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The Technological Specialization of Countries: An Analysis of Patent Data

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Abstract

New methods of analysis of patent statistics allow assessing country profiles of technological specialization for the period 1990-2006. We witness a modest decrease in levels of specialization, which we show to be negatively influenced by country size and degree of internationalization of inventive activities.

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1. Introduction

Several studies in the past have documented a rise in technological specialization of countries. In particular, Archibugi and Pianta (1992) found that technological specialization increased over the period 1975-1988, and tended to be higher in smaller countries. Cantwell and Vertova (2004) reached similar conclusions, showing that country-level technological specialization is more pronounced in the years between 1965 and 1990 when compared to that observed in previous periods. In this paper, we update this debate for the post-1990 years, considering a broader set of countries and overall employing improved methodologies, and we test the effects of country size and internationalization of R&D on technological specialization.

Using patent data, we first assess country profiles of technological specialization. We identify inventions with patent applications, corresponding to filings to all patent offices in the world of at least marginal significance (De Rassenfosse et al., 2013) as reported in the Patstat database (European Patent Office, 2013a and 2013b). In this way, although acknowledging the usual caveats that pertain to the use of patent data, we obtain a comprehensive view on the production of inventions at the world level. Adopting these new methods of analysis effectively overcomes the shortcomings of previous works. Former research approaches focused only on one (albeit important) patent office, such as the USPTO. As such, these studies were affected by a home-bias effect that resulted in a serious sample selection-bias (see for example Cantwell and Vertova, 2004, who are able to consider only eight, mostly large countries).

In the period 1990-2006, we find a modest decrease in the technological specialization of countries, indicating a trend reversal with respect to the findings of other studies analysing previous decades. We take into consideration two broad determinants of specialization. The first pertains to country size. Larger countries have access to a wider pool of resources and a larger domestic market. Therefore, larger nations are expected to be less specialized than smaller nations. Our results confirm this presumption and the findings by Archibugi and Pianta (1992) and Cantwell and Vertova (2004).

The second candidate determinant reflects technological comparative advantage theories. We consider it from the viewpoint of the internationalization of inventive activities, which we measure by means of an innovative metric introduced in Picci (2010). The association between greater internationalization of the economic activity and geographical specialization is a standard result of the trade theory of comparative advantages. These considerations would hint at the presence of a positive association between internationalization and technological

specialization. Contrarily, we find that internationalization has a significant *negative* effect on specialization. In the concluding sections, we propose an explanation for this seemingly counter intuitive result. However, as a practical consequence, this paper indicates that further theoretical work is needed to better understand the determinants of country technological specialization.

2. The data

Patent statistics computations are based on the methodology illustrated in De Rassenfosse et al. (2013), while for the computations of measures of internationalization we adopt one of the metrics introduced by Picci (2010).[2] We use the Patstat database (European Patent Office, 2013a and 2013b) and we consider all priority applications filed at any of a group of 50 patent offices from 1990 to 2006 for 34 countries, representing the virtual totality of worldwide patenting activity.[3] Our analyses thus include 10,222,306 priority applications. As a note, the term patent applications will be henceforth simplified to *patents*.

Patents can be fractionally assigned to countries either according to the nationality of the inventor(s) ("inventor criterion") or of the applicant(s) ("applicant criterion"). In this paper we use the inventor criterion and we define a patent as "national" if all of its inventors and applicants are from the same country, and as "international" otherwise.[4] Picci (2010) analyses a sample of 1000 such "international" patents to find that in 79% of cases the applicant is a MNE's subsidiary or headquarters, with an additional 15% of cases involving firms that are not multinationals.[5] Patent data allow us to distinguish technologies according to the WIPO's International Patent Classification (WIPO, 2013). Throughout this study, we adopt the taxonomy proposed by Schmoch (2008), who identifies 35 technologies. We regroup them

[2] The methodology (De Rassenfosse et al., 2013) takes full advantage of the fact that Patstat allows to track multiple applications in different patent offices claiming the right to priority for the same invention, and to avoid double counting within patent families. Considering patent *applications*, instead of granted patents, allows for the analysis of more recent data (since the granting process may take several years). In what follows, whenever for simplicity we mention patents, in fact we always mean patent applications.

