The role of intra-field and inter-field knowledge spillovers in the diffusion of renewable energy technologies

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1. Introduction

Motivations

- Decarbonization is a key objective, especially in the EU, and implies restructuring industries through low-carbon technologies and improving efficiency (Tian et al., 2022; Montresor and Vezzani, 2023). Knowledge diffusion is essential (Abbas et al., 2022; Probst et al., 2021).

- Technologies are developed by recombining existing components (Usher, 1954; Weitzman, 1998; Belenzon, 2012; Keijl et al., 2016).
  - Some knowledge produced within a specific technological field remains confined to that field (Dosi, 1982)
  - Some knowledge flows across technological fields, contributing to technological variety (Van den Bergh, 2008).

- However, there is very limited research on the characteristics of knowledge that explain the likelihood of knowledge staying within its own technological field or diffusing to other fields.

1. Introduction

Objective

- To explore how the technological proximity of knowledge spillovers incorporated in renewable patents affect their subsequent diffusion across technological fields.

Our contribution

- We consider the acquisition of knowledge in both renewable and non-renewable energy, while also addressing potential knowledge crossover between different technological fields.
- We analyze not only the general effects of knowledge spillovers on diffusion but also the direction of these spillovers toward renewable and non-renewable energy.
- We account for several factors that capture the specific characteristics of patents, which may influence the magnitude and direction of knowledge diffusion.

2. Literature review
2.1. Knowledge recombination

- Knowledge recombination is essential for developing new technologies by combining insights from different fields (Usher, 1954; Arthur, 2009; Gallouj and Weinstein, 1997).

- Combining technologies can lead to cutting-edge inventions (Gilfillan, 1935; Nelson and Winter, 1982; Arthur, 2009).

- Specialized knowledge is also critical for driving innovation progress:
    1) by continuing to focus on an already created and known trajectory (Dosi, 1982; Lettl et al., 2009).
    2) by enabling inventors to better apply related information, which boosts the impact and diffusion of technologies (Cohen and Levinthal, 1990).

- Some technologies benefit from cross-field knowledge, others achieve better results through specialization. It is needed to understand sector-specific dynamics.

2. Literature review.
2.2. The effect of spillovers on knowledge diffusion

- Renewable energy inventions often draw from unrelated areas and interdisciplinarity (Noailly and Shestalova, 2017).

- Knowledge diffusion varies depending on its direction—whether it remains within the same technology field, to a related field, or moves to a different domain (Trajtenberg et al., 1997; Stephan et al., 2019).

- Energy technologies diffuse to a wider variety of technological fields than non-energy patents (Dechezleprêtre et al., 2013).

- Specialized knowledge tends to remain within its own field, whereas diversified prior knowledge might diffuse across different fields (Battke et al., 2016 for battery patents).

- Knowledge spillovers enhances subsequent technological impact (Nemet and Johnson, 2012). The effect of citations to technological close knowledge is larger than that of technological distant knowledge.

3. Data

- **Source**: EPO Worldwide Patent Statistical Database (PATSTAT 2017, Autumn Edition).
- Patent families with at least one application to the EPO.
- **Dataset:**

1) Identification of energy patents based on International Patent Classification (IPC) codes (Noailly and Shestalova, 2017; Haščič et al., 2009, Ardito et al., 2014). 12,966 renewable energy patents applied from 1990-2010.

2) Retrieval of citations of patents obtained in Step 1.

 -Backward citations (or cited patents) to measure knowledge spillovers. Excluding examiner citations.

