



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

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Outline

- 1. Motivation**
- 2. Innovative Activity:**
 - ❖ *Framework for Analysis*
 - ❖ *Patents as Proxy for Innovation*
 - ❖ *Knowledge Flows vs Knowledge Spillovers*
- 3. Knowledge flows:**
 - ❖ *Geographic vs Technological Channels of Knowledge Diffusion (36 countries)*
- 4. Knowledge spillovers**
 - ❖ *Supply vs Demand Determinants of Innovation*
 - ❖ *Internal vs External Knowledge Stock (17 countries)*
- 5. Comments**

1.

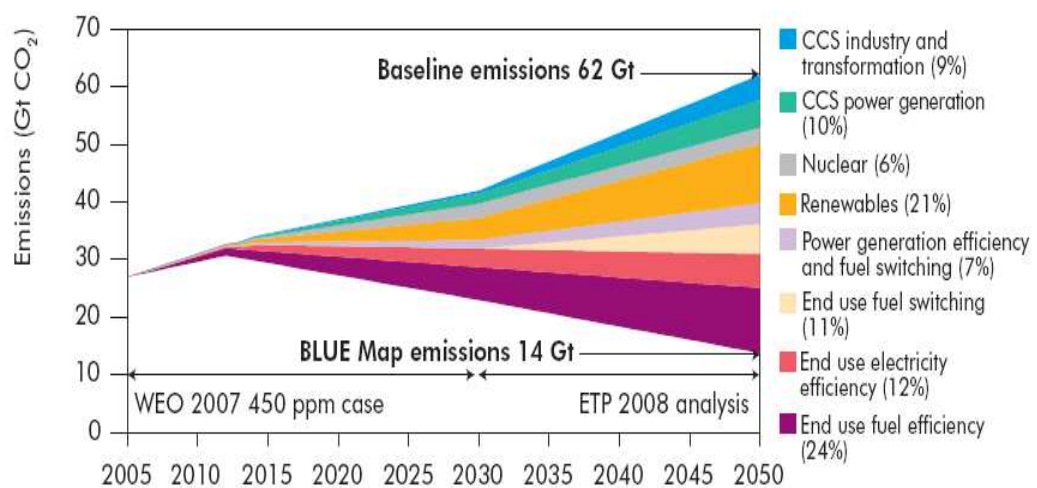
Technical Change, Energy and the Environment

- **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

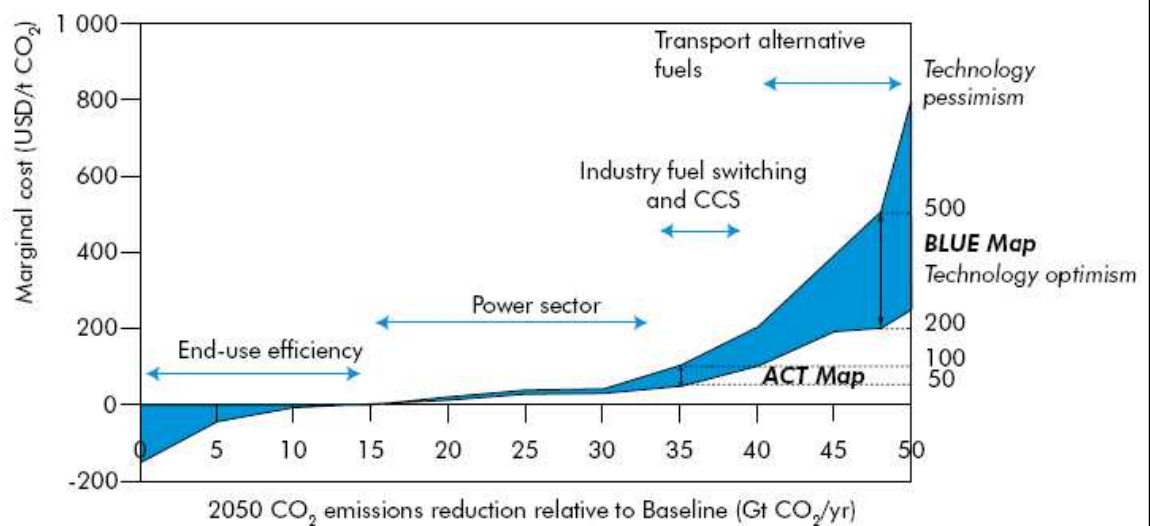
Figure 1: Technologies for reducing energy related CO₂ emissions



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.

