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Lucio Picci and Luca Savorelli

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The “Inventor Balance” and the Functional Specialization in Global Inventive Activities

Lucio Picci and Luca Savorelli¹

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Abstract

Inventors and organizational assets are inputs for inventive activities which are increasingly provided at a global scale. Internationalization, in turn, has created scope for countries to specialize in the provision of one or the other type of inputs. We introduce a new patent-based metric, the “inventor balance”, to quantify this type of functional specialization, which we discover to be considerable, and we propose a conceptual framework to explain it. We find a progressive “decoupling” of national sub-systems providing respectively inventors and organizational assets. Moreover, we find that countries with a high level of innovativeness relative to their economic development, high technological specialization, and strong individualistic cultural traits contribute relatively more inventors than organizations.

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Keywords: Patents, Inventor balance, Inventor criterion, Applicant criterion, Internationalization of R&D, Specialization.

¹ Lucio Picci (*corresponding author*): Department of Economics, University of Bologna, Strada Maggiore, 45, 40126 Bologna, Italy, and JRC-IPTS, Seville, Spain. E-mail: lucio.picci@unibo.it; and Luca Savorelli: School of Economics & Finance, University of St Andrews, Castlecliffe, The Scores, St. Andrews, Fife KY16 9AR, Scotland, United Kingdom. Tel. +44 1334 462449; e-mail: luca.savorelli@st-andrews.ac.uk.

1. Introduction

Inventions are the work of individuals who operate within organizations, most often, firms. Inventors and organizations, as inputs in the production of inventions, are themselves the output of complex processes, which are largely shaped by the interactions between institutions of various types. Also, inventions are increasingly produced at the global scale,² which implies that organizations can obtain inventors and other relevant assets from abroad. As a result, countries might specialize in the provision of some inputs of the inventive process – be them inventors, or organizations. In this paper we aim to study the extent and motives of such form of functional specialization, which so far has attracted scant and unsystematic attention.³ It is a question with potentially important policy implications, because such functional specialization might represent an opportunity for countries to attract foreign assets in order to build up innovation capabilities (Giuliani et al. 2016), but also, by generating lock-in phenomena (Athreye and Cantwell 2007), it could ultimately endanger a country's prospects of future development.

This type of functional specialization can be seen in the light of the motivations behind firms' decisions to internationalize their R&D activities, be them of the 'asset exploiting' or 'augmenting' type (Kuemmerle 1997). In this vein, Lewin et al. (2009) show that one of the main reasons leading US firms to offshore R&D is the relative scarcity of domestic inventors and skilled workers. Other studies have indicated that the creation of a comparative advantage in highly-skilled personnel in the global technology production chain has played an important role to attract complementary assets from multinational corporations (Ernst 2002; Arora and Gambardella 2005; and Iammarino and McCann 2013). Occasionally, this literature has hinted at the presence of functional specialization, where industrialized countries provide relatively more organizational assets, and emerging countries, relatively more inventors. The emerging phenomenon of multinational enterprises based in developing countries, tapping into industrialized countries human capital and

² See among others Guellec and van Pottelsberghe de la Potterie (2001), Criscuolo et al. (2005), Athreye and Cantwell (2007), and Picci (2010).

³ At this stage, we simply note that such specialization at the country level might occur, so as to represent an “empirical fact”. We will discuss its causes and, in the concluding section, the possible roles of policies.

organizational assets, has been attracting increasing attention, and provided nuance to our understanding of the phenomenon (Giuliani et al. 2014).

In this paper we show that functional specialization of inventive activities is a relevant phenomenon not only between emerging and advanced economies, but also among industrialized ones. We quantify functional specialization by introducing a new patent-based metric, the “inventor balance”. It measures the degree by which a country contributes *relatively* more inventors than organizational assets to the production of international patents. The inventor balance exploits the distinction, present in patent records, between inventors (who are invariably persons) and applicants (which in most cases are firms). It equals to zero when there is no imbalance, and it ranges between -1 (in the extreme theoretical case where a country contributes only applicants, and no inventors) and $+1$ (in the opposite extreme theoretical case).

We compute the inventor balance for the period 1980-2009 for a set of 32 countries, also separately for distinct families of technologies. Some countries, such as the United States and Switzerland, are specialized contributors of organizational assets, while others, such as China, Italy, and the United Kingdom, mostly provide inventors. In between we identify a group of countries which are weakly specialized overall, but display specialization in one or more technologies: functional specialization does not occur only when comparing emerging economies with industrialized ones, but it can be observed also within the former group.

To explain this type of functional specialization we build on studies theorizing the role of institutions in innovation systems, to propose a stylized conceptual framework leading to a set of testable hypotheses.⁴ The relevance of institutions has important consequences when considering the motivations of firms to internationalize their R&D activities. In particular, to a 'narrow' view of what defines the relevant assets that inform firms' decisions to internationalize, it leads us to prefer a 'macro' perspective. According to it, when exploiting their assets abroad, firms also leverage on the general characteristics of the domestic innovation system where they are embedded, and when attempting to augment their assets through internationalization, they eventually become embedded into, and benefit from, the innovation system

⁴ See Edquist (1997), Lundvall (1992), and Nelson and Winter (1982). For considerations about the internationalization of innovation systems see also Carlsson (2006), and Soete et al. (2010).

abroad (Criscuolo et al. 2005). Our conceptual framework is grounded on these considerations.

We focus on the inventive step and consider a country's economic system where two domestic sub-systems interact, one providing organizations, the other supplying inventors. Organizations and inventors together produce inventions, within an “invention production function” of which they are the inputs. When internationalization is present, a share of domestic inventors might be matched with foreign organizations, and vice-versa. One of the main testable assumptions that we derive from our conceptual framework is that, as internationalization progresses, the interactions between the two domestic sub-systems weakens, leading to their progressive “decoupling” - that is, to they becoming more independent from each other. In fact, there is mutual causation between these two factors, because such decoupling motivates further internationalization. Our data supports this hypothesis, also by showing that the observed imbalances on average tend to grow in time.

Our conceptual framework provides other testable hypotheses, thus guiding our search for factors explaining observed patterns of functional specialization. We anticipate some of these results. We find that greater internationalization of R&D is associated with more functional specialization. Countries that are not very innovative, relative to their level of economic development, are found to contribute more inventors than applicants, as do those with a high degree of technological specialization relative to the world average. Moreover, the inventor balance depends on a country's relative abundance of inventors vs. applicants. Last, we find that informal institutions and “soft” features (Crescenzi et al. 2016), such as cultural traits, have a role in explaining observed inventor imbalances. In particular, countries where individualistic traits prevail tend to contribute relatively more inventors than applicants.

We proceed as follows. In the next section we illustrate a conceptual framework aimed at explaining the inventor balance. In section 3 we present the data and we introduce a measure of functional specialization, the “inventor balance”, which in section 4 is the object of a descriptive analysis. Section 5 presents results using inferential methods, and section 6 concludes.

2. A Conceptual Framework

Systemic theories of innovation have mostly focused on national systems, and as such they have been challenged by the increasing internationalization of R&D activities (see Carlsson 2006; Soete et al. 2010). Under this light, and of particular relevance to us, Criscuolo et al. (2005) propose a 'macro' perspective on the internationalization of multi-national enterprises (MNEs). Such view certainly accepts that MNEs decisions to internationalize R&D are motivated by traditional 'narrow' reasons, such as exploiting firms' assets, and augmenting them by tapping into assets abroad (Kuemmerle 1997). According to the 'macro' view, however, the overall characteristics of the innovation systems in which a firm is embedded matter, both at home and abroad. When a firm internationalizes, “it seeks to exploit not only its own technological assets, but also those associated with its home country innovatory milieu”, and likewise, it “engage[s] in R&D in a foreign location to avail [itself] of complementary assets that are location specific, [it is] essentially aiming to explicitly internalise several aspects of the systems of innovation of the host location.” (Criscuolo et al. 2005). Dunning and Narula (1995) also provide evidence that home-base augmenting motivations are explicitly driven by the characteristics of the whole innovation system at the foreign location.

We ground our conceptual framework, which we shall illustrate shortly, on such theory, where firms are embedded in the innovation systems where they operate, so that 'narrow' motivations for internationalization coexist with the presence of 'macro' considerations, that in turn might trigger system-wide effects. These might result from the interplay of numerous actors at the micro-level (Soete et al. 2010), in a situation where outcomes are determined by market forces, but whose effects are mediated by many non-market formal and informal institutions. Among the former, we cite the overall configuration of the higher-education system and laws, and among the latter, we mention broadly defined cultural traits, traditions, social norms and social capital.⁵

We focus on the inventive step, and we thus refer to *invention* (rather than innovation) systems. As anticipated in the previous introductory section, our conceptual framework revolves around the production of inventions, resulting from the interaction of organizations with inventors within an *invention production*

⁵ On institutions, and on their role within innovation processes, see Freeman (1987), North (1990), Edquist and Johnson (1997), and Coriat and Weinstein (2002).

function. We define organizations as set of routines and assets (Nelson and Winter, 1982). Inventors are specialized workers who have the skills to develop new processes or products, which we thus call of “inventor grade”. By this we mean that they are professionals, for example engineers that, while having the capability to be inventors, could also be employed otherwise, for example as production engineers. We consider human capital mobility across borders to be difficult, which is consistent with the finding that, also because of the tacit nature of knowledge, human-capital is location-bound (Almeida and Kogut 1999). This relative immobility, in turn, is a chief reason for MNEs to offshore R&D so as to tap into local knowledge abroad (Athreye and Cantwell 2007).

Inventors and organizations are inputs in the production of inventions, and also they are the *outputs* of two complex sub-systems, which we call the “inventors sub-system” and the “organizations sub-system”. Figure 1 illustrates our conceptual framework, which shows the two sub-systems both for the home country, and for a generic foreign country. In the home country, the supply of inventors and of organizations is shown at the top of Figure 1, where thick arrows represent the collaboration of domestic inventors and organizations to produce inventions.

[Figure 1 about here]

The inventors sub-system is shaped by educational institutions and also by cultural traits. The organizations sub-system comprises a more diverse set of institutions, including agencies and bodies determining innovation processes and policies (the “knowledge infrastructure”, as in Smith 1998), coordination mechanisms among actors (Nelson and Rosenberg 1993), the intellectual property right system, labour market laws, and social norms.

The different elements of the model are linked by mutual relationships which we call “feedbacks”. In Figure 1, they are represented by the thin arrows. We consider first the relationships between the two sub-systems within the same country, whose strength, we argue, is an interesting and problematic issue. To fix ideas we begin by assuming the hypothetical case where there is no internationalization in inventive activities, which later we introduce to enrich our analysis.

