The "Inventor Balance" and the Functional Specialization in Global Inventive Activities

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Abstract

Inventors and organizational assets are inputs of inventive activities which are often provided at a global scale, where countries might 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 observe 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 to the global production of inventions.

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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 might be produced at an international scale, which implies that organizations might source 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.

In the background of the phenomena which we analyze, lie the motivations behind multinational enterprises' (MNEs) decisions to internationalize their R&D activities. These might be either of the 'asset exploiting' or 'augmenting' type, according to Kuemmerle (1997), while 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 countries having a comparative advantage in highly-skilled personnel attract complementary assets from multinational corporations (Ernst 2002, Arora and Gambardella 2005, and Iammarino and McCann 2013).

Such strategies, and their effects, should be seen in the light of global knowledge flows among MNEs' different locations, in a situation where organizational capabilities to manage them effectively represent a key factor to deliver valuable innovations (Laurens et al. 2015a, and Gammeltoft 2006). In particular, evidence at the firm level suggests that, since the turn of the century, MNEs have been consolidating the previous advances in R&D internationalization, so as to better organize knowledge flows among remote locations (Laurens et al. 2015a and 2015b). In turn, such consolidation might contribute to the observed widening of the technological gaps between countries close to the technology frontier and the rest of the world (see Castellacci 2011, and Toivanen and Suominen 2015, who single out China and India as exceptions), as leader countries focus on knowledge-intensive tasks, and followers on imitation and standardized inventions (see, e.g., Kemeny 2011). These changes might be interpreted according to evolutionary theory, where "capitalist development is shown to be a process of alternating periods of convergence and divergence, with some signs of a shift towards divergence recently" (Fagerberg and Verspagen 2002).

Firms do not strategize in the void, but rather against a backdrop partly shaped by public policies. First, what is beneficial for an individual firm, might not be desirable collectively: outbound knowledge flows may produce negative externalities on local competitors (or on the whole country, as in the case of military or dual-use technologies). For this reason, we observe policies aimed at limiting transfers of technology abroad. Most importantly, policies often attempt to encourage inbound flows of knowledge. They might provide incentives for foreign firms to establish R&D labs domestically, as in the case of those Chinese policies conditioning generic FDI inflows on such decision, or, for India, facilitating the re-location of foreign plants(see Zanatta et al. 2008). Such foreign presence might generate spillovers, which crucially depend on broadly defined domestic absorption capabilities. The latter also are the object of policies, for example encouraging technical education, or attempting to attract complementary assets from foreign multinational corporations. The degree of success of such policies in establishing indigenous inventive capabilities varies, and has been widely debated (see, among many others, Athreye and Cantwell 2007, and Castellacci 2011).

Within such context, in this paper we show that functional specialization of inventive activities is a relevant phenomenon not only when contrasting developing and advanced economies, but also among countries belonging to the latter group. We quantify functional specialization by introducing a new patent-based metric, the "inventor balance", measuring 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 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 polar case).

We compute the inventor balance for the period 1980-2009 for a set of 34 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 that are weakly specialized overall, but display specialization in one or more technologies.

To explain the observed patterns of functional specialization, we build on studies theorizing the role of institutions in innovation systems, and present a stylized conceptual framework leading to a set of testable hypotheses.[2] Institutions play an important role in shaping the motivations of firms to internationalize their R&D activities and, when exploiting their assets abroad, firms also leverage on the general characteristics of the domestic innovation system where they are embedded. In trying to augment their assets through internationalization, they eventually become embedded into, and benefit from, the innovation system abroad (Criscuolo et al. 2005). Such an approach, in other words, takes a 'macro' perspective, which enlarges a more familiar and also narrower view of what defines the relevant assets that inform firms' decisions to internationalize.

We focus on the inventive step and consider a country's economy 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 hypotheses 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 decoupling and internationalization, because the former also motivates the latter. Our data supports such contention, also by showing that the observed imbalances on average tend to grow in time.

Our conceptual framework provides other testable hypotheses, guiding our search for factors explaining observed patterns of functional specialization. We anticipate the main 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

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[2] 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).

inventors *vs.* applicants. Last, we find that informal institutions and "soft" features (Crescenzi et al. 2016), such as cultural traits, play a role in explaining the observed imbalances. In particular, countries where individualistic traits prevail tend to contribute relatively more inventors than applicants.