[3] The 34 countries are: 30 OECD countries (excluding Czech Republic, Estonia, Iceland, and Slovenia); two countries invited to open discussions for membership to the OECD: China, India; Chile and Taiwan. The 50 patent offices that we consider are the national patent offices of the same countries, plus those of Brazil, Bulgaria, Cyprus, Czech Republic, Estonia, Honk Kong, Iceland, Indonesia, Latvia, Lithuania, Malta, Romania, Russia, Singapore, Slovenia, South Africa and the European Patent Office.

[4] Note that we use the term "international" (patent application) purely out of convenience, and with no reference to where the first filing occurred – nationally, to a regional office such as the European Patent Office, or via the so called "international route".

[5] Our population of patents is about 10% more numerous than in Picci (2010), since we consider additional (minor) patent offices.

into five macro-technologies, which we index as *s=1,2…5*: electrical engineering (*1*), instruments (*2*), chemistry (*3*), mechanical engineering (*4*), and other fields (*5*).[6]

3. **The empirical model**

In this section we first introduce measures of country size, technological concentration, and internationalization, before finally presenting our empirical strategy. We identify country size with so called "inventory size", Inv_{it}, representing the total fractional counting of patent applications of country *i* in year *t,* using the inventor criterion. The year subscript is henceforth omitted for the sake of simplicity.

Country technological specialization is measured by means of the same index employed in Cantwell and Vertova (2004):

$$Spec_i = \frac{\mu_{TRCA_i}}{\sigma_{TRCA_i}}, \qquad (1)$$

where μ_{TRCA} and σ_{TRCA} are, respectively, the mean and the standard deviation of the index of Technological Revealed Comparative Advantage (hence, TRCA), introduced by Soete (1987).[7] *Spec* is therefore the inverse of the coefficient of variation of *TRCA* and is dimensionless. Higher (lower) values of *Spec* represent lower (higher) technological specialization. Intuitively, *Spec = 1* if the distribution of technological sectors is exponential (since $\mu_{TRCA} = \sigma_{TRCA}$).

We measure internationalization through the *InvAppInv* measure (which we call *Iai*), introduced in Picci (2010). It is a relative measure expressing the share of international patents in a country's portfolio:

$$Iai_i = \frac{InvApp_{ij}}{Inv_i}, \qquad (2)$$

[6]These computations also are done fractionally, such that patents with multiple codes belonging to more than one macro-technology are counted appropriately. See Appendix A for a detailed description of the constituent technologies in terms of the IPC classification, and how they are aggregated to form the five macro-technologies.

[7]$TRCA_{si}$ represents a country's worldwide patenting share in one sector relative to its world share of patenting activity:

$$TRCA_{si} = \frac{Inv_{si} / \sum_i Inv_{si}}{\sum_s Inv_{si} / \sum_s \sum_i Inv_{si}},$$

where Inv_{si} is the fractional count of patents in sector *s=1, …,5* in country *i* according to the inventor criterion. $TRCA_{si}$ is greater than 1 if country *i* is relatively specialized in sector *s*, and below 1 otherwise. For previous applications and discussion of the properties of this index see, among others, Patel and Pavitt (1991), Archibugi and Pianta (1992), and Cantwell and Vertova (2004).

where Inv_i is the total fractional counting for country *i* using the inventor criterion; $InvApp_{ij}$ is a fully fractional count of patent applications involving inventors of country *i* and applicants of country *j*, in a given year.

Using the indices (1) – (3), we adopt a very simple baseline empirical model:

$$Spec_{it} = \beta_1 + \beta_2 Log(Inv_{it}) + \beta_3 Iai_{it} + Year_t + \varepsilon_{it}, \quad (3)$$

where $Year_t$ are time (year) fixed effects and ε_{it} is the error term. The log transformation for the inventory size variable is justified in Hart (1991). The empirical model is aimed at identifying the parameters of interest by exploiting cross-sectional variations of the data; this explains the absence of country fixed effects. The presence of such effects would result in a "within" fixed-effect estimator, which would solely reflect the variation of the data in the time series dimension. However, we will also adapt the model so as to consider such "within" variations, using a dynamic model.