First, we note that in the production of inventions, the degree of substitutability

between inventors and organizations is bound to be limited.⁶ For this reason, any relative imbalances in the two productive inputs would reverberate backward to the two sub-systems. A scarcity of inventors might reflect a more general scarcity of skilled personnel, and as such may spur adjustments to induce the inventors sub-system to increase supply. For example, entrepreneurs could successfully lobby to increase public expenditure in higher education. At the sectoral level, a perceived excess demand of highly skilled personnel in one sector would likely modify vocational choices, by inducing young people to pursue careers in the more promising sectors. Also, inasmuch as scarcity in skilled personnel hampers the activities of firms, some of them might be forced to close, or maybe they would not grow unhampered, so as to eventually reduce imbalances.

Such adjustments would be delayed and also, quite likely, they would be weak, in part because both sub-systems cater to needs which go beyond the mere production of inventions, or of inventive organizations. For example, a country where there is an abundance of firms which are not very innovative, but that still need many highly skilled professionals, spurs the education system to supply them. Among these specialists, there would be an oversupply of “inventor grade” specialists persisting in time, to the extent that they can also be employed in non-inventive jobs. In conclusion, even without internationalization, the feedbacks between the two sub-systems would be weak, and delayed in time.

The main insight of our conceptual framework is that internationalization, whose feedbacks are shown in Figure 1 by the dashed arrows, further “decouples” the two sub-systems at the national level, and is both a cause, and an effect, of functional specialization. This is so because when the inputs of the inventions production function may also be sourced abroad, potential domestic inventors are also employable by foreign firms, whereas domestic firms may also hire foreign inventors. As a consequence, the effects of any imbalance between inventors and organizations on the two sub-systems would be even weaker, and adjustments take longer,

⁶ For example, a firm facing a scarcity of inventors may partially substitute them with more capital goods, such as better laboratories, or with better complementary services to enhance the productivity of the existing inventors. However, relative imbalances in the two inputs most likely would not result in much factor substitution *within* a given production process, but rather in the choice of production processes that are compatible with the given relative availability of inputs.

compared to the case of a purely domestic production of inventions. This leads to our first hypothesis:

H1: The observed patterns of functional specialization of countries in the provision of inventor and organizations are persistent in time.

Increased internationalization, by weakening the feedbacks between the inventors and organizations sub-systems further, would then be associated with their progressive *decoupling*. *Internationalization* and *decoupling* of sub-systems co-evolve, and reinforce each other: as feedbacks weaken, imbalances grow, and inventors and organizations have a stronger incentive to seek their desired matching assets abroad. In turn, such increased internationalization further increases the decoupling of the two sub-systems and might further increase imbalances.⁷ These considerations lead to the second of our testable hypotheses:

H2: An increase in the internationalization of inventive activities is associated with an increase in countries' relative imbalances in the contribution of inventors vs. organizations.

The demand for inventors relative to generic specialized professionals varies across countries, depending on the degree of innovativeness and economic development. The demand for inventor-grade specialists is relatively higher in countries which are highly innovative relative to their degree of economic development, because such personnel is employed both for the needs of general production, and of producing inventions. As we argued, any adjustments of the imbalances between the two sub-systems would be partial, and it would occur with delays. For this reason, we expect relatively more innovative countries to run an inventor deficit with respect to countries which are relatively less innovative:

⁷ Please note that the focus is on relative, and not absolute imbalances. Absolute imbalances on average increase as internationalization proceeds. This is not necessarily the case for imbalances *relative* to the level of internationalization.

H3: A country's relative functional specialization in the contribution of inventors is negatively associated with its innovativeness, relative to its degree of economic development.

The next testable hypotheses (H4 – H6) all stem from considerations of the possible determinants of motives of R&D outsourcing by multinational firms which, as we argued, besides 'narrowly' considering their own assets and immediate needs,⁸ also have broader interests of a 'macro' type. Within this backdrop, whenever asset augmenting motivations are relevant, when deciding where to carry out their inventive activities firms likely take into consideration the relative availability of inventive resources provided by the inventors sub-system. If one country has relatively few inventors, it will be more likely to act as a provider of organizations and source inventors from other countries. Likewise, on the basis of standard labour market competition arguments, for a given pool of inventors in the home country, the more abundant are innovating firms, the more difficult it will be for them to hire inventors. Tougher competition for inventors in the home country has two effects: first, home country organizations will be pushed to hire inventors abroad. Secondly, organizations from abroad will find it difficult to hire inventors in the home country. Both effects would result in an inventor deficit in the home country. These considerations lead to the two following hypotheses:

H4: A country's functional specialization in the contribution of inventors vs. organizations depends positively on the relative abundance of inventors,

and:

H5: A country's functional specialization in the contribution of inventors depends negatively on the relative abundance of organizations.

While to some extent organizational routines (such as management skills) are transferable across sectors, specialized invention-grade knowledge is not – for

⁸ Almeida (1996), Kuemmerle (1997), Patel and Vega (1999), and Le Bas and Sierra (2002) provide evidence in support of the home-base exploiting motivation. More recently, some evidence has suggested a shift during recent decades from home-base exploiting R&D activities to home-base augmenting ones (Song et al. 2011).

example, the knowledge of a biotechnology scientist can be hardly transferred to the electrical engineering sector. For this reason, while MNEs might easily access managerial skills domestically, any scarcity in domestically provided specialized human capital might compel them to look for a solution abroad, and in those foreign countries that have a relative advantage in the relevant sectors, as also Cantwell and Vertova (2004) indicate. This amounts to surmise that country i 's inventors are relatively more attractive when country i 's *technological* specialization is high, and country j 's is low. However, as we argued, the attractiveness of a foreign innovation systems stems not only from its patterns of specialization, but also from its overall characteristics, as firms seeking inventive assets abroad “are essentially aiming to explicitly internalise several aspects of the systems of innovation of the host location” (Criscuolo et al. 2005). We then expect some countries to be attractive not only in the technological sectors of specialization but, to an extent, across the spectrum of technologies. From these considerations, the following hypothesis emerges:

H6: A country's functional specialization in inventors (organizations) depends positively (negatively) on the degree of technological specialization. Specialized countries tend to display inventor surpluses across the spectrum of technologies.

Within the 'macro' view on motivations for internationalization of R&D which we have embraced, other overall characteristics of the innovation systems, at home and abroad, might contribute in explaining the observed functional specialization. We consider first the strength of protection for intellectual property rights (IPR; see Park 2008). Countries with stronger IPR protection are more likely to act as providers of organizations, considering that multinational firms usually file their patents through the headquarters in the home country (on this aspect, see the discussion in the next section). Such an effect would follow from the presence of a comparative advantage for foreign firms in the country providing inventors, because they would be better able to enforce IPR with respect to local ones.

Finally, theories of innovation systems place a prominent role on cultural dimensions and informal institutions (Edquist and Johnson 1997). The degree of individualism of a society has been found to have a positive effect on the level of output and of patenting activity across countries (Gorodnichenko and Roland 2010 and 2011) and also across regions within the same country (in the United States,

Gorodnichenko et al. 2011; in China, Talhelm et al. 2014). Different explanations of such findings have been advanced. Gorodnichenko and Roland (2011) argue that individualistic cultures reward inventors with more prestige, while Talhelm et al. (2014) and Henrich (2014) propose that individualistic societies prize analytical reasoning, which in turn enhances novelty and creativity.

We are interested in the possible effects of individualistic traits not on cross-border inventive collaborations *per se*, but on the presence of *imbalances* in the relative provisions of organizations and inventors. Any such effect would arise from the presence of a differential effect of a given cultural trait on the two sub-systems. We anticipate that our results in this respect depend on whether we consider or not the United States which, in terms of the measure of individualism that we use (Hofstede 2001), is both the most individualistic country and the home-base of world-leading highly innovative organizations.

3. The Data and the Inventor balance

We use the Patstat database (European Patent Office 2013a, 2013b) and we consider all priority applications of 34 countries filed at any of a group of 50 patent offices from 1980 to 2009, representing the virtual totality of worldwide patenting activity. We employ the methodology presented in De Rassenfosse et al. (2013),⁹ and whenever for simplicity we mention patents, in fact we always mean patent

⁹ The methodology takes full advantage of the fact that Patstat allows the tracking of multiple applications claiming the right to priority for the same invention in different offices, 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). The 50 patent offices that we consider are the national patent offices of all OECD countries, countries invited to open discussions for membership to the OECD (Brazil, China, India, Indonesia, and South Africa), plus those of Bulgaria, Cyprus, Honk Kong, Latvia, Lithuania, Malta, Romania, Russia, Singapore, Taiwan, and the European Patent Office. In all cases, we adopt so-called “fractional counting” of patents: for example, if a patent has three inventors and two applicants, the inventors are counted 1/3 each, and the applicants 1/2, so that each patent always counts as one, regardless of whether the inventor or the applicant criterion is chosen.

applications. We distinguish between inventors and applicants. While inventors are always individuals, applicants may be firms, universities and other research institutions, governmental organizations, non-profit organizations and, finally, also individuals.¹⁰

Inventors and applicants are assigned to countries according to their address, so subsidiaries of multinational are recorded as separate entities and not consolidated with the headquarters country.¹¹ We define a patent to be “international” if at least one of its inventors and/or applicants resides, or is headquartered, in a country different from those of the others.¹² In our population of 16.212.708 patents we do not identify the nature of the applicant, because it would be prohibitively costly to do so.

Patent applications are assigned to one or more codes describing their technology according to the WIPO’s International Patent Classification (WIPO 2011). We adopt the taxonomy proposed by Schmoch (2008), who identifies 35 technologies that can be regrouped into five macro-technologies: electrical engineering (*Electr*), instruments (*Instr*), chemistry (*Chem*), mechanical engineering (*Mech*), and other fields (*Other*).¹³

We express country i portfolio of patents in the year t as Inv_{it} or App_{it} , depending on whether the inventor or the applicant criterion is adopted. This

¹⁰ 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 headquarter, and another 15% of cases involve firms which are not multinationals. Our population of patents is roughly twice that analysed in Picci (2010), since we consider additional (minor) patent offices and a longer time interval.

¹¹ This perfectly coherent with the necessities of our research questions, which focus on country characteristics. A more granular understanding of the nature of each patent, including the identity of the organization filing it, would be outside of the scope of the present research.

¹² The term “international” is here used 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”.

¹³ These computations also are done fractionally, so that patents with multiple codes belonging to more than one macro-technology are counted appropriately. See Appendix A.2 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.

distinction is important for our empirical exercise. For example, a multinational from country A may employ an inventor from country B to produce a patent, which for country A would count as one patent if we use the applicant criterion, but zero if we adopt the inventor criterion (the opposite would apply for country B). It follows that countries' patent portfolios may diverge depending on whether they are computed using either criterion. Also, the example above shows a case of functional specialization, where country A only provides organizations, and country B only inventors.