The Starting Point: Popp [2003]

- ❖ **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 (1) there are important spillovers between countries and that (2) technology flows through different channels (trade, FDI) and 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?*
- ❖ *What is the role of knowledge spillovers in affecting innovative activity?*
- ❖ *What role of demand-side determinants of innovation other than energy price?*

2.

Patents: Proxies for Innovation and Diffusion

Patents are

- ❖ A set of exclusionary rights (territorial) 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 may vary across countries and technological fields

Knowledge diffusion and patents: Citations widely used as proxy for the “paper trail” for knowledge flows.

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

3.

Channels of Knowledge Diffusion

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

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

- Observable citations c_{ij} , proxy for unobservable diffusion parameter $\phi_{i,j}$
- Process of diffusion depends on a series of “resistance factors”, a set of bilateral characteristics of the sending and receiving countries

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

- ❖ 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

3.

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.

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 general, 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'études prospectives e d'informations internationales*): information on geographical distance
- Negative Binomial model due to count data nature of the dependent variable
- Sensitivity Analysis

3.

Descriptives

Country	Number of Patents	Percentage
United States	12,335	55.48%
Japan	3,669	16.50%
Germany	1,961	8.82%
France	866	3.90%
Canada	506	2.28%
Sweden	428	1.93%
United Kingdom	382	1.72%
Switzerland	370	1.66%
Italy	214	0.96%
Taiwan	185	0.83%
Israel	180	0.81%
Australia	171	0.77%
Austria	171	0.77%
Netherlands	170	0.76%
South Korea	130	0.58%
USSR/Russian Federation	81	0.36%
Finland	76	0.34%
Belgium	57	0.26%
Denmark	51	0.23%

Total Patents	22,274
Non-assigned/individuals	4,661
Assigned	17,613
Number of assignees	4,049
Assignee with:	
1 patent	60.59%
2 patents	14.25%
3-10 patents	18.02%
11-20 patents	3.14%
21-50 patents	2.64%
51-100 patents	0.86%
more than 100 patents	0.44%
Total Citations (10yrs)	38,025
Patents receiving:	
1 citation or none	43.07%
2-10 citations	44.50%
11-50 citations	12.27%
more than 50 citations	0.17%

3.

Results: Diffusion of Knowledge

Specification	I	II	III	IV
Crossing Country Border	-1.851*** (0.24)	-1.399*** (0.25)	-1.326*** (0.25)	-1.340*** (0.25)
1,000 Km Further	(0.02) (0.01)	(0.01) (0.01)	(0.01) (0.01)	(0.01) (0.01)
Crossing Trade Border	-0.272* (0.14)	-0.288** (0.13)	-0.289** (0.13)	-0.290** (0.13)
Crossing Linguistic Border	-0.302*** (0.09)	-0.189** (0.09)	-0.202** (0.08)	-0.202** (0.08)
Technological Distance	- -	-2.008*** (0.37)	-2.042*** (0.36)	-2.045*** (0.36)
Vicinity of Citing to Frontier of Cited	- -	- -	-0.209** (0.09)	-0.215** (0.09)
Both Technological Leaders	- -	- -	- -	5.280*** (0.37)
Both Technological Followers	- -	- -	- -	-5.348*** (0.35)
Cited Country Fixed Effects	yes	yes	yes	yes
Citing Country Fixed Effects	yes	yes	yes	yes
Observations	1444.00	1444.00	1444.00	1444.00
Log-Likelihood	-1374.75	-1351.02	-1348.16	-1348.00
Chi-squared	8712.29	10039.17	9536.03	10298.28

2.

Interpretation of Results

Citations within 10 yrs	drop to percentage of initial level	“what remains local”
Crossing Country Border <i>drops prob. of citation to of the initial level</i>	0.2618 $\exp(-1.340)$	0.7382 $1-\exp(-1.340)$
Crossing Linguistic Border	0.7483 $\exp(-0.202)$	0.2517 $1-\exp(-0.202)$
Crossing Trade Border	0.8171 $\exp(-0.290)$	0.2829 $1-\exp(-0.290)$
Technological Distance if index=1	0.1294 $\exp(-2.045)$	0.8706 $1-\exp(-2.045)$
Both Technological Leaders	196.3788 $\exp(5.032)$	-195.3788 $1-\exp(5.032)$
Both Technological Followers	0.0047 $\exp(-5.218)$	0.9953 $1-\exp(-5.218)$
Value if value = 1	0.8065 $\exp(-0.215)$	0.1935 $1-\exp(-0.215)$
Value if value = -1	1.2399 $\exp(-0.215*(-1))$	-0.2399 $1-\exp(-0.215*(-1))$

2.

