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CONNECTING INTERNATIONAL R&D COOPERATION AND TECHNOLOGY SPECIALIZATION IN OECD COUNTRIES

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Abstract: *Technology specialization is supported by processes combining inhouse and external innovation. Applying a macroeconomic and international trade theory approach (Linder, 1961), country specialization depends on international R&D cooperation partnerships. External, international R&D cooperation is essential for technology specialization, as it raises awareness of countries' position on a global technology map. This paper studies international R&D cooperation as a determinant of countries' technology specialization. Cross-country panel regression was done on a sample of 37 OECD countries for the period 1980-2018. The analysis examined the effect of international R&D cooperation on technology specialization. Data were obtained from the OECD database. Co-patenting with foreign inventors was used to indicate the level of international R&D cooperation. Patent per technology was used to calculate technology specialization based on the Herfindahl index. Results indicate a positive effect of international R&D cooperation on technology specialization. The effect of R&D cooperation on technology specialization is more pronounced when GDP and R&D expenditure were used as control variables. Additionally, the size of the GDP negatively affects technology specialization. This paper identifies international cooperation as a bridge for global information exchange, which results with countries' technology specialization.*

Key words: *International co-operation; Country technology specialization; Cross-country panel regression; OECD.*

JEL classification: *O31, O33, F62.*

INTRODUCTION

Innovation requires exploration of activities beyond existing technological knowledge boundaries, including its recombination and exploitation to create radically different products and services. Self-reliance strategy in innovation activities became

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obsolete due to innovation process complexity, R&D cost intensity, shorter product life cycles and competitive pressures. With its ability to surpass the problem of optimization in knowledge sharing (Takeishi, 2002) and production, R&D collaboration became important for technology upgrade. With its ability to cross country borders, R&D collaboration grows exponentially, facilitates knowledge flows and enhances countries' competitive advantage (Ma & Lee, 2008). Based on a trend of R&D collaboration, technology portfolio increases. Herein, literature distinguishes between two basic directions of technology portfolio growth depending on the way homogeneous or heterogeneous inputs and ideas get creatively recombined: (1) diversification and (2) specialization of portfolio (Lin, Chen, & Wu, 2006). In order to achieve portfolio synergic effect, strategic portfolio management is necessary (Appio, De Luca, Morgan, & Martini, 2019). Innovation activities can be based on collaboration between partners from technologically different and, therefore, distant fields, which could result in radical innovation (Chen, Yang, & Lin, 2013). On the other hand, the homogeneity of partners` technology base can lead to limited novelty, incremental innovation.

This paper is framed around a debate about technology portfolio concentration. Indicating the importance of international collaboration, this paper questions whether the variety of international knowledge sources lead a country toward homogenic or heterogenic technological portfolio. Our findings indicate that a trend of international collaboration, as a source of international knowledge, leads towards high technology concentration. High level of technology concentration indicates that innovation and technology upgrade is based on a recombination of homogenic, existing and familiar knowledge. At first sight an access to complementary and multiple international knowledge sources creates potential for technology portfolio diversification. However, high technology concentration implies a lack of absorptive capacity because of the inability to acquire heterogeneous knowledge. Consequently, a low level of absorptive capacity stirs innovation search toward close and familiar partners, both on the local and global level. These findings complement previous findings on the importance of close, collaborating partners in the process of knowledge recombination (Phelps, 2010; Tripunoski, Nikolovski, & Vasileva, 2015). Furthermore, this paper implies that despite the ability to access diverse international knowledge, a low level of absorptive capacity might cause country to lock into specific technology field (De Noni, Ganzaroli, & Orsi, 2017).

The paper is organized as follows. The next section presents an overview of collaboration and technology concentration literature, which is followed by explanation of the relationship between international collaboration and technology concentration. Methodology and results are presented in the subsequent section. The last section summarizes the conclusion of the study including contributions and limitations for further research.