A first possible concern with the data arises if multinational enterprises file applications in a country where there is a favourable tax treatment for intellectual property, rather than in the country where the inventive activities were developed. However, in some instances such transfer is prohibited by law, and the existing literature suggests that "intellectual property migration" should not affect significantly patent statistics.¹⁴ A second possible concern is that assigning inventors to a country according to their address might lead to mis-measurement due to temporary migration of inventors. However, the available evidence, and in particular Thomson (2013), finds no significant impact of cross-border migration. This is consistent with the evidence that human capital is rather immobile across borders (Almeida and Kogut 1999).

To measure the intensity of collaborations between any two countries, we employ the most general measure of internationalization introduced by Picci (2010): $InvApp_{ijt}$. It is a (fully fractional) multiplicative count of patent applications involving inventors of country i and applicants of country j , in a given year t (the year subscript is henceforth omitted for simplicity). The $InvApp_{ij}$ measure can be interpreted as the strength of the collaboration between country i 's inventors and country j 's applicant. We refer to Appendix A.1 for more information, and to Picci (2010) for a detailed description of this and related measures; here it suffices to underline that this measure aggregates to the overall country portfolios, because, considering a set of countries $\Theta = 1, \dots, i, j, \dots, N$, the following holds:

¹⁴ See the discussions in Thomson (2013, Section 3), and in Danguy et al. (2014); Picci (2010), in the cited sample of 1000 international patents which he considers, finds that 82.6% multinational enterprises filed their applications through their headquarters (see his Table 3).

$$\sum_{j=1}^N InvApp_{ij} = Inv_i . \quad [1a]$$

$$\sum_{i=1}^N InvApp_{ij} = App_j . \quad [1b]$$

Note that the summations include the case when $i=j$, i.e. the own contribution of a country's inventors or applicants to the total country portfolio.

[Table 1 about here]

Table 1 provides a summary of the patent portfolios of the top-ten countries in terms of number of patents. It witnesses the very high number of Japanese patents, a well-known fact partly consequent from their relatively narrow scopes (Coehn et al. 2002; and Sakikabara and Branstetter 2001). Also, Table 1 shows the surge in Korean and in Chinese patents over the most recent years.

[Figure 2 about here]

Figure 2 reports for a small group of important countries $InvApp/Inv$, one of the relative measures of internationalization introduced by Picci (2010).¹⁵ The degree of internationalization, which has increased in time, is pronounced enough to make it *a priori* plausible that functional specialization in inventive activities is a phenomenon deserving attention – in a world without internationalization, there could not be any functional specialization.

3.1 The “inventor balance”

To measure the degree and type of functional specialization of a country, we introduce the “inventor balance”, which we may compute both between pairs of

¹⁵ The upper bound of such measure is 0.5 (or 50%), corresponding to the maximum possible degree of internationalization. Intuitively, this is so because the measure accounts for both the international and the domestic component of patent production, with the latter being present even when the degree of internationalization is at its maximum. See Appendix A.1 and Picci (2010) for additional details.

countries, and also between one country and the rest of the world.

Considering two countries, i and j , we define the *bilateral* inventor balance as:

$$InvBal_{ij} = \frac{InvApp_{ij} - InvApp_{ji}}{InvApp_{ji} + InvApp_{ij}}, \quad [2]$$

where $InvApp_{ij} > 0$ or $InvApp_{ji} > 0$.

It is equal to the relative imbalance in inventors vs. applicants in the collaborative inventive activities involving country i 's inventors and country j 's applicants. $InvBal_{ij}$ ranges from -1 to +1. It is equal to zero if there is no imbalance between country i and country j . If $InvBal_{ij} > 0$, we say that country i displays an ‘‘Inventor Surplus’’ (or ‘‘Applicant Deficit’’), i.e. it contributes relatively more inventors than applicants compared to country j .¹⁶ Likewise, if $InvBal_{ij} < 0$, country i displays an ‘‘Inventor Deficit’’ (or ‘‘Applicant Surplus’’). The lower bound ($InvBal_{ij} = -1$) corresponds to the theoretical extreme case where country i contributes only applicants and no inventors to the joint production of inventions with country j , while at the upper bound ($InvBal_{ij} = +1$) the opposite holds. If country i displays an inventor surplus, country j displays an inventor deficit of the same entity. $InvBal_{ij}$ can be computed both for all technological sectors, and also separately for individual technological sectors, a possibility that we exploit in our analysis.

The inventor balance with respect to the ‘‘Rest Of the World’’, $InvBal_{i,ROW}$, measures whether country i contributes to the production of international innovations more with applicants or with inventors, regardless of where these collaborations occur:

$$InvBal_{i,ROW} = \frac{\sum_{j=1}^N InvApp_{ij} - \sum_{j=1}^N InvApp_{ji}}{\sum_{j=1}^N InvApp_{ij} + \sum_{j=1}^N InvApp_{ji}}, j \neq i. \quad [3]$$

Analogously to the bilateral case, $InvBal_{i,ROW} = +1$ in the extreme theoretical case where country i only contributes inventors, and no applicant, to the production of

¹⁶ The symmetric nature of the inventor balance means that ‘‘Inventors Surplus’’ and ‘‘Applicant Deficit’’ are synonyms and can be used interchangeably.

international patents anywhere in the world, and $InvBal_{i,ROW} = -1$ in the opposite case.

Using [1a] and [1b], straightforward calculations allow us to express [3] so as to make it depend on magnitudes relative to country i alone:

$$InvBal_{i,ROW} = \frac{Inv_i - App_i}{App_i + Inv_i - 2 \cdot InvApp_{ii}} \quad [3']$$

This formulation of the inventor balance has an intuitive appeal. The numerator expresses the difference in a country portfolio depending on which counting criterion is employed. A positive value indicates a prominence of inventors over applicants, which necessarily reflects a situation where national inventors outweigh national applicants in producing international inventions. The denominator is a normalization factor, and intuitively equals twice the national contribution to international innovations.¹⁷ It is the normalization needed to assure that $-1 \leq InvBal_{i,ROW} \leq +1$.

4. Descriptive analysis of the inventor balance

In Table 2 we show the inventor balance, for selected countries, relative to all technologies and computed for the last decade of the time period under consideration (2000-2009).

¹⁷ If every patent were produced by entities residing, or being headquartered, in the same country (that is, if there were no internationalization) then it would follow that $Inv_{it} = App_{it}$ for any i and t . Whenever $Inv_{it} \neq App_{it}$, the divergence in the fractional count must be associated with the presence of international collaborations in patenting activities. $InvBal_{i,ROW}$ is related to Thomson (2013) “net R&D offshoring”, which, using our notation, equals $(App_i - Inv_i)/Inv_i$. (see his Table 3, 3rd column). Our measure differs from Thomson’s in the denominator, which in our case normalizes the metric so that its range is $(-1, +1)$. On the other hand, Thomson’s measure is bounded between -1 and $+\infty$, which complicates its interpretation, since it is not symmetric around zero.

[Table 2 about here]

We focus first on the third column, reporting the inventor balance with respect to the rest of the world. We observe ample variations across countries. Some of them, such as the United States and Switzerland, have a significant applicant surplus, while for others, such as China, Italy and the UK, the opposite holds. To interpret the results, consider that an inventor balance greater than $1/3$ (smaller than $-1/3$) implies that the relative contribution of organizations is twice (half) that of inventors. The extent of the observed imbalances (75% of the values of column three are greater than $1/3$ in absolute value) confirms that, indeed, we observe a pronounced pattern of functional specialization in the production of innovative activities at a global scale, where some countries are strongly specialized in contributing organizations, while others predominantly contribute inventors.

For interpretative purposes, we divide countries into three groups:

1. *Specialized applicant providers*: countries whose $InvBal_{i,ROW} < -1/3$. (Switzerland, South Korea, The Netherlands, and the United States).
2. *Specialized inventor providers*: countries whose $InvBal_{i,ROW} > 1/3$. (Canada, China, France, Italy, United Kingdom).
3. *Weakly specialized providers*: countries for which $-1/3 \leq InvBal_{i,ROW} \leq 1/3$. (Germany, Japan and Taiwan).

The next columns of Table 2 show the bilateral inventor balance for all technologies. In considering them, we should consider that $InvBal_{i,ROW}$ may be seen as a weighted average of the various $InvBal_{ij}$, so that, for example, a “specialized applicant provider” is expected to have bilateral applicant surpluses vis-à-vis most other countries. We observe such fact in the countries belonging to this group, and whenever we observe a negative value, it is with respect to another country belonging to the same group, with South Korea and Switzerland, displaying an applicant deficit vis-a-vis Taiwan, as exceptions. The case of the United States stands out, both for the size of its economy and for the extent of its innovative activities. In the next section, where we research the determinants of the inventor balance, we shall comment upon such an instance of “American exceptionalism”.

Countries belonging to the group of specialized inventor providers, on the other hand, are characterized by a majority of bilateral inventor surpluses. Cases of

inventor deficit are vis-à-vis countries of the same group – with the exception of Canada, which has an inventor deficit with respect to The Netherlands. Countries in the intermediate group of weakly specialized providers all have an applicant deficit vis-à-vis the United States, but never with respect to specialized inventor providers.

Within each group there are countries that are very different among themselves in other dimensions. Among specialized applicants providers there are only mature industrialized countries (South Korea, by now, belonging to this category). These are invariably countries which both have a richly textured economic structure, and also a strong educational sector which is able to supply inventors. Within specialized inventor providers, instead, we observe an emerging country such as China together with more mature industrial countries. Such coexistence hints at the presence of dynamic factors explaining the relative strength of applicants vs. inventors. In particular, as China's native firms become more robust and active abroad, the current strong applicant deficits could possibly turn out to be only a temporary phase within a development trajectory. Different dynamics affect countries such as Canada, Italy or the UK, which like China are specialized inventor dynamics, but that have been industrial countries for a longer while.¹⁸

In Table 3 we show $InvBal_{i,ROW}$ both at an aggregate level and separately for the five broad technological fields, for each decade considered.¹⁹

[Table 3 about here]

Most countries display an inventor balance which is rather stable in time, providing support for our hypothesis *H1*. There are however some exceptions. Taiwan experienced a surge in the applicant surplus in the second decade, which was reversed later. Germany saw its inventor balance progressively change over time from a deficit to a surplus. A clear trend is evidenced for China, whose inventor surplus has become more pronounced in time, as that country has been increasingly targeted by multinational firms as a R&D location. In other words, if for transition economies the presence of an inventor surplus could be a transient phase, as they develop an

¹⁸ In a supplementary results section, for the same group of countries we also report bilateral inventor balances for the five broad technological fields considered.

¹⁹ Note that the values for the inventor balance for all technologies in the third decade are reported both in Table 3 and in the third column of Table 2.

industrial base able to be proactive abroad, the data for China do not show (yet) a turnaround.²⁰

We interpret these facts in the light of the asymmetries between the inventors and the organizations sub-systems which we discussed above, where the latter is the result of the interplay of many more diverse institutions. Countries may more easily target successfully their university system for improvements, while developing successful multinational enterprises able to innovate internationally not only may require challenging encompassing industrial policies, but also, enough time for firms to grow in size. Such differences add to the general concerns on the weakness and delays of adjustments, that our conceptual framework brings to the fore.

