Collaborating Beyond Borders: The Role of Social Ties in International Eco-Innovation Partnerships

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Abstract

We examine the impact of international social ties on international eco-innovation partnerships. Promoting eco-innovation partnerships or collaboration is crucial for environmental sustainability, which has been a global, pressing concern in the last decade due to the detrimental effects of global warming, climate change, and greenhouse gas emissions. This type of collaboration can be facilitated and enhanced by international knowledge spillovers through interpersonal networks. While previous studies explore the role of inter-organizational collaborative networks on different innovation outcomes at a regional level, there is a research gap regarding the impact of social ties across countries on international collaboration, especially within the context of eco-innovation partnerships. Our findings suggest that more socially connected countries are more likely to partner in eco-innovation activities. Our study advances our understanding of the role of social ties in facilitating collaborative eco-innovation efforts and expands the knowledge on cross-regional interpersonal networks and their implications for socio-economic outcomes.

Keywords: social connectedness, international social ties, eco-innovation, international patent collaboration, gravity model

1. Introduction

Cross-regional (international) interpersonal social ties are important for eco-innovation as they stimulate and encourage the transfer and sharing of knowledge and technology, as well as allow the engagement of countries and regions to reach sustainable growth (Corrocher & Mancusi, 2021). Based on the OECD[1] definition of innovation, eco-innovation refers to "*the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organisation [sic] (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives*" (Kemp & Pearson, 2007). By this definition, eco-innovation is similar to other innovations in that it produces and implements new (or enhanced) products or processes in a business context or practice. However, eco-innovation is distinct from other domains of innovation for many reasons. By the same definition of eco-innovation, an innovation would only be considered an eco-innovation if it has a positive environmental effect or impact. In other words, eco-innovation decreases environmental impact and uses resources efficiently (Kemp & Pearson, 2007). Moreover, eco-innovation is fostered and induced by environmental regulations and policies. Therefore, local and international legislations and standards can stimulate and encourage eco-innovation (Lee et al., 2011). Additionally, the domain of eco-innovation requires external knowledge and information from diverse and heterogeneous sources (Ghisetti et al., 2015). Hence, it is particularly important to examine the effect of international social ties on eco-innovation.

International social ties are a crucial factor in promoting eco-innovation and encouraging the growth and diffusion of environment-related technologies (Corrocher & Mancusi, 2021). International collaborations can be facilitated and enhanced by international knowledge spillovers through interpersonal networks (Montobbio et al., 2009; Singh, 2005). Previously, inter-organizational collaborative networks formed by organizational relations between firms, universities, or research institutes have been recognized as crucial channels for knowledge flow (Ter Wal & Boschma, 2009; Xu et al., 2019; Yeung, 2005). However, interpersonal networks, in contrast to formal inter-organizational relations, have gained attention for

[1] See https://www.oecd.org/about/ (Last accessed: June 6, 2023)

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their importance in knowledge sourcing and innovation (Dahl & Pedersen, 2004; Huber, 2013; Xu et al., 2019). Similar to inter-organizational networks, interpersonal networks can foster trust, facilitate communication, and promote a culture of collaboration. This is essential for driving progress in the development of innovation activities. Therefore, interpersonal social ties have the potential to be instrumental in international collaborations in developing and growing environmental-related technologies. Interpersonal networks can enable individuals and organizations across geographic boundaries to work together toward improving environmental sustainability and addressing climate change.

While previous studies explore the role of inter-organizational collaborative networks on different innovation outcomes at a regional level (Aragón Amonarriz et al., 2019; De Noni et al., 2018; Fleming et al., 2007; González-López et al., 2019; Henton et al., 2002; Kallio et al., 2010; Laursen et al., 2012; Nieto & Santamaría, 2007), there is a research gap regarding the impact of social ties across countries on international collaboration, especially within the context of eco-innovation partnerships. This research gap is particularly important to address global environmental challenges such as climate change because international social ties can facilitate knowledge exchange across geographical boundaries and time zones and provide access to diverse perspectives from different cultural backgrounds, thereby enhancing the impact of eco-innovation partnerships on a global scale. In this paper, we aim to fill this important research gap and ask: *What is the effect of social ties across countries on international eco-innovation partnerships?*

