Breakthrough eco-inventions. The impact of knowledge recombination and the moderating role of collaboration

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1. Introduction

Motivations

- The accelerating pace of environmental degradation and the risk of reaching ecological tipping points demand radical technological solutions. In this context, understanding the drivers behind breakthrough inventions becomes increasingly important.

- One factor that remains insufficiently understood is the role of interdisciplinary knowledge in fostering such innovations. While cross-disciplinary knowledge has been widely studied in the field of innovation management and knowledge flows (see, for example, Mowery & Rosenberg, 1999; Arthur, 2007; Nemet, 2012), its specific contribution to the development of breakthrough inventions is still unclear.

- Moreover, the geographical diversity of inventors and the involvement of multiple institutions in the production of a patented invention may also play a significant role in driving these transformative advances.

1. Introduction

Objective

- This study seeks to explore how these dimensions—knowledge interdisciplinarity, inventor geography, and institutional collaboration—affect the likelihood of producing breakthrough inventions.

Our Contribution

- We contribute to the existing literature by analyzing how recombination from different technological origins impacts the generation of breakthrough environmental innovations

- It further explores the effects of inter-institutional and international collaboration on the generation of breakthrough innovations.

1. Introduction

Policy Implications:

The findings offer practical insights for policymakers and stakeholders aiming to promote innovation. Specifically, the results can inform the design of policy tools foster breakthrough inventions

2. Literature review and hypotheses

- Early researchers suggested that disruptive innovation always relied on new knowledge (Poel, 2003; Schoenmakers and Duysters, 2010).

- Capponi et al. (2022) observed that disruptive innovation originates in two stages: search and selection, depending on knowledge recombination.

2. Literature review and hypotheses

- Innovation is not created by a single knowledge component, but by combining a number of components (Xiao et al, 2001). The generation of *breakthrough inventions* requires creative invention, which in turn involves the recombination and selection of knowledge (Fleming, 2001).

- To enhance its capacity for innovation, a firm must engage with *knowledge from external sources* (Xiao et al., 2021).

- Recombination of knowledge plays a vital role in the creation of breakthrough inventions (Phene et al, 2006; Srivastava and Gnyawali, 2011; Nemet and Johnson, 2012) .

A central concept in understanding breakthrough innovation is knowledge recombination (Xiao et al., 2022)

2. Literature review and hypotheses

Knowledge recombination and breakthrough innovation

- Recombining firm developed technology is measured as the number of backward citations made to patents granted to firms (Jung, 2020).

- Knowledge recombination breaks down barriers between technological domains and, outstanding inventions belonging to different technological domains are created (Duysters and Hagedoorn, 1998; Hacklin et al., 2009).

Hypothesis 1: Knowledge recombination, as measured by backward citations, influences the development of disruptive innovations.

2. Literature review and hypotheses

Collaboration and breakthrough innovation

The potential for the creation of inventions that represent a breakthrough depends on two factors (Jiang, 2024).

- Collaboration between individuals and/or organisations is required.
- The consideration of the local knowledge base: intra-regional collaboration has been shown to foster the creation of breakthrough inventions

Hypothesis 2: Collaboration between institutions, influences the development of disruptive innovations.