In most cases, the sign of the inventor balance for individual technologies is the same as that of the aggregate, which we take as *prima facie* evidence that country-specific factors influencing the inventor balance act similarly for all technologies. This result is coherent with the presence of those system-wide effects of national innovation systems which contribute to our hypothesis *H6*.²¹ There are however some exceptions to this tendency. For example, Japan's inventor balance is roughly in equilibrium during the thirty years considered, but we observe important shifts at the sectoral level. In particular, *Instr*, *Mech*, and *Other* shifted from a deficit to a surplus, and the opposite happened to *Electr. Chem*, instead, recorded a sizeable and growing inventor surplus over time.

As a last descriptive exercise, we pose the question as to whether the observed increase in internationalization was accompanied by a progressive decoupling of the supply of organizations and of inventors (our hypothesis *H2*). Such a decoupling could manifest itself through an increase in the magnitude of imbalances in time, both across and within countries. We start by considering the former case. The third column of Table 3 indicates that for most countries, inventor imbalances increased in

²⁰ The comparisons of our Table 2 with Thomson (2013) (Table 3, column 3) “net R&D offshoring” is complicated by the fact that, as we noted, the two metrics are defined differently; moreover, Thomson computes his measure for only one year. However, by and large, the countries displaying a positive (negative) “R&D offshoring” in Thomson's work, present an inventor deficit (surplus) in our analysis.

²¹ The analysis of the bivariate inventor balances by sector (Table 2A in Appendix A4), indicating that countries sectoral bilateral inventor surpluses tend to have the same sign as the aggregate, confirm such result.

time. For all 34 countries considered, a measure of variation within each decade²² is as follows: 0.4062 (1980-1989), 0.4592 (1990-1999), and 0.4713 (2000-2009). The observed increase in the overall amplitude of imbalances is coherent with the presence of a progressive decoupling of the two sub-systems.

When we look within countries and across technological sectors, however, we do not observe an increase in the imbalances. The last column of Table 3 shows a measure of dispersion, measured for each decade, of the sectoral inventor imbalances. The average values are 0.0739 (1980-1989), 0.0619 (1990-1999), and 0.0754 (2000-2009). We read our findings as providing support for hypotheses *H2*, in a situation where, as we argued, effects are system-wide: the fact that imbalances within countries tend to be of the same sign across technological sectors, is coherent with the presence of system-wide effects that define the attractiveness of innovation systems to MNEs contemplating internationalization decisions.

5. Estimation results

We here test the significance of the set of factors identified in the previous section and, with the purpose of providing robust results, we do so in more than one way. First, we consider a series of 30 yearly cross-section regressions, from 1980 to 2009, to explain $InvBal_{i, RoW}$, the inventor balance with respect to the rest of the world. We consider all countries with a world share of patents at least greater than 0.1% in 2009, for a total of 27, that together account for a world share of patents of about 99%.²³

²² It is equal to the square root of the average of the sum of the squared applicant balance, and as such is akin to a standard error. We also computed the median of the absolute applicant balance, obtaining similar results. The measure of dispersion for the sectoral measures, illustrated shortly, equals the square root of the average of the sum of the squared applicant balance, and as such also is similar to a standard error.

²³ We have information on patents with inventors and applicants from a total of 52 countries, but the contribution of some of them is marginal and in some cases negligible. The number of observations for which we have international collaborations ranges from 24 in 1980 to 27 in 2009. Some countries, such as the Russian Federation, are not present in our dataset on internationalization in the early 1980s and were thus not included. The 27 countries are: Australia, Austria, Belgium,

We aggregate the results, that are shown in Table 4, in the following way. For the 30 estimated coefficients relative to each variable, one for each year, we report the median value. To appreciate the overall statistical significance of the estimated coefficients, we indicate first the share of estimates significant at least at the 10% level. Then, we report the share f of coefficients estimated to be positive. Last, we provide an approximate binomial test, similar in spirit to the one reported in Attanasio et al. (2000). It represents the probability that a binomial random variable, with probability of success equal to $\frac{1}{2}$, records a number of successes greater than f , or smaller than $1-f$.²⁴

The data used to estimate the cross-sections are also amenable to pooling and to estimation using a panel data fixed effects model. However, caution should be exercised in adopting such estimation technique. First, fixed effects estimates identify parameters using only the time variation of the data. In the present case, where the focus is mostly on variation across countries, such a criterion is quite onerous on the data, implying that it could result in not detecting an effect of a given variable even when it is present. Most importantly, in a fixed effects estimator, variables which are constant in time are indistinguishable from the fixed effects. In our case in particular, most of the regressors are of this type. These limitations notwithstanding, we also estimated a fixed effects model on the pooled data, and will briefly report in the following paragraphs the results for the two time-varying variables whose effect it allows estimating.

For our second main set of results, shown in Table 5, the dependent variable is the bilateral inventor balance, $InvBal_{ij}$. Focusing on this variable, instead of $InvBal_{i,Row}$, allows us to assess the hypotheses that we derived in Section 2, even if these are formulated in terms directly translatable in terms of $InvBal_{i,Row}$. In fact, the

Canada, China, Czech Republic, Denmark, Finland, France, Germany, Hungary, India, Ireland, Italy, Japan, Mexico, Netherlands, Norway, Poland, South Korea, Spain, Sweden, Switzerland, Taiwan, Turkey, United Kingdom, United States of America.

²⁴ Intuitively, such a probability may be seen as an upper bound p-value for the test of the null hypotheses that the true coefficient is zero, implying a one-half probability of casually observing a point estimate which is positive, or negative (hence the binomial nature of the problem), conditional on independence among trials.

inventor balance with respect to the rest of the world can be interpreted as a weighted average of the bilateral inventor balance: factors associated with the bilateral inventor surplus will also determine its “aggregate” counterpart. This choice of the dependent variable allows us to leverage on much more information with respect to the cross-sectional aggregate analysis of Table 4, and does not require aggregating results from separate regressions. The structure of the data is analogous to that familiar in the estimation of gravity models. However, what we estimate is not a gravity model, because the dependent variable does not represent the intensity of a bilateral relation (such as trade), but a (signed) imbalance of a reciprocal relation.

Since, by construction (see Section 3), $InvBal_{ij} = -InvBal_{ji}$, it follows that if we included a given regressor x twice, once relative to country i (x_i) and once to country j (x_j), the two estimated coefficients would result to be exactly one the opposite of the other. Because of this symmetric nature of the problem, we thus might include only one regressor, the difference $x' = x_i - x_j$, leading to a formulation of the same model which is more compact. A positive estimated coefficient is to be interpreted as a positive impact on the inventor balance, when present in i , and a negative impact of exactly the same magnitude, when present in j .

We use an ordinary least squares estimator. The results of this analysis are presented in Table 5, for two groups of countries: in Panel A, the same group of 27 countries considered also in the cross-section estimates in Table 4; in Panel B, for a smaller group of 12 countries with a share of patents at least greater than 0.5% in 2009.²⁵ Focusing on a smaller set of bigger countries attenuates the risk that results might be driven by few very large firms, and by particular sectors, which in smaller countries might represent a considerable share of total patenting activities. Details on the data are presented in Appendix A.3.

For each sample we present results both using all available years and separately for the sub-periods 1980- 2009, 1990-2009, and 2000-2009, to be able to appreciate any diachronic changes in the underlying relations. For each estimation, we also report results which exclude the United States, for reasons which will become clear shortly. We discuss the results of Table 4 and 5 in conjunction. Please note, again, that when discussing the effect of a given variable, this will be the *level* (or its

²⁵ The 12 countries are: Canada, China, France, Germany, Italy, Japan, Netherlands, South Korea, Switzerland, Taiwan, United Kingdom, United States of America.

log) in the cross-section results of Table 4, and the *difference between the levels* (or their logs) *in countries i and j* , in the empirical model of Table 5.

Before we turn to the results, we observe that, overall, the explanatory variables that we use only account for a fairly modest share of the total variation of the dependent variables, where the R^2 of the pooled models of Table 5 hover at around 40%, which however is reached mostly thanks to the inclusion of the various fixed effects. To exemplify, we consider the results of the model of column 1, of Panel A of Table 5. The R^2 equals 0.357, which would be reduced to 0.280 if we excluded the six main regressors, whose estimate are reported in the table, while including all the fixed effects. The combined presence of the independent variables of interest leads to explaining 7.7% of the total variation of the dependent variable (the difference between the two values of the R^2). While these variables leave most of the total variance of the phenomenon unexplained, in commenting results we will note that their individual estimated effect, as represented by the standardized estimated coefficients, most times are of considerable magnitude.

[Table 4 about here]

[Table 5 about here]

To test $H3$ (see Section 2), we include among the regressors a measure of a country innovativeness, relative to its level of economic development:

$$Innov|GDP = \log\left(\frac{Inv_i + App_i}{2} \cdot \frac{1}{GDP}\right),$$

which is equal to the log of the ratio of a country patent portfolio, computed as the average of the inventories obtained using the inventor and the applicant criterion, and GDP.²⁶

In the cross-section results of Table 4, the effect is estimated to be negative in most cases, while individually it is significantly different from zero only in more than 40% of the estimates, when the US is excluded from the dataset. The results of Table

²⁶ This measure may be criticized on the ground that the numerator depends crucially on the propensity to patent, which varies across countries. See, however, De Rassenfosse and de la Potterie, 2009.

5 for the whole 1980 – 2009 period, on the other hand, unambiguously indicate a significant negative impact of *Innov/GDP* on the inventor balance when the smaller set of countries is considered (Panel B), and indicate contrasting results for the bigger set of countries. Pieced together, our results tend to confirm the hypothesis that in the last decade highly innovative economies, relative to their level of economic development, specialized in the provision of organizations. The magnitude of the effect, as estimated in column (7), Table 5, in terms of its standardized coefficient is equal to -0.42 – that is, a standard deviation change in *Innov/GDP* is associated with about 0.4 negative standard deviation change in the dependent variable.²⁷

All our results unambiguously support *H4* and *H5*: patent inventories positively affect the inventor balance, when adopting the inventor criterion, and negatively, when looking at applicants.²⁸ The effect is sizeable, with standardized estimated coefficients that in most cases are above 4 in absolute values (for the models of Panel A, Table 5). Also, technological specialization has a positive and significant effect on the inventor balance,²⁹ when the whole period 1980 – 2009 is considered. The pooled fixed effects model also indicates a similar positive effect, with an estimated coefficient equal to 0.341, significant at the 5% level. Together with the descriptive evidence of Table 3, indicating persistence of outcome, these results provide support to *H6*. However, overall the effect that we detect is rather modest in magnitude. For example, the estimated coefficient of column (1), Table 5, implies that a one standard deviation change of the technological specialization variable is associated with a change in the dependent variable that is slightly less than 1/10 of a standard deviation.