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. Not considering technological distance would overestimate the impact of geographical distance.

Technological distance is very important variable in assessing knowledge flow: 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

2.

Estimated diffusion parameters

		Receiving country																
		US	JP	DE	FR	GB	CA	SE	CH	IT	NL	AT	AU	FI	BE	DK	NO	ES
S e n d i n g c o u n t r y	US	1	0.15	0.15	0.14	0.19	0.27	0.13	0.08	0.11	0.15	0.06	0.13	0.13	0.07	0.13	0.11	0.10
	JP	0.12	1	0.15	0.13	0.13	0.13	0.11	0.09	0.11	0.13	0.06	0.08	0.12	0.07	0.12	0.11	0.07
	DE	0.09	0.12	1	0.18	0.18	0.11	0.16	0.09	0.16	0.13	0.12	0.09	0.17	0.12	0.13	0.16	0.11
	FR	0.11	0.12	0.20	1	0.18	0.16	0.15	0.14	0.18	0.16	0.12	0.09	0.17	0.13	0.14	0.17	0.11
	GB	0.14	0.13	0.21	0.19	1	0.16	0.19	0.10	0.17	0.16	0.10	0.12	0.18	0.10	0.15	0.17	0.12
	CA	0.23	0.13	0.14	0.17	0.18	1	0.12	0.09	0.11	0.14	0.06	0.11	0.13	0.09	0.11	0.11	0.08
	SE	0.12	0.13	0.20	0.19	0.19	0.13	1	0.10	0.13	0.20	0.07	0.07	0.23	0.06	0.15	0.13	0.10
	CH	0.08	0.10	0.19	0.19	0.14	0.11	0.11	1	0.27	0.10	0.25	0.10	0.12	0.19	0.08	0.18	0.11
	IT	0.08	0.09	0.15	0.16	0.13	0.09	0.09	0.19	1	0.11	0.17	0.10	0.12	0.14	0.08	0.17	0.13
	NL	0.12	0.12	0.17	0.16	0.17	0.13	0.17	0.08	0.11	1	0.05	0.06	0.16	0.08	0.16	0.13	0.09
	AT	0.04	0.06	0.11	0.10	0.08	0.05	0.07	0.24	0.18	0.06	1	0.08	0.07	0.17	0.04	0.15	0.08
	AU	0.10	0.07	0.08	0.09	0.10	0.10	0.05	0.08	0.12	0.07	0.09	1	0.07	0.09	0.05	0.11	0.13
	FI	0.11	0.11	0.17	0.16	0.17	0.12	0.22	0.10	0.12	0.17	0.06	0.07	1	0.09	0.12	0.17	0.08
	BE	0.06	0.07	0.12	0.12	0.10	0.09	0.07	0.20	0.15	0.09	0.19	0.09	0.09	1	0.08	0.18	0.08
	DK	0.12	0.12	0.17	0.14	0.16	0.13	0.17	0.08	0.10	0.18	0.05	0.06	0.17	0.09	1	0.14	0.08
	NO	0.04	0.06	0.07	0.08	0.09	0.03	0.07	0.07	0.10	0.08	0.07	0.05	0.08	0.09	0.10	1	0.09
	ES	0.08	0.07	0.11	0.10	0.10	0.08	0.09	0.10	0.13	0.10	0.08	0.13	0.08	0.08	0.07	0.10	1

4.

Demand and Supply Determinants of Innovation

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

- *Useful* innovation is proxied by number of patents weighted by number of citations received
- Explanatory variables:
 - Own Knowledge Stock
 - Foreign Knowledge Stock
 - Energy price (t-1)
 - GDP/GDPUSA
 - Energy Efficient Policy
 - Time, country and technology fixed effects
- Negative Binomial estimation (count data with overdispersion)