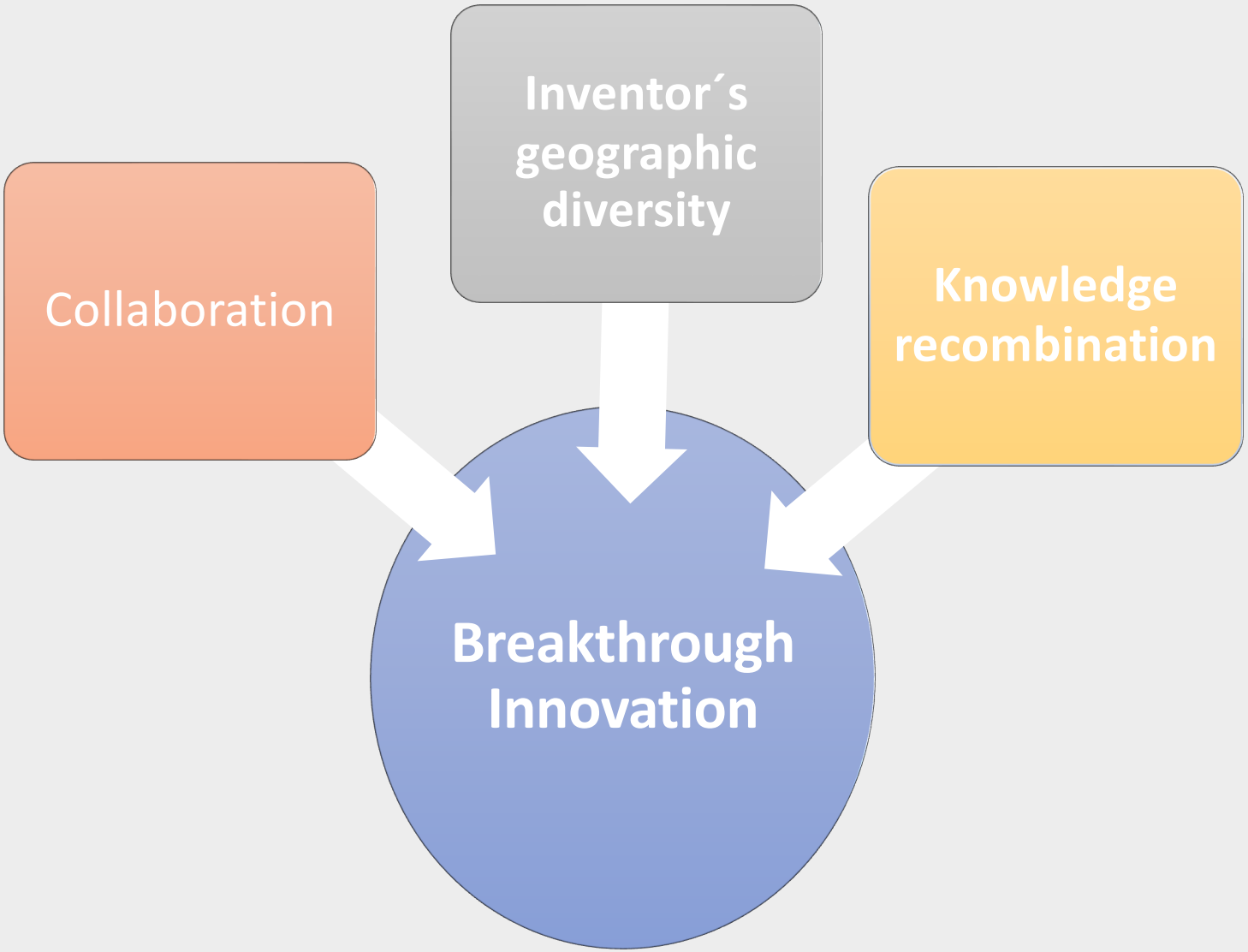
2. Literature review and hypotheses

Geographic diversity and breakthrough innovation

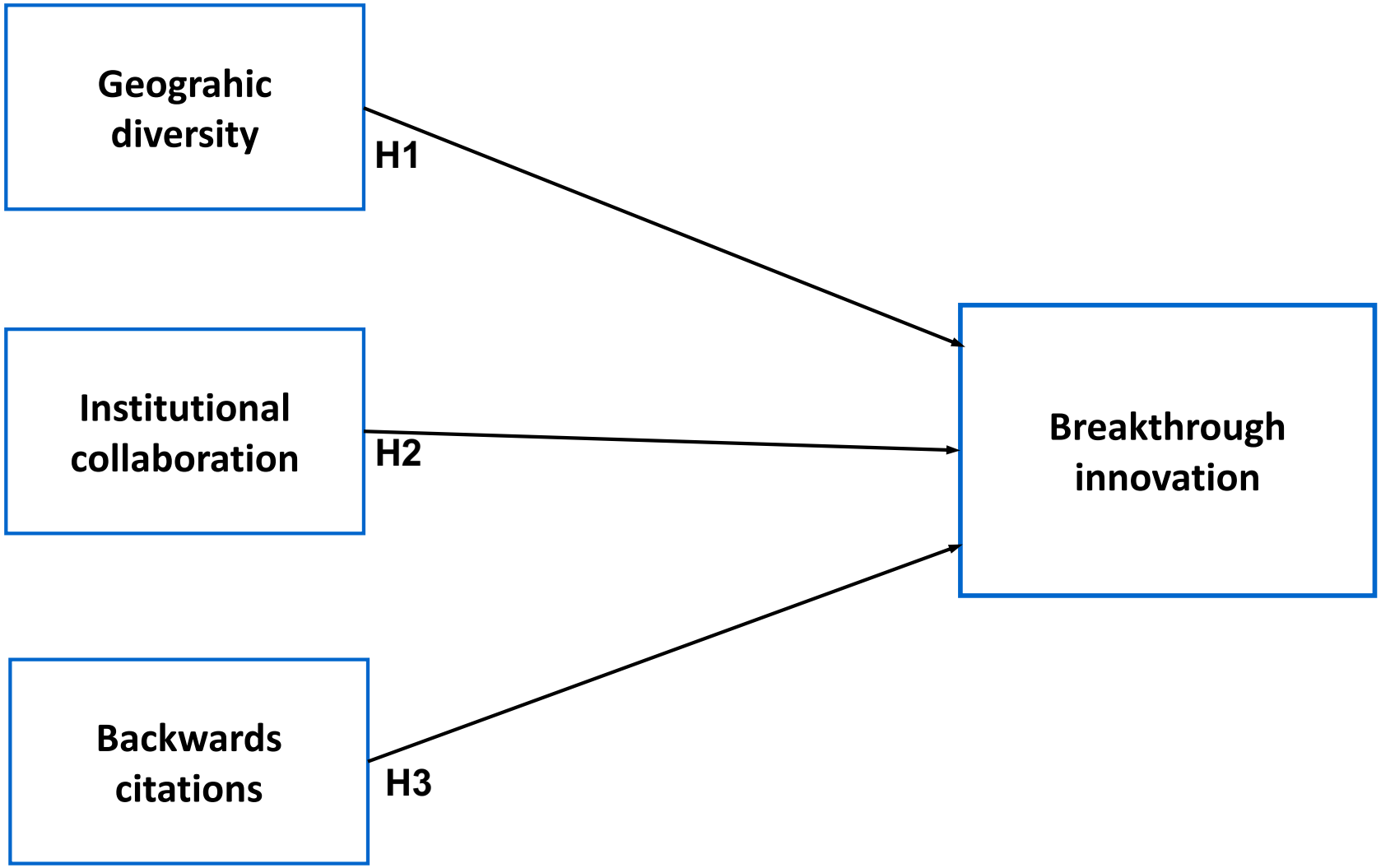
- Several authors found a positive relationship between geographical diversity and breakthrough innovations. (see, por example Kang, B., & Nabeshima, K., 2021; Seo et al., 2020; Zhang, E., et al., 2022).

- Having collaborative arrangements in different countries allows firms to be exposed to different national knowledge bases. This exposure, helps develop skills and competencies, increases the likelihood of discovering valuable new combinations, and contributes to higher levels of innovation success (Zahra et al., 2000).

Hypothesis 3: Geographic diversity influences the creation of disruptive inventions


Collaboration
Inventor´s geographic diversity
Knowledge recombination
Breakthrough Innovation

Hypotheses


Geograhic diversity
H1
Institutional collaboration
H2
Backwards citations
H3
Breakthrough innovation

3. Data

Source: The patent information was obtained from the EPO Worldwide Patent Statistical Database (PATSTAT).