LITERATURE REVIEW

Collaboration is responsible for development of almost all contemporary products (Picci, 2010). Collaboration is defined as an activity of exchanging significant amount of knowledge and resources between two or more partners (Yamin & Otto, 2004). From the organizational perspective it takes a wide spectrum of inter-organizational modes: from total partner independence to complete interdependency. Regardless of the collaboration mode used, its goal is to increase knowledge production and exchange. Last three decades witnessed a significant expansion and decentralization of knowledge networks. The rise of innovation process complexity, shorter product life cycle and competitive pressures fostered the inclusion of R&D collaboration into organizational practices. R&D collaboration enables tacit knowledge exchange (Takeishi, 2002) thereby creating less costly innovation (Husted & Michailova, 2010). The importance of R&D collaboration for innovation (Arvanitis, 2012; Puventhiran & Tugsuz, 2017; Capuano & Grassi, 2019) is studied in different research streams. Some of them include: partner types (Alcácer & Chung, 2007; Badillo & Moreno, 2016), network position (Bettencourt, Kaiser, & Kaur, 2009), regions' technology competiveness (Fleming, King III, & Juda, 2007) and industries' knowledge creation (Lim & Park, 2009). Variety of theoretical and empirical approaches resulted in both advantages and critique of R&D collaborations. R&D alliances are beneficial for controlling uncertainty of complex technologies. Furthermore, they allow partners to receive access to each other's specific resources. On the other hand, partner search, negotiation and contracting can result in increased costs of R&D collaboration (Van Beers & Zand, 2014), while strong embeddedness in one network might hold organizations back from other potential collaboration opportunities(Gulati, Nohria, & Zaheer, 2000).

Strong internationalization of R&D collaboration, often referred to as "Techno-globalism", is an extension of internationalization of trade, investment and accumulation of technological capabilities(Bergek, 2010). Despite the importance of local and technologically close collaborations for, usually, incremental innovations (Picci, 2010), international and technologically distant R&D collaborations are indispensable for generating radical ones (Moodysson & Jonsson, 2007). Innovation complexity and variety of national economic, social, and inter-country settings, palaced international R&D collaboration network on research agenda of many authors (De Prato & Nepelski, 2014). Hence, researchers focused on the effect of geography on collaboration (Gao, Guan, & Rousseau, 2011; Cantner & Rake, 2014). Studies examined the effect of multilevel, city and country, networks on innovation (Guan, Yan, & Zhang, 2017) or international knowledge flow.

Acceleration of global competitiveness induces pressures on production process. Optimization of production processes rests on technology upgrade, which enables the growth of technology portfolio(Appio, De Luca, Morgan, & Martini, 2019). Diversification and specialization are two distinct strategies of achieving portfolio synergic effect. Diversification-specialization distinction depends on recombination of homogeneous or heterogeneous inputs, affecting the technology trajectory. Recombination of homogenous body of knowledge resulted in upgraded technology (Boschma, Balland, & Kogler, 2015; Colombelli, Krafft, & Quatraro, 2014; Essletzbichler, 2015) being kept on same trajectory, and indicating a knowledge specialization, which is a prerequisite for achievement of strong technology portfolio synergic effect(Lin, Chen, & Wu, 2006). Namely, accumulation and depth of specialized technological knowledge (Parchomovsky & Wagner, 2005) provides a strong barrier to entry (Shapiro, 2001) and high returns to investments due to a monopoly in specific technology area. Learning and transfer of knowledge are enhanced within a specialized technology portfolio, forming a foundation of a strong competitive advantage (Lin, Chen, & Wu, 2006). Specialization can, thus, lead to more innovations than a more diverse technology portfolio (Garcia-Vega, 2006) and result in complex product lines.

However, specialization does not come without cost. Being locked within a specific technology field leaves a little room for quick adjustments to fast changes in industry trends (Quintana-García & Benavides-Velasco, 2011), making technology brokerage unavoidable for technology growth (Carnabuci & Bruggeman, 2009). In order to prevent lock-in, an expansion to a variety of technology fields becomes an optimal strategy when composing a risk-averse technology portfolio. Technology portfolio diversification has the ability to generate radical innovation due to an intervening effect of various technology fields (Chen, Yang, & Lin, 2013). This increase transaction costs resulting from difficulties in coordination and communication within technology portfolio, additionally, it that might affect successful integration of technological knowledge. Recent trends, however, point towards diversification with coherent patterns based on technological complementarity between partners' knowledge bases. Finally, this discussion should not lead toward understanding of specialization and diversification as distinct concepts, but rather endpoints in the broad spectrum of technologies.

