- it does not only matter how close two countries are similar in technological space, but also how advanced as compared to average and to one another

3.

Estimated diffusion parameters

	US	JP	DE	FR	GB	CA	SE	CH	IT	NL	AT	AU	FI	BE	DK	NO	ES
US	1	0.152	0.157	0.144	0.187	0.267	0.136	0.086	0.117	0.159	0.058	0.132	0.132	0.071	0.137	0.116	0.103
JP	0.129	1	0.155	0.140	0.139	0.140	0.114	0.094	0.119	0.133	0.065	0.085	0.121	0.076	0.128	0.111	0.077
DE	0.096	0.121	1	0.191	0.191	0.113	0.172	0.093	0.169	0.140	0.121	0.091	0.182	0.118	0.135	0.162	0.111
FR	0.111	0.129	0.211	1	0.187	0.157	0.154	0.139	0.186	0.167	0.121	0.098	0.182	0.126	0.141	0.173	0.112
GB	0.144	0.133	0.221	0.203	1	0.164	0.194	0.105	0.181	0.171	0.101	0.120	0.193	0.107	0.152	0.174	0.121
CA	0.226	0.134	0.147	0.168	0.176	1	0.123	0.087	0.113	0.151	0.059	0.113	0.134	0.088	0.115	0.119	0.080
SE	0.129	0.132	0.206	0.197	0.198	0.132	1	0.103	0.132	0.211	0.071	0.075	0.231	0.067	0.154	0.141	0.100
CH	0.080	0.102	0.186	0.192	0.147	0.112	0.118	1	0.272	0.108	0.250	0.109	0.122	0.193	0.080	0.192	0.112
IT	0.082	0.098	0.152	0.164	0.138	0.096	0.095	0.191	1	0.115	0.180	0.109	0.123	0.146	0.085	0.177	0.132
NL	0.125	0.128	0.181	0.168	0.176	0.133	0.178	0.088	0.120	1	0.057	0.067	0.171	0.077	0.167	0.132	0.096
AT	0.045	0.061	0.114	0.103	0.086	0.055	0.069	0.236	0.184	0.061	1	0.083	0.076	0.172	0.045	0.157	0.082
AU	0.098	0.075	0.088	0.093	0.098	0.101	0.052	0.084	0.127	0.071	0.097	1	0.073	0.091	0.054	0.114	0.136
FI	0.111	0.115	0.180	0.166	0.178	0.122	0.217	0.109	0.124	0.173	0.067	0.070	1	0.090	0.123	0.173	0.079
BE	0.063	0.076	0.123	0.122	0.103	0.086	0.070	0.198	0.161	0.088	0.188	0.093	0.096	1	0.085	0.189	0.088
DK	0.124	0.130	0.175	0.150	0.169	0.137	0.176	0.082	0.107	0.185	0.057	0.063	0.182	0.092	1	0.148	0.080
NO	0.044	0.058	0.078	0.079	0.090	0.035	0.071	0.069	0.101	0.087	0.077	0.053	0.081	0.092	0.106	1	0.098
ES	0.086	0.072	0.110	0.101	0.109	0.081	0.099	0.106	0.131	0.099	0.083	0.138	0.087	0.082	0.073	0.104	1

4. Demand and Supply Determinants of Innovation

$$IA_t = h(Z_t^D, K_{t-1}^{own}, \sum_{j \neq i} \hat{\phi}_{ij} K_{j,t-1})$$

- Innovation is proxied by number of patents (weighted and unweighted by number of citations received)
- Explanatory variables:
  - Own Knowledge Stock
  - Foreign Knowledge Stock
  - Energy price (t-1)
  - GDP/GDPUSA
  - Policy targeting Energy Efficiency
  - Time, (country x technology) fixed effects

$$K_{i,s,t} = EPAT_{i,s,t} + (1-\delta) K_{i,s,t-1}$$

$$K_{i,s,t_o} = \frac{EPAT_{i,s,t_0}}{(\bar{g}_{i,s} + \delta)}$$

- Negative Binomial estimation (count data with overdispersion)

$$EPAT_{i,s,t} = \exp\left(\varphi + \gamma P_{i,t-1} + \theta K_{i,s,t-1} + \mu \sum_{i \neq j} \hat{\phi}_{ij} K_{j,s,t-1} + \sigma VA_{i,t-1} + \eta EEPol_{i,t-1} + \psi (Controls) \right)$$

4. Estimation Results

Specification	I	II	III	IV
Own Stock (T-1)	0.00378*** (0.0004)	0.00311*** (0.0003)	0.00320*** (0.0003)	0.00310*** (0.0003)
Foreign Stock (T-1)	- -	0.00887*** (0.0010)	0.00797*** (0.0011)	0.00890*** (0.0010)
Price (T-1)	0.00767*** (0.0023)	0.00613*** (0.0023)	0.00420* (0.0023)	0.00631*** (0.0023)
R&D (En Eff) (T-1)	- -	- -	0.00017*** -0.00005	- -
GDP/GDPUSA (T-1)	- -	- -	- -	0.06771*** (0.0261)
Policy Index (T-1)	- -	- -	- -	0.34752*** (0.0939)
Individual country-technology effects	yes	yes	yes	yes
Year dummies	yes	yes	yes	yes
Nr of Cases	3740	3740	3740	3740
Log-Likeliood	-4191	4150	-3885	-4140
Chi-Square	287505	312551	264552	308061

4. Estimation Results: Demand And Supply Technologies

Specification	V A	V B
Own Stock (T-1)	0.00321*** (0.0004)	0.00247*** (0.0004)
Foreign Stock (T-1)	0.01848*** (0.0021)	0.00084 (0.0014)
Price (T-1)	0.00907** (0.0040)	0.00795*** (0.0027)
R&D (En Eff) (T-1)	- -	- -
GDP/GDPUSA (T-1)	0.10730*** (0.0410)	0.00297 (0.0260)
Policy Index (T-1)	0.48056*** (0.1532)	0.32127*** (0.1036)
Individual country-technology effects	yes	yes
Year dummies	yes	yes
Nr of Cases	2040	1700
Log-Likeliood	-1983	-2067
Chi-Square	150761	154513

5. Wrapping Up

1. Analysis of the channels of diffusion in the case of energy efficient technologies

2. A diffusion parameter

3. Construction of internal and external knowledge stocks using patent data

4. Empirical analysis of demand-side determinants of innovation (proxied by energy prices, policy and value added of the economy) and supply-side determinants of innovation (proxied by available knowledge stocks)

5. Confirm results of previous analysis and extend them to provide evidence of knowledge spillovers

5. Further Developments

- Update data to 2006
- Increase the number of technologies considered
- Additional proxy for energy policy and environmental policy
- Relax the restricting assumption that diffusion happens at same rate over *t* [Jaffe & Trajtenberg 1996]

Thank you

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