Besides testing the main hypotheses of our conceptual framework, we also controlled for two possible further factors, related to formal and informal institutions,

²⁷ All results with standardized coefficients are available upon request.

²⁸ Please note that to express these measures we only employed *national* patents, a feature made possible by the type of measures which we adopt. In other words, these measures do not include data which also enter in the definition of the dependent variables.

²⁹ See Appendix A.3. We use a measure of technological specialization over the five macro-areas because they imply meaningful technological distinctions. Using a more granular measure of technological specialization, defined in terms of the 35 constituent technologies categorized by Schmoch 2008, leads to very similar results.

which may affect the inventor balance. We find inconclusive evidence on the relevance of the degree of IPR protection. The coefficients are never significant when considering the larger group of countries (Panel A in both Table 4 and Table 5). When, in the analysis of Table 5, we only consider the smaller group of larger patenting countries, the estimated coefficients are strongly significant and negative only in the last decade (2000-2009), and also in the period 1990-2009 if the US are excluded. These results provide some support to the view that countries with strong IPRs protection are more likely to specialize as applicant-organizations, but only for countries with a sizeable patent portfolio and only in the last decade. The overall evidence on the effect of IPRs is however rather mixed.

We also consider the effect of individualistic cultural traits. Results depend on whether we include or not the United States. We first consider the results using the pooled estimator (Table 5). When we include the United States, we find a negative and significant effect of both cultural variables in all cases (columns (1) - (3), and (7) - (9), Table 5). This might be because the United States rank first in individualism, and at the same time are the home base of many important MNEs. In fact, when we exclude the United States, the results are reversed and significant for the whole periods 1980-2009 and also for 1990-2009 (columns (4) – (5), Table 5). The cross-section estimates (Table 4) are less sensitive to the exclusion of a single observation, and in both cases indicate a positive effect of individualism on the inventor balance. However, we note that the median of the estimated coefficients and the share of significant coefficients increase when we exclude the United States (Panel B, Table 4).

We conclude that individualism leads to an inventor surplus, but only when excluding from the analysis the important exception of the United States, which is characterized both by the highest degree of individualism, and by a strong applicant surplus, and whose “exceptionalism” in the field of innovation emerges also from the present analysis. To assess the magnitude of this effect, we refer to the model of column (4), Table 5, which excludes the US and indicates a positive and significant effect of individualism. The magnitude of the effect as measured by standardized coefficients implies that a standard deviation change in the dependent variable is associated with about 1/3 standard deviation positive change in the inventor balance.

Particularly in the early years under consideration, we record many missing values for the dependent variable, corresponding to cases where there was no bilateral

collaboration between a given pair of countries. To correct for a possible sample selection bias we also estimate the model using Heckman's Lambda Method (Wooldridge 2002), which employs a two-stage estimation method. In the first stage, regressors include factors determining the probability for a country pair to record at least one international collaboration. In the second stage, the residuals of the first stage (the "Lambda" variable) are included as control variable to correct for any selection bias. In all cases we reject the null hypotheses that the errors of the equation of interest, and of the selection equation, are correlated. As a consequence, the estimates using the Heckman estimator are very similar to the ones obtained using OLS (see Appendix A.4, supplementary results, Table 5A).

Also, we address the possibility that unobservable variables are correlated within country pairs, by estimating the pooled models of Table 5 while assuming errors clustered by country pairs. Such an estimation technique, where we also include, as before, time and country dummies, is quite onerous on the data, and it is expected to produce wider estimated standard errors. However, by and large we obtain results similar to those of Table 5, again confirming the robustness of our conclusions (see Appendix A.4, supplementary results, Table 5B).

6. Discussion and conclusions

Most innovations are the product of a matching between organizations, which are typically firms, and inventors. In a world where such production increasingly occurs at the global scale, some countries may specialize in providing one or the other. In this article we have provided a coherent picture of the extent, geographic patterns, and general characteristics of such phenomenon.

We found that the magnitude of the observed imbalance is often considerable, and it has increased on average during the last three decades. We interpreted this result as evidence of a progressive "decoupling" of two sub-systems supplying respectively inventors and organizations, as the degree of internationalization in the production of innovations increases.

The presence of the strong imbalances which we have found poses problems and opportunities to policy makers. Consider the case of a country displaying an important inventor surplus. Such a situation could reflect the presence of a strong

productive base which is not very innovative. In this case, that country's educational system would supply inventor-grade specialists both to the need of the domestic productive sector, which demands many production engineers but few inventors, and to the R&D laboratories controlled by foreign entities. However, much of the value added by new inventions would arguably be captured by foreign firms and be siphoned off abroad.

Such a country would be at risk of hollowing-out of its productive base, which in turn would imperil the resources needed to run essential services, its educational system among them, with long-run negative effects on the very provision of skilled labour. In other words, functional specialization may lead to lock-in processes that could possibly foster short-run well-being, while hindering long-run economic growth. Under such a scenario, even well-intentioned politicians would find it difficult to take the necessary steps, because of the intrinsic difficulties in overcoming a collective action problem in the presence of short-term gains. On the other hand, countries, and particularly so developing ones, might find functional specialization advantageous, if it attracts foreign investments which fosters economic development and in the long run it increases domestic capabilities – among them, inventive ones. The extent to which such a virtuous circle may occur is however uncertain (on a similar vein, see also Lewin et al. 2009, and Athreye and Cantwell 2007).

We provided a conceptual framework of innovation systems in a world where inventive activities are increasingly internationalized. Building on some elements of the theory of national systems of innovation (such as the domestic nature of the inventors and organizations sub-systems), we have proposed a conceptual framework where institutions (and the presence of international feedbacks among them) are important. In doing so, we have implicitly adopted some simplifying assumptions. In particular, we have assumed that the two sub-systems, while receiving feedbacks from the invention production function level, are domestic in nature. This characterization is consistent with evidence showing that innovation systems, even though they are increasingly internationalized, still rely on country-specific institutions (Carlsson 2006). To some extent, ours is only a useful simplification of a more complex reality. For example, the higher echelons of the education system might be able to directly attract talented students from abroad (for similar considerations, see Soete et al. 2010). Such interconnection might be seen as the other side of the coin of the 'macro' view on assets which we have embraced: as domestic actors become embedded in

more than one national innovation systems, the distinctions between what is “national” and “international” become blurred.

The presence of the rich set of international interdependencies which we have discussed suggests that purely national innovation policies may come short of expectations. This, in turn, calls for a heightened attention by policy makers. In a sense, we are confronting yet another case where the internationalization of economically relevant activities is an obstacle to the success of policies which are purely national in scope. Consequently, forms of supranational action, either by suitable institutions – the case of the European Union coming to mind – or resulting from the coordination of national actors, would be called for.³⁰ A constant monitoring of the inventor balance, both in the aggregate and at the level of individual technologies, would be a prerequisite for any action, aimed at avoiding that the opportunities arising from the international matching of inventors and organizations backfire into a new trap of the international division of labour and roles.

Our study has limitations, which also provide suggestions for future research. While patent data are a useful mean to measure inventive activities, they account only for codified knowledge. They thus might underestimate the extent of tacit knowledge present in foreign and domestic locations, and its role in determining functional specialization. In addition, in this paper we explicitly took a 'macro' perspective on the motives of internationalization of R&D by MNEs. Because of the nature of the data, we cannot study how the micro-level nature and characteristics of firms may determine specific patterns of functional specialization. Future research could exploit new, firm-level data associated with patents to study “narrow” drivers of functional specialization, as well as the role played by large actors (e.g. MNEs in the pharmaceutical industry) in determining functional specialization.

We clarified that our aim was not to research the presence of causal relations, but of robust correlations.³¹ Future research could study the channels through which such “soft” institutions hinder or favour a country's functional specialization. However, while associations might be useful for forecasting purposes by policy-

³⁰ For an early discussion of factors hindering the emergence of an European innovation system see Gregersen and Johnson (1997).

³¹ In one case, that of culture, the presence of reverse causality is unlikely, since the deeply-rooted measure of individualism that we employ changes at a very slow rate, and it actually pre-dates the beginning of the time period that we consider.

makers, future studies able to address causal mechanisms could provide more precise policy-recommendations, for example regarding the speed and extent at which a government should facilitate the adjustment of its educational system to the pressure of foreign instances. Changes in such educational policies (e.g. reducing or increasing quotas for students enrolling in engineering) could provide natural experiments to test policy effects on functional specialization.

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[To be added]

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Appendix

A.1 Measures of internationalization in Picci 2010.

The strength of the collaboration between inventors in country i and applicants in country j , for a single patent p , is defined as follows:

$$InvApp_{ijp} = Inv_{ip} \cdot App_{jp}.$$

Summing over patents provides a measure of the strength of the overall collaboration between country i inventors and country j applicants:

$$InvApp_{ij} = \sum_{p=1}^P InvApp_{ijp}$$

We measure internationalization through the measure $InvAppInv$, introduced in Picci (2010). It is a relative measure and expresses the share of international patents in a country's portfolio and it is defined as:

$$InvAppInv_{ij} = \frac{InvApp_{ij}}{Inv_i}.$$

A.2 Taxonomy of technologies (Schmoch 2008).

Electr (Electrical engineering)

- 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.

Instr (Instruments)

- 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.

Chem (Chemistry)

- 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.

Mech (Mechanical engineering)

- 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 (Other fields)

- 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.

A.3 Data description

Patent data. Source: European Patent Office 2013a,b. See the methodological description in Section 3.

Tech specialization: we use Krugman 1991 index of technological specialization over five technological macro-sectors defined as in Appendix A.2 (Schmoch 2008). The Krugman index TS expresses the degree by which country shares of different technologies differ with respect to the shares prevailing in the rest of the world:

$$TS_i = \sum_{s=1}^5 |\alpha_{s,i} - \alpha_{s,-i}|$$

where $|\cdot|$ indicates the absolute value, $\alpha_{s,i}$ is the share of technology s ($s=1,2,\dots,5$, 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.

Individualism. Source: Hofstede 2001. We use the well-known measure of individualism by Hofstede. Questionnaire-based elicitation, 88000 respondents across 72 countries.

Distance. the distance between the capital cities of pairs of countries computed with the great circle formula.

Border: a dummy indicating the presence of a common border between pairs of countries.

Timezone: difference in time zone between pair of countries.

Intellectual Property Rights. Source: Park 2008. Measure of level IPR protection from Park 2008.

Language similarity. Source: Fearon 2003, author's database updated in 2009. The similarity between couple of languages is computed using data from the Ethnologue Project (<http://www.ethnologue.com/>), as collected and organized by James Fearon (see Fearon 2003). The similarity between two languages is based on the distance between "tree branches" (Fearon 2003). Unlike in Fearon's work, who obtains his measure by dividing the number of branches that are in common by the maximum number of branches that any language has (which is equal to 15), we divide it by the maximum number of branches within each couple of language, so as to take into account that the granularity of the branch definition may be not the same across languages.