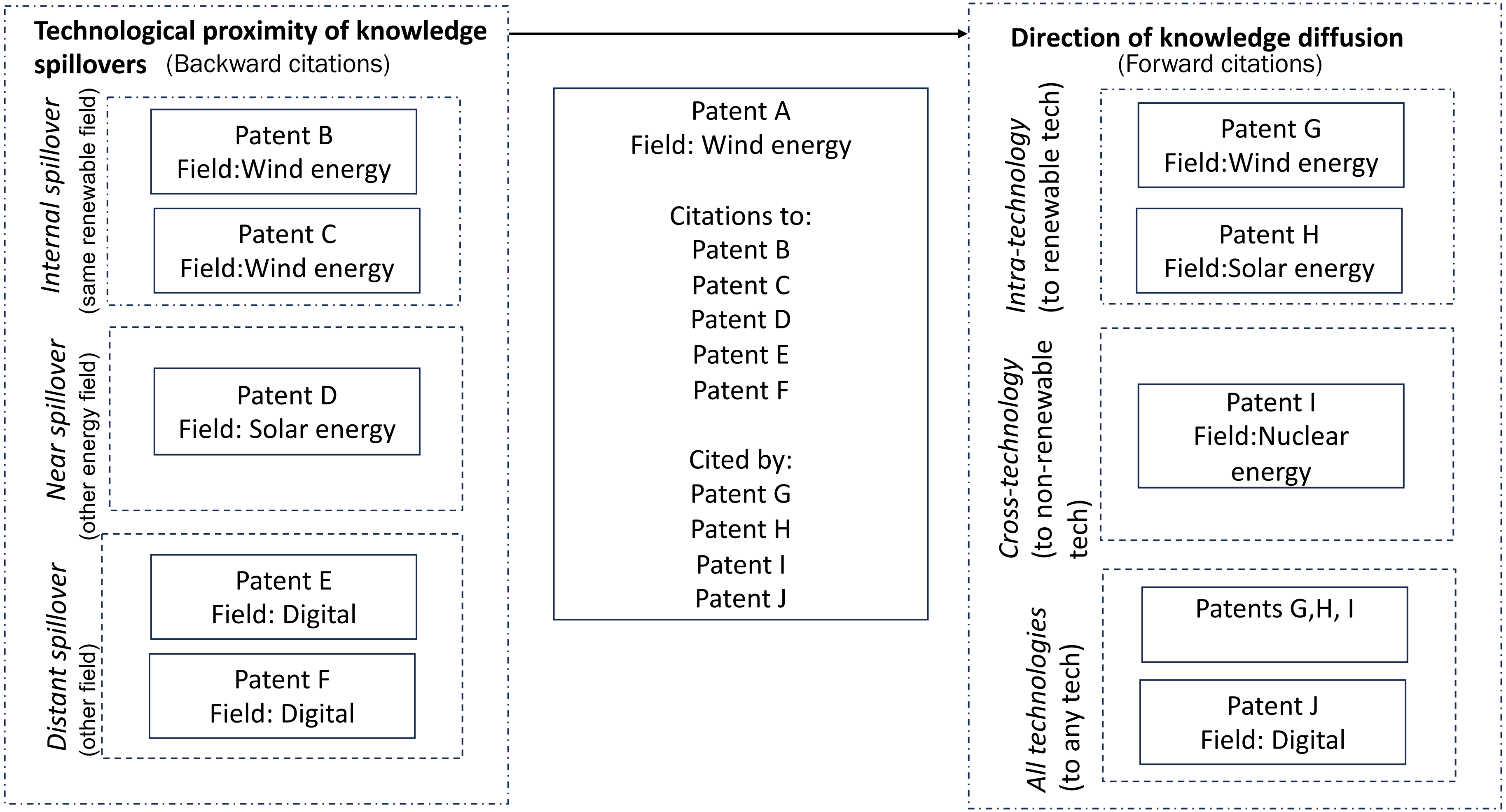
 -Forward citations (or citing patents) to measure knowledge diffusion. Excluding examiner and self-citations.

3) Link cited and citing patents obtained in Step 2 to their IPC codes.

4. Variables and Model

Variable	Definition		
Dependent variables: Variables capturing knowledge diffusion direction of renewable energy technologies			
Intra-technology	Number of forward citations from renewable energy technologies in a 5-year window		
Cross-technology	Number of forward citations from non-renewable energy technologies in a 5-year window		
All technologies	Number of all forward citations in a 5-year window		
Explanatory variables: Variables capturing technological proximity of knowledge spillovers in renewable energy technologies			
Internal	*Number* of backward citations to the same energy field	C_Intra	% of backward citations to the same energy field
Near	*Number* of backward citations to another energy field	C_Near	% of backward citations to another energy field
Distant	*Number* of backward citations to a non-energy field	C_Distant	% of backward citations to a non-energy field
Control variables			
Claims	Number of claims		
Inventors	Number of inventors		
USJP	Dummy variable, where 1 indicates protection in the US and/or JP, 0 otherwise		
NPL	Number of non-patent literature citations		
Size	Number of different jurisdictions in which the patent has been applied		
Scope	Number of different IPC4 codes		
Year dummies	1990-2010.		
Field dummies	Wind, Solar, Geothermal, Marine, Hydro, Biomass, Waste and Storage.		

Figure 1. Effect of technological proximity of knowledge spillovers on the direction of knowledge diffusion. Empirical framework.



4. Variables and Model

Empirical model

$$fpc5_i = \exp\left(\beta_0 + \beta_1 internal_i + \beta_2 near_i + \beta_3 external_i + \beta_4 claims_i + \beta_5 inventor_i + \beta_6 \mathrm{USJP}_i + \beta_7\, npl_i + \beta_8 fsize_i + \beta_9 scope_i + \sum_{k=1}^{K} \lambda_k\, sector_{ik} + \sum_{t=1}^{T} \varphi_t\, year_{it} + \varepsilon_i\right)$$

where the dependent variable *fpc5* is the indicator of diffusion (forward patent citation count) and '*i*' is our unit of analysis (patent family).