Collaboration provides partners with access to specific and spatially distributed knowledge and resources. However, variety of knowledge does not imply compatibility. Technological, geographical, social, institutional and organizational distance among collaborating partners result in different levels of homogenic/heterogenic knowledge (De Noni, Ganzaroli, & Orsi, 2017), whose exploitation differs. Absorption of knowledge is easier if a knowledge domain is closely related to its current knowledge base (Cohen & Levinthal, 1990). However, with absorption of homogenic knowledge partners are very limited in number of innovative combinations. This spurs a motivation to approach and absorb more heterogenic knowledge. Collaborating with different distant partners reflects a need for balanced ratio of homogeneous and heterogeneous knowledge absorption (De Noni, Ganzaroli, & Orsi, 2017). As new knowledge is always derived from re-combinations of existing knowledge, the extent of specialization and diversification will depend on creative re-combinations of homogeneous and heterogeneous inputs.

These arguments posit a question whether variety of international knowledge sources/partners leads a country toward a more specialized or diversified technological portfolio.

METHODOLOGY

This study uses OECD database for the period between 1980 and 2018 of 37 OECD countries. OECD countries comprise core knowledge creators. More specifically, the majority of international knowledge interactions, comprising international patenting activities, are performed within the OECD group (Guan & Chen, 2012). Furthermore, OECD countries account for 83% of the global R&D expenditure. Hence, this paper uses explores the link between international co-patenting activities and technology specialization of 37 OECD countries. Patents are the most significant innovation output indicator (Frietsch & Grupp, 2006). Patents are intellectual property rights generated by inventor enabling him or her the sole right to exclude others from making, using or selling their invention for a set period of time, in most cases for the period of 20 years. Technology concentration is calculated by using Herfindahl index, which is a composite measure that encompasses both the quantity and the type of technological activity. OECD database includes a list of a number of patent applications filed under PCT per country per year based on 35 technology domains grouped in 6 technology fields. All 35 technology domains were used to calculate yearly Herfindahl index for the period 1980-2018. Firstly, shares of patents in particular technology domains in total patents were calculated for each technology domain. Secondly, shares were approximated using a Herfindahl index based on the following formula[1]:

$$HHI = s1^2 + s2^2 + s3^2 + \ldots + s35^2$$

where is the share of patents in a particular technology domain in total patents using 35 technology domains. Greater concentration of a particular technology domain is shown as higher HHI. International cooperation based on international co-patenting activities is a patent application filed under PCT where at least one inventor from a country different than the country in which a patent applicant or inventor resides(Carayol & Roux, 2007; Guan & Chen, 2012). Hence, this study approximates international cooperation based on yearly international co-patenting activities for the period 1980 – 2018 per country. Data were obtained from the OECD database. GDP and R&D expenditure were used as control variables in the model. Namely, greater the size of the country's GDP, more diversified portfolio of technology of a country. Similarly, greater size of the R&D expenditure reflects a more diversified technology portfolio and, hence, less technology specialization.

RESULTS

Data is obtained for the period between 1980 and 2018, and includes the 37 OECD countries' patent applications and a model is estimated using a log-log form. Descriptive statistics of the variables are present in Table 1.

Table 1. Descriptive statistics of variables

	LOG PCT SCOPE	LOG INT CO-PCT	LOG GDP	LOG R&D EXPENDITURE
Mean	-2.65	2.96	5.51	3.79
Median	-2.91	3.02	5.46	3.82
Maximum	0.00	4.61	7.28	5.74
Minimum	-3.36	-0.18	3.95	1.62
Std. Dev.	0.72	0.86	0.66	0.79
Skewness	2.03	-0.67	0.08	-0.00
Kurtosis	6.77	3.67	2.91	2.80
Jarque-Bera	1679.41	119.95	1.71	1.86
Probability	0.00	0.00	0.43	0.39
Sum	-3476.24	3768.08	7 091.35	4 054.68
Sum Sq. Dev.	681.98	940.84	554.22	671.72
Observations	1314	1275	1287	1070

Source: Authors' calculations

[1] All the formulas are well generated in econometrics.

Basic cross-country panel OLS regression model is presented in Equation 1.