Gross Domestic Product. Source: World Economic Outlook. Gross domestic product based on purchasing-power-parity (PPP) valuation of country GDP.

A.4 Supplementary results

Table 2A. Bilateral inventor balance, 2000-2009, by sector.

	CA	CH	CN	DE	FR	IT	JP	KR	NL	TW	UK	US
All		-0.52	0.02	-0.04	-0.23	0.36	-0.48	-0.77	0.28	-0.17	0.66	-0.65
Electr		0.09	-0.22	0.07	-0.35	0.71	-0.75	-0.87	0.29	-0.55	0.85	-0.57
Instr	CA	-0.46	0.61	-0.32	0.00	0.55	-0.59	-0.54	0.37	0.48	0.33	-0.79
Chem		-0.84	0.08	-0.12	0.23	-0.64	-0.23	-0.59	0.18	0.35	0.21	-0.81
Mech		-0.85	0.00	0.06	0.38	-0.33	-0.41	-0.82	-0.20	0.00	0.27	-0.61
Other		-0.46	0.16	-0.05	0.83	0.74	0.53	-0.15	0.98	0.38	0.04	-0.70
All	0.52		0.57	0.55	0.88	0.82	0.57	-0.20	0.38	0.14	0.64	0.17
Electr	-0.09		0.49	0.68	0.81	0.81	-0.41	-0.48	0.03	-0.05	0.60	-0.27
Instr	0.46	CH	0.33	0.51	0.90	0.76	0.18	-0.33	0.44	0.20	0.60	0.36
Chem	0.84		0.93	0.56	0.92	0.87	0.83	-0.24	0.10	-0.10	0.74	0.25
Mech	0.85		0.75	0.48	0.91	0.81	0.56	-0.33	0.76	0.00	0.72	0.67
Other	0.46		0.30	0.49	0.81	0.61	0.12	1.00	0.63	0.79	0.24	0.34
All	-0.02	-0.57		-0.69	-0.40	0.38	-0.26	-0.65	-0.54	-0.80	-0.50	-0.84
Electr	0.22	-0.49		-0.73	-0.78	-0.03	-0.58	-0.67	-0.61	-0.85	-0.63	-0.87
Instr	-0.61	-0.33	CN	-0.77	-0.03	-1.00	0.09	-0.92	-0.39	-0.73	0.09	-0.76
Chem	-0.08	-0.93		-0.89	-0.37	0.00	-0.32	-0.80	-0.88	-0.59	-0.69	-0.72
Mech	0.00	-0.75		-0.73	0.64	0.33	-0.35	0.04	0.09	-0.64	-0.02	-0.85
Other	-0.16	-0.30		0.01	0.58		0.21	0.27	-1.00	-0.25	0.12	-0.67
All	0.04	-0.55	0.69		0.01	0.51	-0.30	-0.45	-0.19	0.24	0.53	-0.60
Electr	-0.07	-0.68	0.73		-0.62	0.37	-0.71	-0.69	-0.32	0.08	0.43	-0.51
Instr	0.32	-0.51	0.77	DE	0.07	0.16	-0.19	-0.42	-0.23	0.13	0.44	-0.56
Chem	0.12	-0.56	0.89		0.35	0.66	0.61	-0.39	-0.31	0.73	0.41	-0.53
Mech	-0.06	-0.48	0.73		0.61	0.71	-0.33	-0.02	0.34	0.43	0.71	-0.69
Other	0.05	-0.49	-0.01		0.46	0.42	-0.35	0.25	-0.26	0.33	0.17	-0.74
All	0.23	-0.88	0.40	-0.01		0.17	-0.65	-0.77	-0.69	-0.93	-0.29	-0.47
Electr	0.35	-0.81	0.78	0.62		0.81	-0.81	-0.81	-0.74	-0.96	-0.13	-0.40
Instr	0.00	-0.90	0.03	-0.07	FR	0.09	-0.56	-0.90	-0.60	-0.89	-0.58	-0.57
Chem	-0.23	-0.92	0.37	-0.35		-0.12	-0.01	-0.76	-0.65	-0.52	-0.41	-0.32
Mech	-0.38	-0.91	-0.64	-0.61		-0.46	-0.28	-0.56	-0.59	-0.98	-0.39	-0.77
Other	-0.83	-0.81	-0.58	-0.46		-0.72	-0.44	-0.50	-0.33	-1.00	-0.37	-0.50
All	-0.36	-0.82	-0.38	-0.51	-0.17		-0.19	-0.82	-0.48	-0.15	-0.57	-0.88
Electr	-0.71	-0.81	0.03	-0.37	-0.81		-1.00	-0.76	-0.32	-1.00	-0.38	-0.91
Instr	-0.55	-0.76	1.00	-0.16	-0.09	IT	-0.03	-0.50	-0.31	-1.00	-0.62	-0.90
Chem	0.64	-0.87	0.00	-0.66	0.12		-0.88	-1.00	-0.71	-0.33	-0.67	-0.74
Mech	0.33	-0.81	-0.33	-0.71	0.46		-0.19	-1.00	-0.60	-0.80	-0.25	-0.88
Other	-0.74	-0.61		-0.42	0.72		0.14	-1.00	-0.54	0.60	-0.55	-0.93
All	0.48	-0.57	0.26	0.30	0.65	0.19		-0.84	-0.72	-0.45	0.80	-0.08
Electr	0.75	0.41	0.58	0.71	0.81	1.00		-0.88	-0.88	-0.41	0.89	-0.01
Instr	0.59	-0.18	-0.09	0.19	0.56	0.03	JP	-0.76	-0.42	-0.81	0.94	-0.07
Chem	0.23	-0.83	0.32	-0.61	0.01	0.88		-0.70	-0.80	-0.62	-0.06	-0.43
Mech	0.41	-0.56	0.35	0.33	0.28	0.19		-0.88	-0.07	-0.22	0.63	0.10
Other	-0.53	-0.12	-0.21	0.35	0.44	-0.14		-0.59	0.81	-0.55	0.63	-0.41
All	0.77	0.20	0.65	0.45	0.77	0.82	0.84		0.74	-0.83	0.78	0.14
Electr	0.87	0.48	0.67	0.69	0.81	0.76	0.88	KR	0.92	-0.89	0.92	0.32
Instr	0.54	0.33	0.92	0.42	0.90	0.50	0.76		0.00	-0.98	0.84	0.14
Chem	0.59	0.24	0.80	0.39	0.76	1.00	0.70		-0.10	-0.01	0.34	0.00
Mech	0.82	0.33	-0.04	0.02	0.56	1.00	0.88		-0.27	-0.27	0.09	-0.39
Other	0.15	-1.00	-0.27	-0.25	0.50	1.00	0.59		0.00	-1.00	0.04	-0.33
All	-0.28	-0.38	0.54	0.19	0.69	0.48	0.72	-0.74		-0.57	0.63	0.26
Electr	-0.29	-0.03	0.61	0.32	0.74	0.32	0.88	-0.92	NL	-0.68	0.70	0.61
Instr	-0.37	-0.44	0.39	0.23	0.60	0.31	0.42	0.00		-0.49	0.48	0.17
Chem	-0.18	-0.10	0.88	0.31	0.65	0.71	0.80	0.10		0.00	0.60	-0.33
Mech	0.20	-0.76	-0.09	-0.34	0.59	0.60	0.07	0.27		-0.59	0.65	-0.23
Other	-0.98	-0.63	1.00	0.26	0.33	0.54	-0.81	0.00		0.00	0.30	0.07
All	0.17	-0.14	0.80	-0.24	0.93	0.15	0.45	0.83	0.57		0.29	-0.56
Electr	0.55	0.05	0.85	-0.08	0.96	1.00	0.41	0.89	0.68	TW	0.14	-0.44
Instr	-0.48	-0.20	0.73	-0.13	0.89	1.00	0.81	0.98	0.49		0.10	-0.50
Chem	-0.35	0.10	0.59	-0.73	0.52	0.33	0.62	0.01	0.00		0.05	-0.71
Mech	0.00	0.00	0.64	-0.43	0.98	0.80	0.22	0.27	0.59		0.74	-0.83
Other	-0.38	-0.79	0.25	-0.33	1.00	-0.60	0.55	1.00	0.00		0.11	-0.79
All	-0.66	-0.64	0.50	-0.53	0.29	0.57	-0.80	-0.78	-0.63	-0.29		-0.83
Electr	-0.85	-0.60	0.63	-0.43	0.13	0.38	-0.89	-0.92	-0.70	-0.14	UK	-0.87
Instr	-0.33	-0.60	-0.09	-0.44	0.58	0.62	-0.94	-0.84	-0.48	-0.10		-0.77
Chem	-0.21	-0.74	0.69	-0.41	0.41	0.67	0.06	-0.34	-0.60	-0.05		-0.74
Mech	-0.27	-0.72	0.02	-0.71	0.39	0.25	-0.63	-0.09	-0.65	-0.74		-0.86
Other	-0.04	-0.24	-0.12	-0.17	0.37	0.55	-0.63	-0.04	-0.30	-0.11		-0.78
All	0.65	-0.17	0.84	0.60	0.47	0.88	0.08	-0.14	-0.26	0.56		
Electr	0.57	0.27	0.87	0.51	0.40	0.91	0.01	-0.32	-0.61	0.44		
Instr	0.79	-0.36	0.76	0.56	0.57	0.90	0.07	-0.14	-0.17	0.50		
Chem	0.81	-0.25	0.72	0.53	0.32	0.74	0.43	0.00	0.33	0.71	US	
Mech	0.61	-0.67	0.85	0.69	0.77	0.88	-0.10	0.39	0.23	0.83		
Other	0.70	-0.34	0.67	0.74	0.50	0.93	0.41	0.33	-0.07	0.79		

Note: Countries with world share of patents > 0.5%. Country *i*: horizontal, first row. Country *j*: indicted in bold in empty columns.

Table 5A. Determinants of bilateral inventor balance. Heckman's Lambda Method.**Panel A. Countries with world share of patents > 0.1%.**

Dep Variable_	(1) All countries (n=27)			(2) Excluding the US		
Bilateral inventor balance. (eq. 2)	1980-2009	1990-2009	2000-2009	1980-2009	1990-2009	2000-2009
Innov GDP	0.168*** (0.0466)	0.0578 (0.0600)	-0.402** (0.131)	0.160** (0.0516)	0.0552 (0.0652)	-0.432** (0.139)
Log(inv-national)	1.663*** (0.0863)	1.238*** (0.103)	1.330*** (0.201)	1.727*** (0.0989)	1.229*** (0.116)	1.256*** (0.219)
Log(app-national)	-1.785*** (0.0899)	-1.266*** (0.110)	-0.958*** (0.204)	-1.831*** (0.104)	-1.248*** (0.124)	-0.852*** (0.220)
IPR	-0.00947 (0.00743)	-0.0123 (0.00857)	0.00626 (0.0122)	-0.0139 (0.00874)	-0.0146 (0.0102)	0.0151 (0.0155)
Tech specialization	0.289*** (0.0491)	0.119 (0.0702)	0.0360 (0.126)	0.280*** (0.0572)	0.134 (0.0786)	0.0383 (0.134)
Individualism	-1.331*** (0.369)	-2.273*** (0.493)	-5.503*** (1.117)	0.0871*** (0.00913)	0.0804*** (0.0110)	0.0000937 (0.0207)
Observations	18750	12750	6500	17280	11760	6000
of which, uncensored	10898	8284	4688	9452	7296	4188
Rho	0.000601	0.000371	-0.000257	0.000925	0.000694	0.000164
Wald test, p-value	0.000	0.000	0.000	0.000	0.000	0.000

Panel B. Countries with world share of patents > 0.5%.