Reverse causality may be present. With respect to a country's size, Koren and Tenreyro (2013) posit that more technologically diversified economies are able to better absorb shocks, and thus technological specialization may hinder growth and eventually result in smaller inventory size. In regard to internationalization, greater specialization might in turn attract further R&D activities by MNEs, consequently increasing the level of internationalization. For these reasons, we also use two-stage least squares, employing the lags of the two main dependent variables as instruments. We also consider "within" variation. First, we estimate long-difference variations on a cross-section of data. In addition, we also adopt a dynamic panel-data model, utilizing both a standard OLS Fixed Effects estimator and Arellano and Bond (1991) one-step estimator.

4. **Results**

Table 1 shows that technological diversification, as measured by the world average of *Spec*, has slightly increased across the period under consideration. The same result applies if we focus on an alternative measure of technological specialization, the Krugman (1991) index of technological specialization (see Appendix B), which is highly negatively correlated with *Spec*.

[Table 1 about here]

The last column shows that internationalization has increased since 1990, implying a negative correlation between internationalization and specialization.

[Table 2 about here]

Table 2 shows the results of the estimated empirical models. The dependent variable is always our measure of diversification *Spec*, with the exception of Column 3, where the dependent variable is the variation of *Spec* between 1990 and 2006. Column 1 shows OLS estimates. Both country size and the degree of internationalization in the production of technologies have a strong and highly significant positive effect. The results change only marginally when employing an Instrumental Variable estimator (Column 2), where the 5th lags of the two dependent variables are used as instruments[8]. Both specifications include year fixed effects. In Column 3 the dependent variable is the difference $\Delta Spec = Spec_{i,2006} - Spec_{i,1990}$. The model enquires whether the values of the two independent variables in the first year of the sample ($Inv_{i,\ 1990}$ and $Iai_{i,\ 1990}$) have an effect in explaining *changes* in the dependent variable. The answer is negative for both variables of interest. In Columns 4 and 5 we check whether the effects that we find when looking at the cross-sectional variation of the data (Columns 1 and 2) are also present when we use the aforementioned *within* variation of the data to identify the parameters of interest. The dynamic nature of the model causes the simple OLS Fixed Effects estimator to be biased, but taking into account the considerations in Attanasio et al. (2000) on dynamic panel data models in instances when *T* is rather large, we also show those results (Column 4), together with Arellano and Bond (1991) one-step estimates (Column 5).

When using a standard Fixed Effect estimator (Column 4) we find a significant effect for both variables.[9] Arellano-Bond one-step instrumental variable estimator (Column 5), however, indicates that the effect of country size, while correctly signed, is not significant at conventional levels (p-value = 0.205). Overall, looking at the within variation of the data confirms our results.

[8] Changing the order of the lag, from 1 to 10, leaves the results qualitatively unchanged.
[9] The choice of lag-length, 1, emerged unambiguously both by looking at the t-statistics of the dependent variable lagged twice, and, in the Arellano-Bond estimates (last column), by considering the results of the Arellano-Bond autocorrelation tests.

5. **Conclusions and discussion**

This paper shows that technological country specialization in recent times did not increase as it had been previously demonstrated in research on the 1970s and 1980s. In fact, specialization slightly decreased during the period under review in this study. Our estimates show that both country size and country internationalization have a negative effect on the degree of country specialization. The former effect is expected. The latter finding is to some extent surprising, since from the theory of comparative advantage we would rather expect a positive association between internationalization and specialization. Identifying the channels through which internationalization influences technological specialization is an open question. A tentative explanation of our results could be along the lines proposed by Caselli et al. (2012); internationalization of R&D might be motivated by strategies to reduce domestic, sector-specific technological shocks by diversifying inventive activities. Additionally, comparative advantage motives may be at work in the opposite direction, i.e., an increase in specialization may lead to a subsequent increase in a country's exposure to sector-specific shocks. If this holds, the balance between shock-minimization and comparative advantage motives is what determines the observed outcomes.