We estimate several regression models by using the intra-technology, cross-technology and all-technology fpc5 as dependent variables.

Estimation: Poisson pseudo maximum likelihood (PPML) (Wooldridge, 2010; Santos Silva and Tenreyro, 2011) .

-Robust standard errors.

5. Results

	1	2	3		4	5	6
	Intra-technology (renewable) fpc5	**Cross-technology (non-renewable) fpc5**	**All-technology fpc5**		**Intra-technology (renewable) fpc5**	**Cross-technology (non-renewable) fpc5**	**All-technology fpc5**
internal	0.022***	0.022***	0.013***	C_internal	0.006***	0.007***	0.004***
near	0.03	0.178***	0.037**	C_near	0.009**	0.028***	0.009***
distant	-0.002	-0.025**	0.006***	C_distant	-0.001*	-0.005**	0.002***
claims	0.010***	0.016***	0.011***	claims	0.010***	0.017***	0.011***
inventors	0.039***	0.044	0.052***	inventors	0.046***	0.073**	0.055***
usjp	0.025	0.021	0.079	usjp	0.051	0.075	0.085*
npl	0.0[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
size	0.0[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
scope	0.0[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
cons	-1.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Time dummies	YE[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Field dummies	YE[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Obs.	12[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
R^2_Adj.	0.2[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Log likelihood	-2[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wald chi^2	27[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

* p < 0.10; ** p [illegible]

- Incorporating internal knowledge—defined as knowledge within the same energy field—facilitates diffusion of both general and energy technologies.

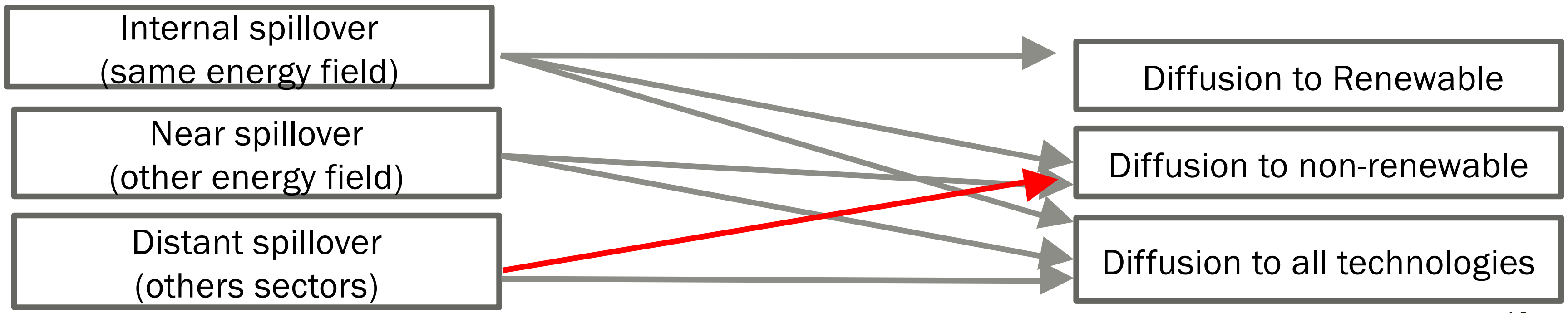
- Incorporating *near* knowledge —defined as knowledge from other energy field—, is crucial for:
  - Diffusion to non-renewable energy technologies (cross-tech)
  - General diffusion to all technologies

- Drawing from distant technological knowledge—defined as knowledge from non-energy fields—positively affects general technology diffusion but not specific diffusion to energy technologies

6. Conclusions

- Incorporating *internal* knowledge —defined as knowledge within the same energy field— facilitates diffusion (both to general and energy technologies).

- Incorporating *near* knowledge —defined as knowledge from other energy field—, is crucial for:
  - Diffusion to non-renewable energy technologies (cross-tech)
  - General diffusion to all technologies
- Drawing from *distant* technological knowledge- —defined as knowledge from non energy fields— positively affects general technology difussion, but not specific difussion to energy technologies.



Policy Implications

- Promoting innovation and spillovers of renewable energy technologies is key for fostering knowledge difussion

- Facilitating innovation and knowledge spillovers between renewable energy and non-renewable energy technologies.
  - *This could motivate greener non-renewable energy technologies and avoid lock-in processes.*

- Keep fostering innovation and knowledge spillovers from non-energy technologies if the objective is promoting general innovation.
  - But this is not crucial for enhancing energy technologies.

Limitations and Extensions

- The study is limited to knowledge flows and difussion of renewable technologies.
- Explore the influence of institutional skills and other contextual variables as mediator variables in the process of technological proximity-direction of difussion.

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