Dep Variable_	(3) All countries (n=12)			(4) Excluding the US		
Bilateral Inventor Balance (eq. 2)	1980-2009	1990-2009	2000-2009	1980-2009	1990-2009	2000-2009
Innov GDP	-0.251*** (0.0762)	-0.382*** (0.0903)	-0.621** (0.192)	-0.321*** (0.0889)	-0.452*** (0.104)	-0.751*** (0.211)
Log(inv-national)	0.755*** (0.185)	0.776*** (0.210)	1.436*** (0.399)	0.428 (0.224)	0.423 (0.244)	1.279** (0.458)
Log(app-national)	-0.554** (0.183)	-0.457* (0.210)	-0.851 (0.451)	-0.168 (0.226)	-0.0520 (0.249)	-0.566 (0.520)
IPR	0.0167 (0.0132)	-0.0229 (0.0144)	-0.0857*** (0.0208)	0.00780 (0.0165)	-0.0365* (0.0182)	-0.105*** (0.0288)
Tech specialization	0.317*** (0.0844)	0.0187 (0.112)	-0.0504 (0.273)	0.361*** (0.101)	0.101 (0.130)	0.0722 (0.300)
Individualism	-5.064*** (0.589)	-5.936*** (0.711)	-7.567*** (1.727)	0.0478*** (0.0138)	0.0361* (0.0162)	-0.00461 (0.0307)
Observations	3300	2200	1100	2700	1800	900
of which, uncensored	2815	2058	1082	2218	1658	882
Rho	-0.000278	0.000000951	-0.000000365	-0.000279	-0.000000142	0.000000193
Wald test, p-value	0.000	0.000	0.000	0.000	0.000	0.000

Note: Estimation method: Heckman's lambda method. 1st stage equations use the following regressors: log(GDP), log patent inventory (both according to the inventor and the applicant criterion), for both for i and j countries; the logged distance between capitals, the distance in terms of time zones, a dummy representing the presence of a common border, a measure of technological proximity, and a measure of linguistic proximity. The selection equation may be seen as a gravity model, where the dependent variable is binary and it indicates whether there was collaboration in inventive activities between two countries. Because of the symmetric nature of the problem, regressors are defined as the difference between observations in country i and j – see the discussion in Section 5. A positive estimated coefficient implies that a positive impact on the inventor balance, when present in i , and a negative one, of exactly the same magnitude, when present in j . Time and country fixed effects are included. Robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Source of the data: see Appendix A.3.

Table 5B. Determinants of bilateral inventor balance. OLS, clustered errors.**Panel A. Countries with world share of patents > 0.1%.**

Dep Variable_ Bilateral Inventor Balance. (eq. 2)	(1) All countries (n=27)			(2) Excluding the US		
	1980-2009	1990-2009	2000-2009	1980-2009	1990-2009	2000-2009
Innov GDP	0.193** (0.0689)	0.0472 (0.0864)	-0.460*** (0.131)	0.181* (0.0758)	0.0372 (0.0932)	-0.494*** (0.138)
Log(inv-national)	1.466*** (0.127)	1.146*** (0.121)	1.248*** (0.175)	1.497*** (0.139)	1.131*** (0.132)	1.178*** (0.190)
Log(app-national)	-1.613*** (0.138)	-1.168*** (0.140)	-0.831*** (0.179)	-1.624*** (0.153)	-1.140*** (0.154)	-0.726*** (0.192)
IPR	-0.0136 (0.0111)	-0.0154 (0.0100)	0.00484 (0.0130)	-0.0191 (0.0129)	-0.0184 (0.0118)	0.0123 (0.0166)
Tech specialization	0.284*** (0.0747)	0.120 (0.0865)	0.0542 (0.112)	0.281** (0.0863)	0.139 (0.0950)	0.0563 (0.120)
Individualism	-1.147 (0.586)	-2.324** (0.735)	-5.969*** (1.148)	0.0924*** (0.0146)	0.0784*** (0.0177)	-0.00754 (0.0243)
Observations	12152	9194	5182	10646	8166	4662
R ²	0.357	0.367	0.440	0.316	0.328	0.403

Panel B. Countries with world share of patents > 0.5%.

Dep Variable_ Bilateral Inventor Balance (eq. 2)	(1) All countries (n=12)			(2) Excluding the US		
	1980-2009	1990-2009	2000-2009	1980-2009	1990-2009	2000-2009
Innov GDP	-0.221 (0.124)	-0.367** (0.133)	-0.652*** (0.166)	-0.304* (0.143)	-0.467** (0.155)	-0.774*** (0.178)
Log(inv-national)	0.580** (0.212)	0.553* (0.241)	1.054** (0.351)	0.352* (0.237)	0.307 (0.261)	0.949* (0.407)
Log(app-national)	-0.413 (0.254)	-0.258 (0.275)	-0.472 (0.388)	-0.117 (0.292)	0.0605 (0.308)	-0.255 (0.446)
IPR	0.00838 (0.0224)	-0.0315 (0.0179)	-0.0881*** (0.0224)	-0.000. (0.0274)	-0.0441 (0.0230)	-0.113*** (0.0321)
Tech specialization	0.269* (0.119)	-0.00973 (0.138)	-0.0536 (0.209)	0.307* (0.140)	0.0777 (0.152)	0.0332 (0.230)
Individualism	-0.0944*** (0.0209)	-0.0962*** (0.0201)	-0.102*** (0.0237)	0.0938*** (0.0220)	0.0203 (0.0298)	-0.0164 (0.0398)
Observations	3392	2464	1296	2734	2024	1076
R ²	0.501	0.501	0.548	0.466	0.467	0.516

Note. Standard errors clustered by country pairs. Because of the symmetric nature of the problem, regressors are defined as the difference between observations in country i and j – see the discussion in Section 5. A positive estimated coefficient implies that a positive impact on the inventor balance, when present in i , and a negative one, of exactly the same magnitude, when present in j . Time and country fixed effects are included. Cluster-robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Source of the data: see Appendix A.3.

Tables and Figures

Table 1. Total patent portfolios, top-ten patenting countries in 2009.

Year	1980		1995		2009	
Country	N. patents	%	N. patents	%	N. patents	%
JP	165968	56.4	318989	58.2	261549	40.1
KR	307	0.1	26267	4.8	113274	17.4
US	38178	13.0	73920	13.5	51265	7.9
CN	8	0.0	8927	1.6	47088	7.2
DE	27784	9.4	31257	5.7	44843	6.9
TW	122	0.0	2535	0.5	24884	3.8
UK	10129	3.4	18887	3.4	16740	2.6
FR	10693	3.6	11765	2.1	14512	2.2
IT	7194	2.4	7770	1.4	10404	1.6
NL	2085	0.7	2783	0.5	4122	0.6
Total (52 countries)	294408	100.0	548300	100.0	652650	100.0

Note: Number of patents are rounded, and computed according to the applicant criterion, using fractional counting, and including the case where $i=j$, i.e. also domestic patents. Shares (%) are computed over the sum of all 52 countries patent portfolios included in the analysis.

Table 2. Inventor Balance, all technologies, 2000-2009.

Country	n.	InvBal RoW	CA	CH	CN	DE	FR	IT	JP	KR	NL	TW	UK	US
CA	4	.54		.52	- .02	.04	.23	- .36	.47	.77	- .28	.17	- .66	.65
CH	10	- .56	- .52		- .57	- .55	- .88	- .82	- .57	.20	- .38	- .14	- .65	- .18
CN	1	.77	.02	.57		.69	.41	- .38	.26	.65	.55	.81	.50	.84
DE	6	.19	- .04	.55	- .69		.00	- .51	.30	.45	.20	- .24	- .53	.60
FR	3	.36	- .23	.88	- .41	.00		- .18	.65	.77	.69	.93	.29	.47
IT	0	.66	.36	.82	.38	.51	.18		.19	.82	.49	.15	.57	.88
JP	6	.07	- .47	.57	- .26	- .30	- .65	- .19		.84	.72	.45	- .80	.08
KR	10	- .34	- .77	- .20	- .65	- .45	- .77	- .82	- .84		- .74	.83	- .78	- .14
NL	7	- .35	.28	.38	- .55	- .20	- .69	- .49	- .72	.74		.57	- .63	- .26
TW	8	- .01	- .17	.14	- .81	.24	- .93	- .15	- .45	- .83	- .57		- .29	.56
UK	3	.63	.66	.65	- .50	.53	- .29	- .57	.80	.78	.63	.29		.83
US	8	- .49	- .65	.18	- .84	- .60	- .47	- .88	- .08	.14	.26	- .56	- .83	

Note: Countries with world share of patents > 0.5%. Vertical: country *i*; horizontal: country *j*. Second column: number of bilateral applicant surpluses. Shaded cells indicate an inventor deficit.