We proceed as follows. In the next two sections we illustrate a conceptual framework aimed at explaining the inventor balance. In section 4 we present the data and we introduce a measure of functional specialization, the "inventor balance", which in section 5 is the object of a descriptive analysis. Section 6 presents results using inferential methods, and section 7 concludes.

2. A Conceptual Framework

Systemic theories of innovation have mostly focused on national systems, and as such they have been challenged by the internationalization of R&D activities (see Carlsson 2006, and Soete et al. 2010). In this light, and of particular relevance to us, Criscuolo et al. (2005) propose a 'macro' perspective on the internationalization of multinational 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). However, the overall characteristics of the innovation systems in which a firm is embedded, both at home and abroad, should also matter. 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, essentially aiming to explicitly internalise several aspects of the systems of innovation of the host location" (Criscuolo et al. 2005).[3]

We espouse such 'macro' perspective, where firms' actions, being embedded in such a broader context, are such that they might trigger systemic effects, resulting from the interplay of numerous actors at the micro-level (Soete et al. 2010). Outcomes are determined by market forces and are mediated by many non-market formal (e.g., the higher-education system, laws) and informal institutions (e.g., broadly defined

[3] 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.

cultural traits, traditions, social norms and social capital).[4]

We focus on the inventive step, and we thus refer to *invention* (rather than innovation) systems. Our conceptual framework revolves around the production of inventions, which results from the interaction of organizations with inventors, within an *invention production function*. Organizations are sets of routines and assets (Nelson and Winter 1982), and we define "inventor grade" workers as professionals who are potentially capable of developing new processes or products. Such workers, however, might also be employed otherwise, for example, as engineers on the shop floor. We assume long-distance knowledge flows to be problematic, both because human capital is not very mobile, and because much knowledge is tacit (Almeida and Kogut 1999). Such relative immobility in fact is a chief reason for MNEs to offshore R&D, as we reviewed in the previous section.

Inventors and organizations are inputs in the production of inventions, and in turn they are the outputs of two complex sub-systems, which we call the "inventors sub-system" and the "organizations sub-system". Figure 1 illustrates the conceptual framework, showing the two sub-systems both for the home country, and for a generic foreign country. The supply of inventors and of organizations of the home country is located 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 broadly defined cultural traits. The organizations sub-system comprises a more diverse set of institutions, including agencies of various types which shape innovation processes and policies (the "knowledge infrastructure", 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" (thin arrows in Figure 1). We consider first the feedbacks between the two sub-systems within the same country, whose strength is an interesting and problematic issue. To fix ideas, we begin by assuming the hypothetical

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

case where there is no internationalization in inventive activities, which we later admit.

First, we note that in the production of inventions, the degree of substitutability between inventors and organizations is bound to be limited.[5] For this reason, any relative imbalance in the two productive inputs would reverberate backward, generating a re-adjustment of the two sub-systems. For example, a relative scarcity of invention-grade professionals might eventually induce the inventors sub-system to increase their supply, possibly because entrepreneurs successfully lobby to increase public expenditure in higher education. Without any such action, scarcity in skilled personnel would hamper the activities of firms. As a consequence, some of them would be forced off the market, or their growth would be hindered, so that the imbalance would eventually be addressed via a reduction of demand of inventors. Such adjustments would take time to occur and also, likely, would be weak, because the sub-systems cater to needs beyond the production of inventions or inventive organizations. For example, a rapidly developing country might provide an increasing number of highly skilled professionals, who in part would be of inventor grade. However, only few of them would be employed as inventors in domestic firms, which would take time to become truly innovative, so that the oversupply of these potential inventors would persist. In summary, even without internationalization, the feedbacks between the two sub-systems would be weak and delayed.