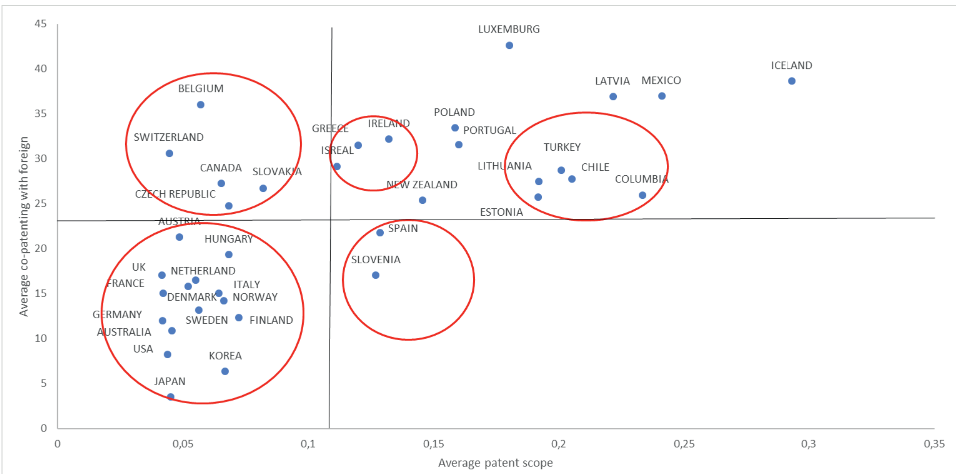
$$\log y_{it} = \beta_1 + \beta_2 \log x_{it2} + \ldots + \beta_k \log x_{itk} + \varepsilon_{it}$$

$$i = 1,2 \ldots N \; t = 1,2, \ldots T \qquad (1)$$

where y_i is a dependent variable, x_i is a independent variable, β_1 is a constant, β_2 is a regression coefficient, i,t are indices for individuals and time and ε is an error term. Assumptions of the model are error terms that are independently and identically distributed with expected value 0 and a constant variance.

However, set of countries could be interdependent (Figure 1.). Figure 1 positions each country on a patent scope and international co-patenting plane illustrating the possible cross-sectional dependence. Appendix 1 portrays the similar rationale.

Figure 1. Average patent scope – average international co-patenting plane



Source: Authors' estimations

Breusch-Pagan LM ($p < 0.05$) showed that we cannot reject the hypothesis that there is correlation between cross-sections. As heteroskedasticity and cross-sectional dependence could cause the estimators obtained from panel analysis to be inconsistent, panel analysis should be conducted in a manner to account for possible inconsistencies. Sarafidis and Wansbeek (Sarafidis & Wansbeek, 2012) provide an overview of techniques with large number of units (N) in a lot of observations over time (T) and link a concept of cross-sectional dependence to the spatial and factor structure approaches. When T is fixed and N is large, cross-sectional dependence can be modelled using the seemingly unrelated regression method (SUR) proposed by Zellner (Zellner, 1962). Moreover, this approach is to be used when T > N. Therefore, this analysis was performed by estimating generalized least square (EGLS) and running the panel data regression with cross-section weights.

$$\log y_{it} = \beta_1 + \beta_i \log \mathbf{x'}_{it} + \varepsilon_{it}$$
$$i = 1,2 \ldots N \; t = 1,2,..T \qquad (2)$$

where y_i is a dependent variable, x_i is a independent variable, β_1 is a constant or individual specific effect, β_2 is a p × 1 vector of unknown coefficients, $x$it is a p × 1 vector of explanatory variables on the ιth cross-sectional unit at time t, and ε is an error term. It results in feasibly generalized least squares estimator in which OLS is conducted to each individual – specific equation to get consistent estimators $\{\beta_i\}_{i=1}^{N}$ used to compute the residuals $\{\widehat{e_{\iota t}}\}_{1\le i\le N, 1\le t\le T}$ employed to estimate the covariance between units i and j using $\frac{1}{T}\sum_{t=1}^{T} \hat{e}_{it}\,\hat{e}_{jt}$ in the first stage, while the coefficient estimators are obtained using the generalised least squares with the inverse of the estimated covariance matrix as a weighting matrix in the second stage.

Results of the unbalance panel approximated seemingly unrelated regression with cross-section weights is presented in Table 2.