Table 3. Inventor Balance with respect to the Rest of the World for a selection of countries

Country	Period	All	Electr	Instr	Chem	Mech	Other	All SD
CA	80-89	.40	.15	.44	.52	.41	.33	.0578
	90-99	.14	- .10	.32	.35	.31	.27	.0844
	00-09	.54	.47	.64	.67	.54	.57	.0361
CH	80-89	- .44	- .06	- .36	- .47	- .57	- .46	.0815
	90-99	- .54	- .39	- .51	- .57	- .59	- .45	.0358
	00-09	- .56	- .37	- .54	- .62	- .66	- .50	.0467
CN	80-89	.38	.19	.72	.08	.46	.90	.1448
	90-99	.33	.53	.56	.18	.35	- .19	.1242
	00-09	.77	.84	.68	.67	.58	.36	.0941
DE	80-89	- .10	- .22	- .32	- .21	- .04	- .19	.0603
	90-99	.08	.13	.17	.00	.08	.02	.0289
	00-09	.19	.25	.23	.13	.15	.20	.0202
FR	80-89	.73	.85	.80	.62	.74	.72	.0362
	90-99	.53	.45	.60	.51	.60	.77	.0552
	00-09	.36	.08	.53	.45	.72	.67	.1165
IT	80-89	.33	.42	.60	.35	.18	.19	.0710
	90-99	.58	.54	.66	.65	.47	.42	.0434
	00-09	.66	.70	.56	.67	.62	.69	.0235
JP	80-89	- .01	.00	- .29	.22	- .12	- .25	.0901
	90-99	- .01	- .16	- .14	.34	- .07	.06	.0827
	00-09	.07	- .09	.16	.50	.09	.44	.1177
KR	80-89	- .56	- .44	- .48	- .71	- .71	- .23	.0835
	90-99	- .62	- .77	- .49	- .54	- .36	- .46	.0754
	00-09	- .34	- .51	- .41	- .35	.01	.33	.1555
NL	80-89	- .25	- .09	.02	- .33	- .22	- .51	.0830
	90-99	- .19	- .19	.04	- .25	- .11	- .32	.0556
	00-09	- .34	- .57	- .28	- .16	.10	- .24	.1098
TW	80-89	.13	.27	- .02	.39	.20	.04	.0690
	90-99	- .69	- .70	- .62	- .38	- .75	- .71	.0644
	00-09	- .01	- .10	- .04	.24	.18	.23	.0811
UK	80-89	.49	.60	.60	.52	.19	.46	.0683
	90-99	.68	.85	.70	.49	.58	.70	.0553
	00-09	.63	.73	.57	.45	.63	.45	.0558
US	80-89	- .44	- .57	- .46	- .42	- .49	- .29	.0408
	90-99	- .37	- .36	- .49	- .34	- .39	- .51	.0375
	00-09	- .49	- .43	- .44	- .52	- .63	- .67	.0475

Note: Countries with world share of patents > 0.5%. Negative values/shaded cells denote an Inventor Deficit. All: all technologies. Other classifications: See Appendix.

Table 4. Determinants of the Inventor balance (with respect to the Rest of the World). Ordinary Least Squares.

Panel A: All countries

Dependent variable: inventor balance, with respect to RoW (eq. 3).

	(1)	(2)	(3)	(4)	(5)	(6)
	Log(Innov GDP)	Log(national patent inventory, Inv)	Log(national patent inventory, App)	IPR	Technological specialization	Individuali sm
Median	-0,045	3,670	-3,631	0,001	0,297	0,006
% p-value <0.10	0	100	100	33	20	37
% coeff>0	23	100	0	50	73	97
Binomial p-value	0,003	1,000	0,000	0,572	0,997	1,000

Panel B: Excluding the US

	(7)	(8)	(9)	(10)	(11)	(12)
	Log(Innov GDP)	Log(national patent inventory, Inv)	Log(national patent inventory, App)	IPR	Technological specialization	Individuali sm
Median	-0,138	3,337	-3,235	0,008	0,352	0,009
% p-value <0.10	43	100	100	33	20	80
% coeff>0	0	100	0	60	83	100
Binomial p-value	0,000	1,000	0,000	0,900	1,000	1,000

Note. Summary of results relative to 30 estimated cross-sections (1980-2009). A constant is included in all regressions. Median: median of the estimated coefficient. % p-value < 0.10: fraction of coefficients estimates which are significant at least at the 10% level. % coeff > 0: fraction of coefficients estimates which are greater than zero (equal to the number x of positive estimated coefficients, divided by 30). Binomial p-value: twice the probability of obtaining a number of successes $\geq x$ (if $x > 15$), or $\leq x$ (if $x < 15$) in 30 draws of a binomial random variable where the probability of success equals one half.

Table 5. Determinants of bilateral inventor balance. OLS.**Panel A. Countries with world share of patents > 0.1%.**

Dep Variable_	(a) All countries (n=27)			(b) Excluding the US		
Bilateral inventor balance. (eq. 2)	(1)	(2)	(3)	(4)	(5)	(6)
	1980-2009	1990-2009	2000-2009	1980-2009	1990-2009	2000-2009
Innov GDP	0.193*** (0.0439)	0.0472 (0.0577)	-0.460*** (0.127)	0.181*** (0.0483)	0.0372 (0.0624)	-0.494*** (0.134)
Log(inv-national)	1.466*** (0.0743)	1.146*** (0.0916)	1.248*** (0.185)	1.497*** (0.0833)	1.131*** (0.101)	1.178*** (0.201)
Log(app-national)	-1.613*** (0.0817)	-1.168*** (0.102)	-0.831*** (0.188)	-1.624*** (0.0925)	-1.140*** (0.113)	-0.726*** (0.202)
IPR	-0.0136 (0.00713)	-0.0154 (0.00823)	0.00484 (0.0118)	-0.0191* (0.00832)	-0.0184 (0.00970)	0.0123 (0.0148)
Tech specialization	0.284*** (0.0473)	0.120 (0.0673)	0.0542 (0.121)	0.281*** (0.0547)	0.139 (0.0751)	0.0563 (0.129)
Individualism	-1.147** (0.352)	-2.324*** (0.479)	-5.969*** (1.083)	0.0924*** (0.00856)	0.0784*** (0.0105)	-0.00754 (0.0200)
Observations	12152	9194	5182	10646	8166	4662
R ²	0.357	0.367	0.440	0.316	0.328	0.403

Panel B. Countries with world share of patents > 0.5%.

Dep Variable_	(c) All countries (n=12)			(d) Excluding the US		
Bilateral Inventor Balance (eq. 2)	(7)	(8)	(9)	(10)	(11)	(12)
	1980-2009	1990-2009	2000-2009	1980-2009	1990-2009	2000-2009
Innov GDP	-0.221** (0.0694)	-0.367*** (0.0865)	-0.652*** (0.182)	-0.304*** (0.0811)	-0.467*** (0.100)	-0.774*** (0.199)
Log(inv-national)	0.580*** (0.138)	0.553** (0.170)	1.054*** (0.315)	0.352* (0.158)	0.307 (0.189)	0.949** (0.351)
Log(app-national)	-0.413** (0.146)	-0.258 (0.176)	-0.472 (0.357)	-0.117 (0.170)	0.0605 (0.200)	-0.255 (0.398)
IPR	0.00838 (0.0126)	-0.0315* (0.0137)	-0.0881*** (0.0194)	-0.000 (0.0155)	-0.0441** (0.0171)	-0.113*** (0.0266)
Tech specialization	0.269*** (0.0805)	-0.00973 (0.107)	-0.0536 (0.252)	0.307** (0.0954)	0.0777 (0.123)	0.0332 (0.273)
Individualism	-0.0944*** (0.0113)	-0.0962*** (0.0125)	-0.102*** (0.0202)	0.0938*** (0.0126)	0.0203 (0.0198)	-0.0164 (0.0376)
Observations	3392	2464	1296	2734	2024	1076
R ²	0.501	0.501	0.548	0.466	0.467	0.516

Note. Because of the symmetric nature of the problem, regressors are defined as the difference between observations in country *i* and *j* – see the discussion in Section 5. A positive estimated coefficient implies that a positive impact on the inventor balance, when present in *i*, and a negative one, of exactly the same magnitude, when present in *j*. Time and country fixed effects are included. Robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Source of the data: see Appendix A.3.

Figure 1. A conceptual model of the production of inventions at the global scale

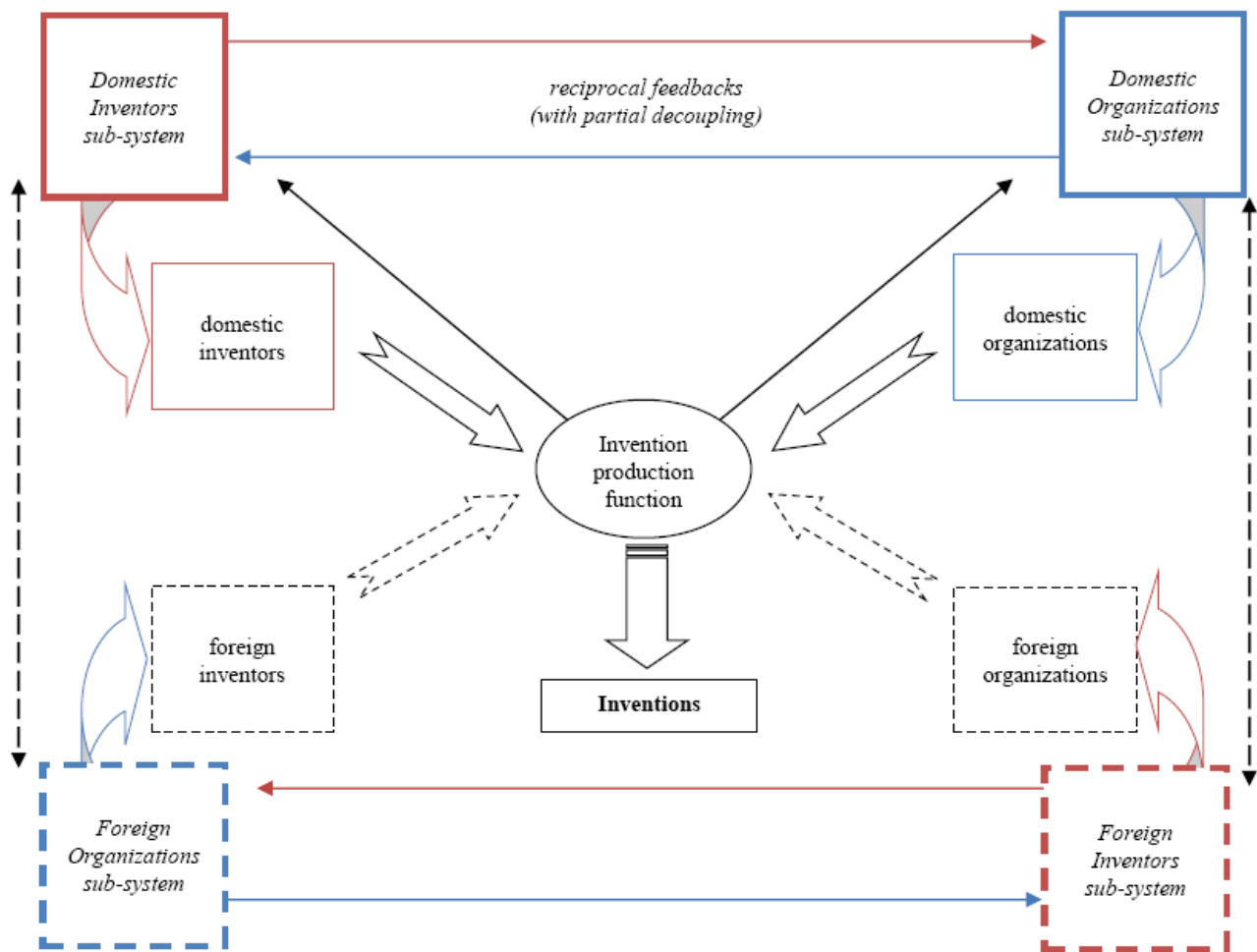


Figure 2. InvApp/Inv relative measure of internationalization for FR, DE, JP, UK and US. 1980-2009.