Dataset:

- Our unit of measurement is the patent family with more than one inventor. We identified the patent families using the International Patent Classification (IPC)

- The final sample contains more than 185.000 patents between the years 1991-2020.

4. Variables and model

4.1 Variables

- **Dependent variable**

A patent's importance in terms of its findings is directly related to the frequency with which it is cited in subsequent patents (Trajtenberg, 1990; Harhoff et al., 1999; Fleming, 2001; Zucker et al., 2002; Fleming et al., 2007; Kelley et al., 2013).

Following Singh & Fleming, (2010), we use normalized forward citations to construct high-impact breakthrough as a dummy variable indicating that the patent belongs to the top 1% of citation distribution (top2% for robustness analysis

- Top1
- Top2 (used for robustness analisys).

Main independent variables

- Geographic diversity (*Blau-Index*)
- Collaboration: dummies variables (*compcomp, uniuni, compuni, compgov, unigov, compunigov*)
- Environmental backwards citations (*bsa-env*)
- Non-environmental backwards citations (*bsa-ext*)

Other independent variables

- Citations to non-patent literature (*npl*).
- Scope of the patent (*scope*).
- Originallity index (*ori*, used for robustness analisys).
- Institutional diversity index (*blauinst*, used for robustness análisis)

Control variables

- Year and sector dummies.

4. Variables and models

4.2 Models

- Main model→Logit Model

$$top1_i = G\left(\beta_0 + \beta_1 bsa\_env_i + \beta_2 bsa\_ext_i + \beta_3 compcomp_i + \beta_4 uniuni_i + \beta_5 compuni_i + \beta_6 compgov_i + \beta_7 unigov_i + \beta_8 compunigov + \beta_9 npl_i + \beta_{10} blaugeo_i + \beta_{11} scope_i. + \sum_{k=1}^{K} \lambda_j \, sector_k + \sum_{t=1}^{T} \varphi_j \, year_t + \varepsilon\right)$$

- Robustness analysis:

Ordinary Least Squares (OLS) no sale una de las regresiones Probit se puede usar regression lineal???,

5. Results

	top1				top2			
	m1	m2	m3	m4	m5	m6	m7	m8
	Coef./Std. err.	Coef./Std. err.	Coef./Std. err.	Coef./Std. err.	Coef./Std. err.	Coef./Std. err.	Coef./Std. err.	Coef./Std. err.
_cons	0.0015***	-0.0044***	-0.0170***	-0.0466***	0.0026***	-0.0073***	-0.0310***	-0.0685***
	(0.0004)	(0.0006)	(0.0016)	(0.0095)	(0.0006)	(0.0014)	(0.0024)	(0.0132)
bsa_env		0.0003***				0.0007***		
		(0.0001)				(0.0001)		
bsa_ext		0.0003***				0.0003***		
		(0.0000)				(0.0000)		
ori			0.0105***	0.0173***			0.0264***	0.0363***
			(0.0011)	(0.0046)			(0.0016)	(0.0067)
blau_inst				-0.0401***				-0.0589***
				(0.0047)				(0.0064)
compcomp		0.0098***	0.0122***			0.0171***	0.0193***	
		(0.0012)	(0.0014)			(0.0017)	(0.0019)	
uniuni		-0.0039	-0.0095			-0.0147**	-0.0242***	
		(0.0046)	(0.0060)			(0.0059)	(0.0072)	
compuni		-0.0074***	-0.0105***			-0.0047	-0.0071	
		(0.0023)	(0.0029)			(0.0038)	(0.0044)	
compgov		-0.0074***	-0.0105***			-0.0150***	-0.0192***	
		(0.0021)	(0.0030)			(0.0032)	(0.0041)	
unigov		-0.0080***	-0.0113***			-0.0190***	-0.0237***	
		(0.0026)	(0.0036)			(0.0032)	(0.0042)	
compunigov		-0.0078	-0.0153**			-0.0242***	-0.0350***	
		(0.0063)	(0.0071)			(0.0068)	(0.0074)	
npl		0.0013***	0.0017***	0.0014***		0.0019***	0.0024***	0.0018***
		(0.0001)	(0.0001)	(0.0001)		(0.0001)	(0.0001)	(0.0001)
blaugeo		0.0054***	0.0038	0.0345***		0.0057**	0.0035	0.0344***
		(0.0019)	(0.0025)	(0.0081)		(0.0027)	(0.0033)	(0.0097)
scope		0.0009***	0.0011***	0.0021***		0.0016***	0.0017***	0.0029***
		(0.0001)	(0.0001)	(0.0003)		(0.0001)	(0.0001)	(0.0003)
YEAR DUMMIES	YES	YES	YES	YES	YES	YES	YES	YES
SECTOR DUMMIES	YES	YES	YES	YES	YES	YES	YES	YES
Observations	370269	253523	185062	20457	370269	224355	185062	20457
R	0.01	0.07	0.06	0.10	0.01	0.07	0.07	0.11
Log likelihood	330537.57	205448.47	126809.71	7442.38	204769.39	94773.05	67480.26	2117.93