Table 2. Cross-country panel regression for OECD, 1980-2018

Dependent variable	**Log PCT SCOPE**			
Indep. variable/Model				
Constant	-3.77*** (0.01)	-1.39*** (0.02)	-1.62*** (0.02)	-2.16*** (0.03)
log INT COPCT	0.36*** (0.00)	0.18*** (0.00)	0.07*** (0.00)	0.06*** (0.00)
log GDP		-0.34*** (0.00)		0.21*** (0.01)
log RD expenditure			-0.36*** (0.00)	-0.52*** (0.02)
Adjusted R-squared	0.90	0.92	0.91	0.92
S.E. of regression	0.83	0.83	0.80	0.79
Prob. (F-statistic)	0.00	0.00	0.00	0.00
Mean dependent variable	-2.73	-3.76	-13.34	-14.87
S.D. dependent variable	21.53	28.29	21.76	25.11
Durbin -Watson	1.48	1.48	1.39	1.28
Observations	1275	1211	1047	1015

Note: Standard errors in parentheses. Statistical significance: *<0.10; **<0.05; ***<0.01.

Source: Authors' calculations

Cross-section dependence Breusch-Pagan LM test ($p > 0.05$) showed that we can accept the hypothesis stating no correlation at conventional significance levels. Table 2 shows that international co-patenting positively influences country's technology specialisation at the 1% significance level. As we have expected, the effect of international co-patenting on country's technology specialisation is lessened when the model includes GDP and R&D expenditure.

DISCUSSION AND CONCLUSION

This paper addresses a crucial domain of country technology portfolio. Focusing on homogeneity and heterogeneity of technology, it directs significant attention to a level of countries technology concentration. In order to sustain its competitive position, constant progress in innovation activities is of a paramount importance. Technology portfolio has to be characterized with radical innovation rising from re-combinations of heterogenous knowledge, as well as with breath, deep understanding of knowledge achieved with homogeneous knowledge recombination. According to De Noni, Ganzaroli & Orsi (De Noni, Ganzaroli, & Orsi, 2017) a perfect balance is desirable.

As international collaboration provides a whole new perspective for partners in innovation process, it is a mean for knowledge extraction. Collaboration provides partners with access to partner specific knowledge and resources. However, variety doesn't mean compatibility. Despite a variety of knowledge that could lead towards a high possibility of radical innovations, one has to be aware that knowledge from abroad might be country-specific and with that difficult to use in a domestic environment. A downside of international knowledge comes from often huge technological distance between partners in the innovation process (Gilsing, Nooteboom, Vanhaverbeke, Duysters, & van den Oord, 2008). Distance makes mutual understanding and communication between partners difficult (Enkel, Groemminger, & Heil, 2018). In order to mitigate this problem partners tend to collaborate over a long time period (Heimeriks, Duysters, & Vanhaverbeke, 2007), thereby enabling filtering incompatibility. Long term international collaboration develops absorptive capacity, namely knowledge acquisition, while calculating for the risks of technological distance (Bröring & Leker, 2007). Specifically, a low level of absorptive capacity enables a search towards familiar international partners and does not incite a search for unfamiliar ones. Following a capability-based view, this paper advocates a national strategy for concentrating on core competences and technology fields in which they achieve best results. Concentrating on technological knowledge in a small number of fields, homogeneous knowledge alleviates portfolio synergy. Furthermore, focusing on patents in a small number of patent fields enables a protection of national core competences and restrains potential entrants to those technology fields. Specialization is, however, followed by a significant downside of technology lock-in. Problem of technology lock-in should not be disregarded as it leaves a country inflexible for fast changing technological trends.

Countries' technological overview was a topic of numerous studies. However, how variety of international knowledge frames country's technology portfolio is a relatively unexplored field. This paper introduces a novel approach for predicting future technological directions. It emphasizes the importance of knowledge globalization and global researchers' interdependence in countries technology foresight. Hence, directing policymakers toward supporting international research projects initiatives. In other words, it emphasizes the importance of a country's technology open-mindedness while defining institutional environment. Finally, private companies possess 85% of countries' international technology collaboration, making technology managers important for countries' technological environment and community. Results indicate that they are leading country toward technology specialization and consequently in a direction of more incremental innovation. This might lead toward decreasing of radical technology breakthroughs. Managers should be coordinated with policymakers while framing country technology strategy.

This study has some limitations, especially in relation the methodological approach adopted. This study encompasses all OECD members countries. Herein, the level of technological development among countries differs. Furthermore, countries have different technology scope and patent practice differs between technological fields. Concentration measurement index is often criticized as a static measure, implying a lack of dynamics of a diversification process (Chen, Jang, & Wen, 2010). Furthermore, according to Garcia-Vega (Garcia-Vega, 2006), HHI index can be biased downwards in a case of companies with small scale of technological activities.

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