While the mechanism itself is intuitive, the lack of comprehensive data on social connections at an aggregate country level has made it nearly impossible for researchers to study interpersonal networks across countries. Until now, it has been difficult to measure social ties across different geographic regions. However, Bailey et al. (2018) addressed this issue by de-identifying data from Facebook to construct a measure of pairwise Social Connectedness Index (SCI) between regions, including countries. This new measure has been used in several studies that have found strong correlations between social connectedness across regions and various socio-economic outcomes, such as patent citations and international trade (Bailey et al., 2021; Diemer & Regan, 2022; Dornseifer & Rehbein, 2022; Rehbein & Rother, 2019; Wilson, 2022).

In this study, we use Facebook's aggregated data to explore whether and to what degree social connections across countries can influence international eco-innovation partnerships.[2] We employ a panel dataset of 142 countries and 7,099 country pairs spanning from 2006 to 2019. Our unique compiled dataset merges different sources of information about each country, including data from the Organization for Economic Cooperation and Development (OECD),[3] United Nations Conference on Trade and Development (UNCTAD),[4] the CEPII Gravity Database,[5] and Facebook. We propose a gravity model to explain the effect of social connections on international eco-innovation partnerships. We estimate the gravity model by using the Poisson Pseudo Maximum Likelihood (PPML) estimator. In addition, we apply an instrumental variable approach to assess the robustness of the findings. Our findings suggest that more socially connected countries are more likely to partner in eco-innovation activities.

Our study makes several contributions. First, we contribute to the literature on the impact of networks on innovation collaborations (Aragón Amonarriz et al., 2019; De Noni et al., 2018; Fleming et al., 2007; González-López et al., 2019; Henton et al., 2002; Kallio et al., 2010; Laursen et al., 2012; Nieto & Santamaría, 2007) by providing an initial examination of how social connections across countries affect international eco-innovation partnerships. This understanding is essential in a globally interconnected world where innovation and knowledge transfer transcend national boundaries. By exploring this relationship, we contribute to a deeper understanding of the role of social ties in fostering collaborative innovation efforts on a global scale.

Second, we contribute to a growing literature on the role of social connections across regions in socio-economic outcomes by utilizing a comprehensive dataset derived from de-identified Facebook data (Bailey et al., 2021; Carril-Caccia et al., 2022; Diemer & Regan, 2022; Dornseifer & Rehbein, 2022; Rehbein & Rother, 2019). This unique dataset enables us to measure and analyze social connections at an aggregate level and addresses the previous research gap in studying cross-border interpersonal networks. By leveraging this dataset, we provide valuable insights

[2] See https://data.humdata.org/dataset/social-connectedness-index. The currently available SCI data belongs to 2021. In this study, we used 2020 SCI data.
[3] See https://stats.oecd.org/# (Last accessed: January 29, 2023)
[4] See https://unctadstat.unctad.org/EN/Classifications.html (Last accessed: January 19, 2023)
[5] See http://www.cepii.fr/CEPII/en/bdd_modele/bdd_modele.asp (Last accessed: November 10, 2022)

into the influence of cross-border social ties on international eco-innovation partnerships.

2. Theory background and hypothesis development

Interpersonal networks formed through social connections have attracted research attention for decades. For instance, prior literature has examined the structural properties of interpersonal networks (Burt, 1992), and the characteristics of social ties and connections (Granovetter, 1973). Over the years, researchers have shifted their attention from interpersonal networks formed between individuals and extended their studies to inter-organizational networks such as between firms or institutions to examine how these networks could influence different organizational performance measures (Gulati, 1999; Gulati et al., 2011; Kraatz, 1998).