Future empirical research should be devoted to better identify the role of motives other than comparative advantages in determining countries' profiles of technological specializations, and theoretical contributions should clarify how the different factors at play interact.

Appendix A - Taxonomy of technologies (Schmoch, 2008)

Electrical engineering, s=1
1 - Electrical machinery, apparatus, energy: F21#, H01B, H01C, H01F, H01G, H01H, H01J, H01K, H01M, H01R, H01T, H02#, H05B, H05C, H05F, H99Z. **2 - Audio-visual technology:** G09F, G09G, G11B, H04N-003, H04N-005, H04N-009, H04N-013, H04N-015, H04N-017, H04R, H04S, H05K. **3 - Telecommunications:** G09F, G09G, G11B, H04N3, H04N5, H04N9, H04N13, H04N15, H04N17, H04R, H04S, H05K, H04W, G08C, H01P, H01Q, H04B, H04H, H04J, H04K, H04M, H04N1, H04N7, H04N11, H04Q, H04W.**4 - Digital communication :** H04L. **5 - Basic communication processes:** H03.6 - Computer technology: G06 (but not G06Q), G11C, G10L.**7 - IT methods for management:** G06Q. **8 - Semiconductors:** H01L.

Instruments, s=2
9 - Optics: G02, G03B, G03C, G03D, G03F, G03G, G03H, H01S. **10 - Measurement:** G01B, G01C, G01D, G01F, G01G, G01H, G01J, G01K, G01L, G01M, G01N, G01N33G01P, G01R, G01S, G01V, G01W, G04, G12B, G99Z. **11- Analysis of biological materials:** G01N33. **12 - Control:** G05B, G05D, G05F, G07, G08B, G08G, G09B, G09C, G09D. **13 - Medical technology:** A61B, A61C, A61D, A61F, A61G, A61H, A61J, A61L, A61M, A61N, H05G.

Chemistry, s=3
14 - Organic fine chemistry: C07B, C07C, C07D, C07F, C07H, C07J, C40B, A61K8, A61Q. **15 - Biotechnology:** C07G, C07K, C12M, C12N, C12P, C12Q, C12R, C12S. **16 - Pharmaceuticals:** A61K, A61K8, A61P (added, not present in WIPO document). **17 - Macromolecular chemistry, polymers:** C08B, C08C, C08F, C08G, C08H, C08K, C08L **18 - Food chemistry:** A01H, A21D, A23B, A23C, A23D, A23F, A23G, A23J, A23K, A23L, C12C, C12F, C12G, C12H, C12J, C13D, C13F, C13J, C13K. **19 - Basic materials chemistry:** A01N, A01P, C05, C06, C09B, C09C, C09F, C09G, C09H, C09K, C09D, C09J, C10B, C10C, C10F, C10G, C10H, C10J, C10K, C10L, C10M, C10N, C11B, C11C, C11D, C99Z. **20 - Materials, metallurgy:** C01, C03C, C04, C21, C22, B22. **21 - Surface technology, coating:** B05C, B05D, B32, C23, C25, C30. **22 - Micro-structure and nano-technology:** B81, B82. **23 - Chemical engineering:** B01B, B01D0, B01D1, B01D2, B01D, B01D41, B01D5 (added, not clear in WIPO document), B01D8 (added, not clear in WIPO document), B01D9 (added, not clear in WIPO document), B01D43, B01D57, B01D59, B01D6, B01D7, B01F, B01J, B01L, B02C, B03, B04, B05B, B06B, B07, B08, D06B, D06C, D06L, F25J, F26, C14C, H05H. **24 - Micro-structure and nano-technology:** A62D , B01D45 , B01D46 , B01D47 , B01D49 , B01D50 , B01D51 , B01D52 , B01D53, B09, B65F, C02, F01N, F23G, F23J, G01T, E01F8, A62C.