More generally, policy-making enters our framework in two ways: first, by shaping the elements of the organizations and inventors sub-systems, and second, by strengthening the feedbacks between them. The case of education policies belongs to the first type. Across the world, they are often seen as a starting point to develop absorptive capacity and to attract complementary assets from multinational corporations (Zanatta et al. 2008). As the organization of cross-border knowledge flows is increasingly becoming a core goal for multinationals firms (Laurens et al. 2015a and 2015b, Gammeltoft 2006), relevant policies include those fostering

[5] 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 available human capital. 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.

coordination mechanisms among actors and addressing intellectual property rights and their enforcement. These policies often aim at internationalizing the system, with implications to be discussed in the next section. Other national policies, whose goal is to strengthen feedbacks, aim at favouring the matching of resources within the two sub-systems, acting against their decoupling. This might be achieved by incentivizing employment of highly educated specialists by firms (instead of academia), as in Brazil; by creating academia-enterprise hubs; or, as in in several countries' higher education system, by setting outreach and forms of external engagement as an explicit goal of universities - their so-called "third mission".

3. Testable Hypotheses

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 cause and effect, of functional specialization. Such conclusion derives directly from the fact that, 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, compared to the case of a purely domestic production of inventions which we considered above. 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 of R&D, which we observe until at least the turn of the century, 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, as a consequence, it increases relative imbalances.[6] 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 workers 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 producing inventions, and of general production. On the other hand, countries which innovate little relative to their degree of economic development have a relative over-supply of inventor-grade specialists. These considerations lead to the following hypothesis:

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, also have broader interests of a 'macro' type. Within this backdrop, when deciding where to carry out their inventive activities, asset-augmenting firms take into consideration the relative availability of inventive resources provided by the inventors sub-system. If one country has relatively few inventors, relative to domestic organizations willing to hire them, tougher competition for such scarce resource in the home country pushes domestic organizations to source inventors from abroad, resulting in an inventor deficit in the home country. Relative abundance of factors in

[6] Please note that the focus is on relative, and not absolute imbalances. All else being equal, absolute imbalances on average increase with internationalization. This is not necessarily the case for imbalances *relative* to the level of internationalization.

the aggregate within countries, in other words, should affect the observed degree of functional specialization:

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.

Organizational routines, such as managerial skills, to some extent are transferable across sectors; however, specialized invention-grade researchers often are not – a biotechnology scientist would not be able to invent in electrical engineering. For this reason, MNEs have strong incentives to search those sectoral specialists, which are in short supply at home, in those foreign countries where they are relatively specialized in the desired technologies (for similar considerations, see Cantwell and Vertova 2004). 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 system stems not only from its patterns of specialization, but also from its overall characteristics. Firms seeking inventive assets abroad explicitly aim to internalise features of the foreign system of innovation (Criscuolo et al. 2005). As a consequence, we 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 to 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 2016 and 2011) and also across regions within the same country (in the United States, Gorodnichenko and Roland 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.

4. 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), and whenever for simplicity we mention patents, in fact we always mean patent *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.[7]

Inventors and applicants are assigned to countries according to their address, so subsidiaries of multinational firms are recorded as separate entities and are not consolidated with the headquarters country. 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. 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*).

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 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 about 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

[7] 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. Further details on all data used in this paper are in the Data Appendix.

literature suggests that “intellectual property migration” should not affect significantly patent statistics.[8] 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 $\Theta = 1,...,i,j,...,N$, the following holds:

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

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

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

[8] 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).

terms of number of patents in 2009. It witnesses the very high number of Japanese patents, a well-known fact partly consequent on their relatively narrow scope (Cohen 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).[9] The degree of internationalization has increased in time, possibly with a degree of reversion in the last years of the sample, as also witnessed in Laurens et al. (2015a) and (2015b). It is pronounced enough to make *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.

4.1 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 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:

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

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

9 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.

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. The symmetric nature of the inventor balance means that "Inventors Surplus" and "Applicant Deficit" are synonyms and can be used interchangeably. 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 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.[10] It is the normalization needed to assure that $-1 \leq InvBal_{i,\,ROW} \leq +1$.

5. 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).

[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

[10] 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 $(App_i\text{-}Inv_i)/Inv_i$ (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 + ∞, which complicates its interpretation, since it is not symmetric around zero.

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. To analyse these results, 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. Those countries mostly have positive bilateral inventor balances. Whenever it is negative, the other country also belongs to the "specialized applicant provider" 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 the specialized inventor providers, on the other hand, mostly display 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 differ 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 an educational sector strong enough to supply many 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 providers, but that have been industrial countries for a longer while.[11]

In Table 3 we show $InvBal_{i,ROW}$, also separately for the five broad technological fields, for each decade considered. 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.