Additionally, social connections can have significant socio-economic impacts as they play an important role in facilitating knowledge and information transfers and flows between individuals in a social network (Burt, 1997; Singh, 2005). For instance, prior literature has shown that social connections can be an important determinant of foreign direct investments (Dornseifer & Rehbein, 2022), and internal and external social connections can affect fundraising outcomes (Guo et al., 2021). Another key area in which social connections can be an important tool is innovation. Inter-organizational networks have been found to be important drivers of innovation (Laursen et al., 2012; Ye & Crispeels, 2022). Through inter-organizational networks, knowledge can transfer across organizations, which is a key factor for innovation and economic performance (Laursen et al., 2012; Singh, 2005; Ye & Crispeels, 2022). Through interactions with other units within an inter-organizational network, new opportunities and knowledge can be learned and acquired, which in turn promotes collaboration (Tsai, 2001).

However, inter-organizational networks, which are characterized by their formal nature as opposed to interpersonal networks between individuals, are not the only source for knowledge transfer and innovation collaboration (Huber, 2013). Interpersonal (informal) networks are also relevant and significant to innovation as these networks play a vital role in enabling knowledge sharing and fostering collaboration (Chang & Harrington, 2007; Xu et al., 2019). With the advances in information and mobile technologies in the last two decades, the cost of long-distance connections and knowledge sourcing between individuals has lowered. Therefore, individuals can expand their relationships and exchange knowledge and information through social contacts that can span across regional boundaries (Dahl & Pedersen, 2004). Also, individuals can connect with other individuals of diverse backgrounds and shared interests, which in turn, increases the likelihood of knowledge transfer and innovation development. Social connections and networking are important factors for eco-innovation development as they facilitate the knowledge transfer required to achieve sustainability requirements (Wong, 2013).

Eco-innovation advancements refer to the development of environmental-related technologies and products that address environmental challenges, reduce negative environmental impacts of resource usage, and contribute to the development of sustainable goals (Díaz-García et al., 2015; Klewitz & Hansen, 2014). There has been growing social and political attention to the significance of environmental sustainability and innovation (Díaz-García et al., 2015). As noted earlier, interpersonal social connections can help foster and facilitate global efforts in those advancements (Díaz-García et al., 2015; Wong, 2013). These connections become more crucial at a global level to help encourage international collaborations and promote an environment for eco-innovation and environmental-related technology development. However, research has not been able to empirically examine the effect of social connections between countries on international eco-innovation partnerships. Until today, this has been due to the lack of comprehensive data and measures of social connections at an aggregate country level. Therefore, from a broader picture perspective, we aim to empirically study this effect.

We examine the relationship between social connections and international eco-innovation partnerships through the lens of knowledge spillovers. Knowledge spillovers among individuals and firms are crucial drivers of productivity and economic growth (Aghion & Howitt, 1990; Lucas Jr, 1988; Romer, 1986). Knowledge spillovers are also a key factor for technological change (de Almeida et al., 2021; Li, 2014). Spillovers occur when knowledge is unintentionally exchanged, without monetary compensation, among various entities, such as individuals, firms, or regions, through both formal and informal channels (de Almeida et al., 2021; Feldman & Langford, 2021). In the context of eco-innovation partnerships, social connections can act as a conduit for knowledge spillovers, facilitating the transfer of environmentally sustainable practices, technological advancements, and scientific discoveries. Through international knowledge spillovers, countries can leverage their social connections to access a wider range of expertise and innovative ideas. As a result, they can tap into a wider pool of expertise and innovative ideas, enhancing their capacity for eco-innovation and fostering stronger international partnerships. Hence, we test the hypothesis that social connections enable the diffusion of knowledge across national borders:

H1: Social connections across countries lead to greater international eco-innovation partnerships.

3. Data and methodology

3.1. Data

Our dependent variable is the level of international eco-innovation partnerships (Patents), sourced from the OECD database. The OECD database includes bilateral patent collaboration data across various technology domains, including environmental-related technologies, climate change adaptation technologies, and sustainable ocean economy, dating back to the 1960s. In our analysis, we particularly focus on the subgroup of environmental-related technologies, given their prevalence, as patents in climate change adaptation technologies and the sustainable ocean economy domain are relatively less frequent. Due to the nature of the data, the distribution is highly right-skewed, with several country pairs having no recorded collaborations over the years.