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

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

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

4. Estimation Results

	I	II	III	IV	V	VI
Own Knowledge Stock	0.00063*** (0.0002)	0.00112*** (0.0002)	0.00107*** (0.0002)	0.00114*** (0.0002)	0.00111*** (0.0002)	0.00116*** (0.0002)
Foreign Knowledge Stock	- -	0.00705*** (0.0010)	0.00700*** (0.0010)	- -	0.00708*** (0.0010)	0.00707*** (0.0010)
Foreign Knowledge Stock -- Top 5	- -	- -	- -	0.00711*** (0.00)	0.01054** (0.00)	0.01055** (0.00)
Price (t-1)	0.00979** (0.0041)	0.01020** (0.0041)	0.00878** (0.0042)	0.00868** (0.0042)	- -	- -
Public R&D (t-1)	- -	- -	0.00010** (0.0001)	0.00010** (0.0001)	- -	- -
GDP/GDPUSA	- -	- -	- -	- -	0.08484* (0.0457)	0.09607** (0.0457)
Policy	- -	- -	- -	- -	- -	0.23389* (0.1347)
Country FE	yes	yes	yes	yes	yes	yes
Technology FE	yes	yes	yes	yes	yes	yes
Year FE	yes	yes	yes	yes	yes	yes
Nr of Cases	3740	3740	3740	3740	3740	3723
Log-Likelihood	-6300	-6300	-6300	-6300	-6300	-6200
Chi-Square	4951.15	5279.22	5482.15	5477.97	5338.57	5294.53

4.

Estimation Results: Demand And Supply Technologies

	I - S	II - S	I - D	II - D
Own Knowledge Stock	0.00378** (0.0017)	0.00415** (0.0019)	0.00154*** (0.0002)	0.00153*** (0.0002)
Foreign Knowledge Stock	0.01529*** (0.00)	0.01488*** (0.00)	0.00910*** (0.00)	0.00908*** (0.00)
Price (t-1)	0.01 (0.0068)	0.01159* (0.0068)	0.01379*** (0.0050)	0.01359*** (0.0049)
GDP/GDPUSA	0.04 (0.0802)	0.06 (0.0792)	0.00802*** (0.0026)	0.00816*** (0.0026)
Policy		0.43687* (0.2292)		0.33698* (0.1902)
Country FE	yes	yes	yes	yes
Technology FE	yes	yes	yes	yes
Year FE	yes	yes	yes	yes
Nr of Cases	2040.00	2032.00	1700.00	1691.00
Log-Likelihood	-3200	-3200	-3400	-3300
Chi-Square	1941.53	1956.28	3016.29	3106.28

5.

Wrapping Up

1. Analysis of the channels of diffusion in the case of energy efficient technologies
2. Construction of internal and external knowledge stocks using patent data
3. Empirical analysis of demand-side determinants of innovation (proxied by energy prices) and supply-side determinants of innovation (proxied by available knowledge stocks), in particular pointing to the distinction between internal and external knowledge stocks and the estimation of a measure 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]
- Use of econometric results for more accurate calibration of climate-economy models (e.g. FEEM's WITCH)

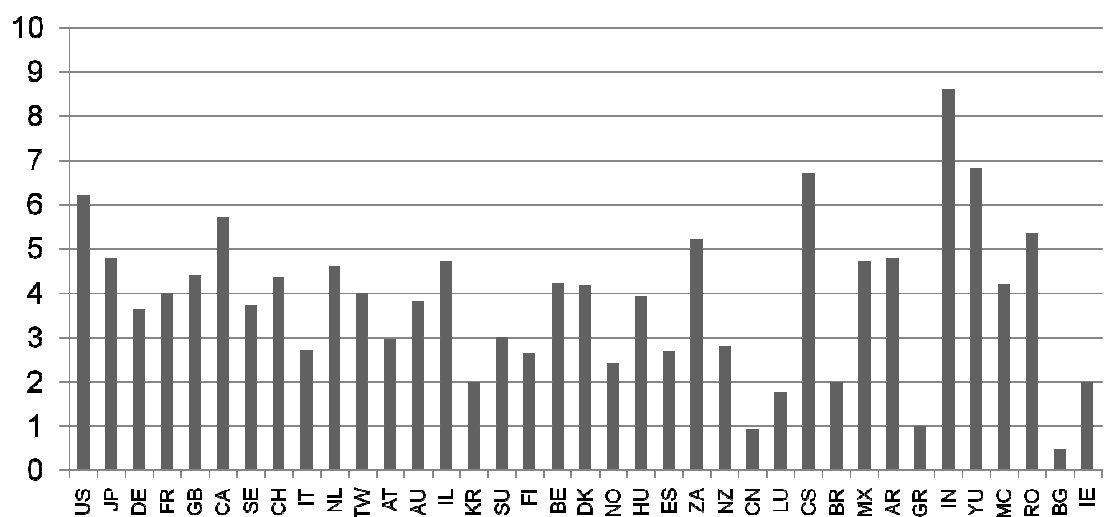
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