[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. For transition economies, the presence of an inventor surplus could be a transient phase, as they develop an industrial base able to be proactive abroad. However, the data for China do not show (yet) a turnaround: its inventor surplus has become more pronounced in time, as that country has been increasingly targeted by multinational firms as a R&D location.[12]

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

[11] In a supplementary results section (Table 2A), for the same group of countries we also report bilateral inventor balances for the five broad technological fields considered.

[12] 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 off-shoring" in Thomson's work, present an inventor deficit (surplus) in our analysis.

result of the interplay of many more diverse institutions. Countries may more easily target successfully their university system for improvements, while the development of successful multinational enterprises able to innovate internationally, besides being all but certain, requires much time. 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*.[13] 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 time. For all 34 countries considered, a measure of variation within each decade[14] 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.

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[13] The analysis of the bivariate inventor balances by sector (Table 2A in the supplementary results section), indicating that countries sectoral bilateral inventor surpluses tend to have the same sign as the aggregate, confirms such result.

[14] 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 inventor 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 inventor balance, and as such also is similar to a standard error.

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.

6. 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 share of 99% of global patenting activity.

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 ½, records a number of successes greater that f, or smaller than $1-f$.[15]

The data used to estimate the cross-sections are also amenable to pooling and

[15] 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.

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, variables which are constant in time are indistinguishable from the fixed effects, and in our case 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 its results.

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 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. 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 (1980 - 2009), and separately for the sub-periods 1990-2009 and 2000-2009, so as 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 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 hoover 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), 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:

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

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.[16]

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 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, economies which are highly innovative relative to their level of economic development, specialized in the provision of organizations *vs.* inventors. 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.

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.[17] 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,[18] when the whole period 1980 – 2009 is

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16 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).

17 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.

18 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 con-

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, 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 (Panel B), 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 period 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).

stituent technologies categorized by Schmoch (2008), leads to very similar results.

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).

7. Discussion and conclusions

Most innovations are the product of a matching between organizations 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 this type of functional specialization. Its magnitude is often considerable and 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 invention has generally increased. Our results, together with the conceptual framework which we adopted, set the stage for some final reflections, more of a speculative nature, on what policy suggestions might be drawn.

The presence of the strong imbalances that we have documented poses problems and opportunities to policy makers, which are usefully considered in the light of a wider literature on so-called “technology gaps”. These gaps appear to have been increasing since the 1970s (Kemeny 2011, and Toivanen and Suominen 2015), notwithstanding the observed convergence in human capital among developed and developing countries (Canestracci 2011). Both the evidence on technology gaps, and our analysis of the inventor surplus, suggest that developing countries are at risk of being trapped in what might be indicated as a “low-invention equilibrium”, or even of losing ground. Well-meaning policies, aimed at improving the supply of invention-grade specialists, could result in these specialists being employed abroad, or domestically by foreign MNEs, but with no meaningful spillovers being created. This might result in wider global technological gaps between leaders and followers (Toivanen and Suominen 2015, and Kemeny 2011), that is, the opposite of what is desired. In a sense, in such cases policies would in fact be functional to an international division of labour where few countries “cream skim” those activities exhibiting the highest value added. Such risk, arguably, is today particularly acute in the information and communication technologies, where few big platforms, mostly based in the United States, have taken advantage of the unique cost structure of digital goods, coupled with the presence of powerful network effects, to produce huge profits. Specialists educated abroad, at a high cost, contribute to those very lucrative activities, with very little advantages, and many disadvantages, for their originating countries.

Under this light, policies aimed at improving higher technical education should be accompanied by explicit provisions to facilitate absorption and spillovers.[19] Also, policies should aim at transferring inventive-specific organizational capabilities, such as technology and science management routines, which are essential to the catch-up process. In this context, our “inventor balance” measure is well-suited as a sector-specific monitoring tool, as it allows policy makers to appreciate how imbalances evolve in time, to better assess the effects of past interventions, and to tailor future ones.

For what concerns the countries which are close to the technology frontier, we took notice of the recent reported tendency of MNEs to improve the flows of information among their R&D labs around the world (Laurens et al. 2015a and 2015b). However, such developments, accompanied by general progresses in information and communication technologies, might also increase the risk of undesired spillovers abroad, eventually hollowing out the productive base of the host country. Obviously, this scenario would be beneficial to those countries trying to escape the “low-innovation equilibrium” which we have discussed above.