We use Facebook's SCI (Bailey et al., 2020) to measure the impact of social connections between countries. The SCI is constructed between 194 country pairs using aggregated information from friendship links among Facebook users who have interacted with Facebook over the 30 days prior to the March 2020 snapshot. The measure of social connectedness between country i and country j is defined as follows:

$$SCI_{ij} = \frac{FB\_Connections_{ij}}{FB\_Users_{i} * FB\_Users_{j}} \qquad (1)$$

FB_Users_i and FB_Users_j are the numbers of Facebook users in country i and country j, and $FB\_Connections_{ij}$ is the number of Facebook friendship connections between the two countries. It is scaled to have a maximum value of 1,000,000,000. In our study, we disregard within-country connections as we are only interested in the role of social connectedness across countries. The SCI values linking different counties range from 73 to 44,025,810. The dataset has 194 countries and 18,721 country pairs. We use the SCI measure as a time-invariant variable in our model. The latest SCI measure, which belongs to October 2021, is available by Humanitarian Data Exchange.

In addition, we include several covariates in our model that may explain the variation in international eco-innovation partnerships. Table 1 provides a list of these covariates and their definitions.

Table 1. The list of covariates; all variables except OECD membership are from the CEPII Gravity Database; OECD membership information is provided in the UNCDAT database.

Variable Name	Definition	Variable Type
Distance	Distance between the most populated city of each country (km)	Time-invariant
Common border	The dummy variable is equal to 1 if country *i* and country *j* share a border	Time-invariant
Common language	The dummy variable is equal to 1 if country *i* and country *j* share a common official or primary language	Time-invariant
Common colonizer	The dummy variable is equal to 1 if country *i* and country *j* share a common colonizer post 1945	Time-invariant
Common legal origin	The dummy variable is equal to 1 if country *i* and country *j* share a common legal origin	Time-invariant
Common religion	Religious proximity index between country *i* and country *j*	Time-invariant
Colonial relationship after 1945	The dummy variable is equal to 1 if country *i* and country *j* share a common colonial relationship post 1945	Time-invariant
Common ethnological language	The dummy variable is equal to 1 if country *i* and country *j* share a common language spoken by at least 9% of the population	Time-invariant
Regional trade agreement	The dummy variable is equal to 1 if country *i* and country *j* currently have a regional trade agreement	Time-variant
EU membership	The dummy variable is equal to 1 if country *i* and country *j* are in the European Union (EU)	Time-variant
OECD membership	The dummy variable is equal to 1 if country *i* and country *j* are in the Organization for Economic Cooperation and Development (OECD)	Time-invariant

When combined, we end up with 142 countries and 7,099 country pairs spanning from 2006 to 2019. There are a total of 38,164 observations over the span of 14 years. Observations that are fully explained by the fixed effects are dropped from the sample. All covariates except for *Distance* and *Common Religion* are dummy variables. *Common religion* is an index ranging from 0 to 1. Lastly, *Distance* is a continuous variable. The descriptions of the final dataset are given in Table 2.

Table 2. Descriptive statistics. The number of data points (N) is 38,164.

Variables	Mean	Std. Dev.	Min	Max
Patents	1.16	9.90	0	348
SCI	12,006	62,839	74	4,083,169
Distance	6,862	4,564	59.62	19,951
Common border	0.03	0.17	0	1
Common official language	0.09	0.29	0	1
Common colonizer	0.04	0.20	0	1
Common legal origin	0.25	0.43	0	1
Common religion	0.15	0.24	0	0.99
Colonial relationship after 1945	0.01	0.10	0	1
Common ethnological language	0.11	0.32	0	1
Regional trade agreement	0.33	0.47	0	1
EU membership	0.10	0.10	0	1
OECD membership	0.20	0.40	0	1