Mechanical engineering, s=4
25 - Handling: B25J, B65B, B65C, B65D, B65G, B65H, B66, B67. **26 - Machine tools:** B21, B23, B24, B26D, B26F, B27, B30, B25B, B25C, B25D, B25F, B25G, B25H, B26B. **27 - Engine pumps, turbines:** F01B, F01C, F01D, F01K, F01L, F01M, F01P, F02, F03, F04, F23R, G21, F99Z. **28 - Textile and paper machines:** A41H, A43D, A46D, C14B, D01, D02, D03, D04B, D04C, D04G, D04H, D05, D06G, D06H, D06J, D06M, D06P, D06Q, D99Z, B31, D21, B41. **29 - Other special machines:** A01B, A01C, A01D, A01F, A01G, A01J, A01K, A01L, A01M, A21B, A21C, A22, A23N, A23P, B02B, C12L, C13C, C13G, C13H, B28, B29, C03B, C08J, B99Z, F41, F42. **30 - Thermal processes and apparatus:** F22, F23B, F23C, F23D, F23H, F23K, F23L, F23M, F23N, F23Q, F24, F25B, F25C, F27, F28. **31 - Mechanical elements:** F15, F16, F17, G05G. **32 - Transport:** B60, B61, B62, B63B, B63C, B63G, B63H, B63J, B64.

Other fields, s=5
33 - Furniture, games: A47, A63. **34 - Other consumer goods**: A24, A41B, A41C, A41D, A41F, A41G, A42, A43B, A43C, A44, A45, A46B, A62B, B42, B43, D04D, D07, G10B, G10C, G10D, G10F, G10G, G10H, G10K, B44, B68, D06F, D06N, F25D, A99Z.**35 - Civil engineering:** E02, E01B, E01C, E01D, E01F1, E01F3, E01F5, E01F7, E01F9, E01F1, E01H, E03, E04, E05, E06, E21, E99Z.

Appendix B – Krugman index of technological specialization.

The Krugman (1991) specialization index (hence, TS) expresses the degree by which country shares of different technologies differ with respect to the shares prevailing in the rest of the world:

$$TS_i = \sum_{s=1}^{5} abs(\alpha_{s,i} - \alpha_{s,-i}),$$

where *abs* indicates the absolute value, $\alpha_{s,i}$ is the share of technology *s* (*s=1,2,…5* in our case) in country *i* and $\alpha_{s,-i}$ is the share of technology *s* in the rest of the world. It is easy to show that $0 \leq TS_i \leq 2$. At its lower bound, the technological structure of a country is the same as the rest of the world. At its upper bound, the country does not share any technology with the rest of the world.

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Tables

Table 1. Patents specialization and internationalization.

Period	*Spec*	*TS*	*Iai*
1990 – 1993	2.529	.428	8.305
1994 – 1997	3.018	.382	9.135
1998 – 2002	3.428	.377	12.405
2003 – 2006	3.147	.378	12.645

Notes: Spec is the inverse of the coefficient of variation of the TRCA index. *TS* is Krugman's (1991) index of technological specialization. *Iai* is the *InvAppInv* measure of internationalization of R&D activities in Picci (2010).

Table 2. Estimates

	(1)	(2)	(3)	(4)	(5)
Log inventive size	0.536***	0.691***	0.016	0.136**	0.613
	(0.050)	(0.074)	(0.195)	(0.067)	(0.475)
Internationalization	0.022***	0.049***	-0.023	0.013**	0.043**
	(0.005)	(0.010)	(0.017)	(0.005)	(0.016)
1-year lag *Spec*				0.746***	0.381*
				(0.099)	(0.203)
Observations	578	408	34	544	510
R^2	0.326	0.298	0.017	0.621	
Adjusted R^2	0.304	0.274	-0.047	0.608	
F	9.086		0.950	68.833	3.469
Fixed Effects	Yes	Yes	No	Yes	Yes

Notes: The independent variable in Columns 1,2,4,5 is the *Spec* index of specialization. In Column (3) it is the variation of *Spec* between 1990 and 2006. Column (1) displays the results for the OLS regression. Column (2) displays the results for the Instrumental Variable model. Column (3) displays the OLS results for changes in *Spec*. Column (4) employs the Fixed Effects estimator, and Column (5) employs the Arellano – Bond estimator. *** indicates significant at 1% level; ** at 5% level; * at 10% level. Robust error options are used in all cases.