Recent research on the diffusion of knowledge provides some support to such a possibility. Whereas Chen and Guan (2016), using a patent citation analysis, show that knowledge flows are very intense within a core group of countries, while those from these countries to peripheral ones are weaker, an emerging body of evidence points to the presence and relevance of reverse flows of knowledge originating from developing countries. They are the result of MNEs, based in developing countries, tapping into industrialized countries human capital and organizational assets (Giuliani et al. 2014, 2016), and occasionally carrying out various types of reverse and frugal innovation (Zeschky et al. 2014). For countries close to the technology frontier, the “inventor balance” measure is also well-suited as a sector-specific monitoring tool of such dynamics.

Countries desiring to address the imbalances which we have analysed upon could also focus on the connection between the two sub-systems – inventors’ and organizations’. There are several examples of policies that might be seen as aiming at

[19] For example, Padilla-Perez and Gaudin (2013) show for Central America that FDI attraction policies did not include policy tools to promote indigenous capabilities or even technology absorption. On a similar vein, see also Athreye and Cantwell (2007).

reducing their decoupling in various ways.[20]

In providing a conceptual framework of innovation systems in a world where inventive activities are increasingly internationalized, 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 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 (Soete et al. 2010). Such interconnection might be seen as the other side of the coin of the 'macro' view which we have embraced: as domestic actors become embedded in more than one national innovation systems, the distinction between what is "national" and what is "international" becomes blurred.

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, our data, and our overall 'macro' approach, are silent on how the micro-level nature and characteristics of firms may determine specific patterns of functional specialization. Future research could exploit emerging big datasets on firms and on their patenting activities, so as to study their behaviours under the light of the present findings.

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[20] An example is provided by the Brazilian Innovation Law (Law n. 10.973/04, Zanatta et al. 2008); and by those policies favouring knowledge transfers and collaborations between University and enterprise. Beyond the well-known European practices, we mention the case of Mexico (De Fuentes and Dutrénit 2012), Canada (Sa and Litwin 2011), Taiwan (Mathews and Hu 2007), United Kingdom, where the allocation of research funds and ranking of departments has been made to depend also on measures of their spillovers.

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References

Almeida, P., Kogut, B., 1999. Localization of knowledge and the mobility of engineers in regional networks. *Management science*, *45*(7), 905-917.

Arora, A., Gambardella, A., 2005. From Underdogs to Tigers: The Rise and Growth of the Software Industry in Brazil, China, India, Ireland, and Israel. Oxford University Press, Oxford.

Athreye, S., Cantwell, J., 2007. Creating competition? Globalisation and the emergence emergence of new technology producers, Research Policy, 36 (2), 209-226.

Attanasio, O. P., Picci, L., Scorcu, A. E., 2000. Saving, growth, and investment: a macroeconomic analysis using a panel of countries. Review of Economics and Statistics, 82(2), 182-211.

Cantwell, J., Vertova, G., 2004. Historical evolution of technological diversification, Research Policy, 33(3), 511-529.

Carlsson, B., 2006. Internationalization of innovation systems: A survey of the literature. Research Policy, 35(1), 56-67.

Castellacci, F., 2011. Closing the Technology Gap? Review of Development Economics, 15: 180–197.

Chen, Z., Guan, J., 2016. The core-peripheral structure of international knowledge flows: evidence from patent citation data, R&D Management, 46(1), 1467-9310.

Cohen, W.M., Goto, A., Nagata, A., Nelson, R. R., Walsh, J.P., 2002. R&D spillovers, patents and the incentives to innovate in Japan and the United States. Research Policy, 31(8-9), 1349—1367.

Coriat, B., Weinstein, O., 2002. Organizations, firms and institutions in the generation of innovation. Research Policy, 31(2), 273-290.

Crescenzi, R., Nathan, M., Rodríguez-Pose, A., 2016. Do inventors talk to strangers? On proximity and collaborative knowledge creation. Research Policy, 45(1), 177-194.