3.2. Empirical specification

To understand the relationship between social connectedness and international eco-innovation partnerships, we propose the following gravity regression:

$$Patents_{ijt} = \exp\,[\beta_1\big(\log\big(SCI_{ij}\big) + \ \beta_2\big(W_{ij}\big) + \beta_3\big(X_{ijt}\big) + \delta_{it} + \delta_{jt}\big] * \epsilon_{ijt}, \qquad (2)$$

where $Patents_{ijt}$ denotes the level of international eco-innovation partnerships between country *i* and country *j* in year *t*; SCI_{ij} refers to the social connectedness between country *i* and country *j*; W_{ij} denotes the set of time-invariant country pair characteristics; X_{ijt} denotes the set of time-variant country pair characteristics[6]; $\boldsymbol{\delta_{it}}$ and $\boldsymbol{\delta_{jt}}$ are *country i-year* and *country j-year* fixed effects; and $\boldsymbol{\epsilon_{ijt}}$ is the error term.

Introducing fixed effects in our model addresses concerns regarding differences in the representativeness of Facebook data across countries. Bailey et al. (2020) suggest that Facebook friendships represent countries with high internet penetration, such as the United States, where Internet access is widely available. However, in countries with low internet penetration, access to the Internet may be available to certain segments of the population, such as wealthier individuals, leading to a potential overestimation of social connectedness. By incorporating fixed effects in our model, we can control for these differences and obtain more accurate estimates of the relationship between social connectedness and international collaboration.

We estimate this regression using PPML to account for zero patent partnerships between several country pairs and address heteroskedasticity bias due to Ordinary Lest Squares (OLS) estimator. PPML has advantages over OLS as it accommodates the presence of zero patent partnerships between several country pairs, a consideration that is crucial for our analysis. (Silva & Tenreyro, 2006). Moreover, the PPML estimator is also ideal for our analysis as our dependent variable is a count variable that is highly skewed in its distribution. We cluster the standard errors at *country i-year* and *country j-year* levels.

4. Results

4.1. Baseline results

The results of the regression analysis are presented in Table 3. Our results indicate that a 1% increase in social connectedness leads to a 0.48% increase in international patent partnerships in environmental-related technologies. These findings suggest that international eco-innovation partnerships between countries are likely to increase as social connectedness between countries increases.

Table 3. PPML results

Dependent variable	Patents
log(SCI)	0.479*** (0.033)
Observations	38,164
Pseudo R-squared	0.898
Control variables	Yes
country i-year fixed effects	Yes
country j-year fixed effects	Yes

[6] Please refer to Table 1 for a list of covariates

*** p<0.01
Robust standard errors are given in parentheses.

4.2. Instrumental variable approach

We acknowledge the possibility of endogeneity issues in our baseline results, primarily due to the absence of a natural experimental setting and the likelihood of unobserved factors associated with social connections across countries that could impact international collaboration. We also recognize the possibility of reverse causality issues. It is plausible that friendships across countries were formed because of international partnerships, creating a situation where international collaboration impacts social connectedness, resulting in an endogeneity problem. To mitigate these concerns, we adopt an instrumental variable approach.

In our study, we use an instrument that was previously used by Dornseifer and Rehbein (2022). Our instrumental variable is historical bilateral migration data obtained from the World Bank's Global Bilateral Migration Database. This data is available for five consecutive census years up to 2000, and we use the data from 1960 to 1980. The historical migration movement can plausibly lead to the development of social connections between countries, which may persist over time. We believe that this historical migration data represents a valid instrumental variable for our study because while these historical migration patterns may not directly explain collaboration behaviors in the post-2006 era, they can still shed light on the evolving social connections facilitated by platforms like Facebook over time. It is unlikely that migration directly affects international collaboration through mechanisms that are independent of social connections across countries.

We employ a control function approach (Lin & Wooldridge, 2018; Wooldridge, 2015) used by Dornseifer and Rehbein (2022) to address the challenges of using an instrumental variable with a PPML estimator. This approach has two steps: 1) Regress the SCI on the bilateral migration and other control variables using a simple OLS, and 2) Include the residuals as another control variable in the PPML estimation. The results of the first-stage regression are given in Table 4.