5. Results

	bsa_env	bsa_ext	compcom	uniuni	compuni	compgov	unigov	compun~v	npl	blauge~l	scope
bsa_env	1										
bsa_ext	0.2960	1									
compcomp	0.0362	0.0394	1								
uniuni	-0.0012	0.0121	-0.0076	1							
compuni	0.0023	0.0027	0.0052	0.0952	1						
compgov	-0.0053	-0.0034	0.0122	-0.0058	-0.0078	1					
unigov	-0.0097	-0.0028	-0.0187	0.1927	-0.0064	-0.0051	1				
compunigov	-0.004	-0.0003	0.012	0.087	-0.0033	-0.0027	-0.0022	1			
npl	0.2911	0.3464	0.0912	0.0994	0.0418	0.0078	0.0299	0.0138	1		
blaugeoefl	0.0043	0.0052	0.0696	0.0416	0.0303	0.0309	0.0289	0.0181	0.0453	1	
scope	0.1027	0.0992	0.0496	0.0198	0.0174	-0.0011	0.0039	0.0100	0.1508	0.0175	1

Multicollinearity is not an issue since the correlations among the explanatory variables are small

5. Results

Variable	VIF
bsa_env	1.19
bsa_ext	1.20
compcomp	1.02
uniuni	1.07
compuni	1.02
compgov	1.00
unigov	1.04
compunigov	1.01
npl	1.32
blaugeoefl	1.02
scope	1.16
MEAN VIF	1.10

5. Results

Table 6. Hypotheses acceptance/rejection

Hypothesis 1: Knowledge recombination, as measured by backward citations, influences the development of disruptive innovations.	✓
Hypothesis 2: Collaboration between institutions, influences the development of disruptive innovations.	✓
Hypothesis 3: Geographic diversity influences the creation of disruptive inventions	✓

5. Conclusions

- Geographic diversity affects positively on breaktrough invention. Team diversity improves performance due to the unique combination of knowledge and novel resources that geographic diversity provides to a firm's innovation system as pointed out, for example, by (Phene et al., 2006). A diversity of national origins broadens the scope of the knowledge base that is accessible and provides access to network resources that can stimulate innovation (Gulati, 1999).

- Although inter-firm collaboration has been positively linked to disruptive innovation, consistent with the works of (Bouncken et al., 2018; Ritala et al., 2018; Haus-Reve et al., 2019), other forms of institutional collaboration appear to be negatively correlated with it. Consequently, the overall impact of cross-institutional interaction on disruptive innovation is unclear.

- Knowledge recombination is a key factor in the development of disruptive innovations. Our study yields the same findings as previous studies (Jung et al., 2016; Moaniba et al., 2018; Jung, 2020)

- Scientific knowledge positively affects disruptive innovation (Ahmadpoor and Jones, 2017; Wu et al., 2024, Lian et al., 2025)

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