Table 4. First-stage regression results of the control function approach

Dependent variable	**log(SCI)**	**log(SCI)**	**log(SCI)**
	(1)	(2)	(3)
log (Migration 1960)	0.101***		
	(0.004)		
log (Migration 1970)		0.116***	
		(0.004)	
log (Migration 1980)			0.123***
			(0.004)
Observations	38,164	38,164	38,164
Adj R-squared	0.731	0.736	0.739
Control variables	Yes	Yes	Yes
country i-year fixed effects	Yes	Yes	Yes
country j-year fixed effects	Yes	Yes	Yes
*** p<0.01			
Robust standard errors are given in parentheses.			

Table 5 presents the results of the instrumental variable approach. Column 1 applies the natural logarithm transformation to the bilateral migration data from 1960, while Column 2 applies it to the data from 1970, and Column 3 applies it to the data from 1980. We find that the results of the instrumental variable approach are robust to our main findings from Table 3.

Table 5. Instrumental variable model results. The dependent variable is *Patents*

Instrumental variable	**log(Migration 1960)**	**log(Migration 1970)**	**log(Migration 1980)**
	(1)	(2)	(3)
log(SCI)	0.340***	0.491***	0.328***
	(0.116)	(0.098)	(0.103)
first-stage residuals	0.158	-0.014	0.184
	(0.126)	(0.109)	(0.113)
Observations	38,164	38,164	38,164
Pseudo R-squared	0.898	0.898	0.898
Control variables	Yes	Yes	Yes
country i-year fixed effects	Yes	Yes	Yes
country j-year fixed effects	Yes	Yes	Yes
*** p<0.01			
Robust standard errors are given in parentheses.			

5. Discussion and conclusion

International collaborations in green technologies are a crucial factor in encouraging the growth and diffusion of environment-related technologies. In this paper, we examine the impact of interpersonal networks on international eco-innovation partnerships. Our findings suggest that more socially connected countries are more likely to partner in eco-innovation activities. Econometrically, our results indicate that a 1% increase in social connectedness leads to a 0.48% increase in international patent partnerships in environmental-related technologies.

Our study contributes to the literature on interpersonal networks, knowledge spillover, and innovation by examining the impact of social connections across countries on international eco-innovation partnerships, utilizing a comprehensive dataset derived from de-identified Facebook data. The findings in this study advance our understanding of how social connectedness facilitates collaborative eco-innovation efforts at a global level. This study also helps us expand our knowledge of cross-regional interpersonal networks and their implications for socio-economic outcomes.

With respect to contribution to policy implications and practice, the positive impact of social connections on international eco-innovation partnerships can help the global community promote a culture of knowledge sharing and innovation collaboration. Building and maintaining strong social ties between countries can facilitate knowledge-sharing and collaborative efforts in addressing environmental issues. Policy interventions aimed at enhancing social relationships across countries, such as diplomatic efforts, cultural exchanges, or communication networks, can potentially promote international collaborations in the area of environmental-related technologies. Increased social connections can lead to knowledge spillovers, technology transfer, and joint R&D efforts, which may result in improved environmental practices.

Our study is not without limitations. First, while the strength of a relationship between each pair of countries corresponds to the relative frequency of Facebook friendship links, it is important to note that in our analysis, each friendship link on the Facebook network is treated equally. Second, the SCI data is a one-time snapshot of all Facebook users who have interacted with Facebook over the 30 days prior to the March 2020 snapshot. Longitudinal data is not available. Even though it is a one-time snapshot, the SCI is very persistent and reflects patterns of immigration, culture, and socio-economic characteristics apart from geographic closeness. Third, it is important to acknowledge the possible endogeneity of the SCI measure. The social network graph might not be entirely exogenous, as it could be influenced by unobservable factors that could also affect international eco-innovation partnerships. Moreover, social connections formed over time can influence international collaborations, but such an impact may appear in the long run. Although we mitigate this concern by using an instrumental variable approach, we remain cautious in interpreting the causal implications of our findings. Finally, our analysis primarily focuses on the main effects of social connections on international eco-innovation partnerships, with a particular focus on environmental-related technologies. It would be valuable for future research to investigate the underlying mechanisms and factors that may enhance or hinder the effect of social connections on international eco-innovation partnerships with a focus on different types of technology collaborations, including climate change adaption and sustainable ocean economy.

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