Criscuolo, P., Narula R., Verspagen B., 2005. Role of home and host country innovation systems in R&D internationalisation: a patent citation analysis, Economics of Innovation and New Technology, 14(5), 417-433.

Danguy, J., De Rassenfosse, G., de la Potterie, B., 2014. On the origins of the worldwide surge in patenting: an industry perspective on the R&D-patent relationship, Industrial and corporate change, 23(2), 535—572.

De Fuentes, C., Dutrenit, G., 2012. Best channels of academia–industry interaction for long-term benefit. Research Policy, 41(9), 1666-1682.

De Rassenfosse, G., de la Potterie, B., 2009. A policy insight into the R&D–patent relationship. Research Policy, 38(5), 779-792.

De Rassenfosse, G., Dernis, H., Guellec, D., Picci, L., de la Potterie, B., 2013. The worldwide count of priority patents: A new indicator of inventive performance. Research Policy, 42(3), 720-737.

Dunning, J.H., Narula, R., 1995. The R&D Activities of Foreign Firms in the United States. International Studies of Management & Organization, 25, 39–73.

Edquist, C. 1997, Systems of Innovation: Technologies, Institutions and Organizations, London: Pinter.

Edquist, C., Johnson, B., 1997. Institutions and Organizations in Systems of Innovation. in Edquist, C. (Ed.), Systems of innovation – Technologies, institutions and organizations (41-60). London: Pinter.

Ernst, D., 2002. Global production networks and the changing geography of innovation systems: implications for developing countries. Economics of Innovation and New Technology 11 (6), 497–523.

European Patent Office, 2013a. PATSTAT database, April 2013 Edition.

European Patent Office, 2013b. Data catalogue for the EPO Worldwide Patent Statistical Database, April 2013 Edition.

Fagerberg, J., Verspagen, B., 2002. Technology-gaps, innovation-diffusion and transformation: an evolutionary interpretation. Research Policy, 31: 1291–1304.

Fearon, J. D., 2003. Ethnic and cultural diversity by country. Journal of Economic Growth, 8 (2), 195–222.

Freeman, C., 1987. Technology Policy and Economic Performance: Lessons from Japan. Pinter, London.

Gammeltoft, P., 2006. Internationalisation of R&D: trends, drivers and managerial challenges. International Journal of Technology and Globalisation, 2, 177-199.

Giuliani, E., Gorgoni, S., Günther, C., Rabellotti, R., 2014. Emerging versus advanced country MNEs investing in Europe: A typology of subsidiary global–local connections. International Business Review, 23(4), 680-691.

Giuliani, E., Martinelli, A., Rabellotti, R., 2016. Is Co-Invention Expediting Technological Catch Up? A Study of Collaboration between Emerging Country Firms and EU inventors. World Development, 77, 192-205.

Gorodnichenko, Y., Roland, G., (2016). Culture, Institutions and the Wealth of Nations. Review of Economics and Statistics, doi:10.1162/REST_a_00599.

Gorodnichenko, Y., Roland, G., 2011. Which dimensions of culture matter for long-run growth?. American Economic Review: Papers & Proceedings, 101(3), 492–498.

Henrich, J., 2014. Rice, psychology, and innovation. Science, 344, 593-594.

Hofstede, G., 2001. Culture's Consequences: Comparing Values, Behaviors, Institutions and Organizations across Nations. second ed. Thousand Oaks, CA: Sage Publications.

Iammarino, S., McCann, P., 2013. Multinationals and economic geography: Location, technology and innovation. Edward Elgar Publishing, Cheltenham.

Kemeny, T., 2009. Are international technology gaps growing or shrinking in the age of globalization? Journal of Economic Geography, 11, 1–35.

Krugman, P. R., 1991. Geography and trade. MIT press, Cambridge, Massachusetts.

Kuemmerle, W., 1997. Building Effective Capabilities Abroad. Harvard Business Review, March–April, 61–70.

Laurens P., Le Bas C., Schoen A., Villard L., Laredo P., 2015a. The rate and motives of the internationalisation of large firm R&D (1994-2005): Toward a turning point? Research Policy, 44, 765-776.

Laurens P., Le Bas C., Schoen A., Villard L., Laredo P., 2015b. Internationalisation of European MNCs R&D: "deglobalisation" and evolution of the locational strategies. Management international, 19(4), 83-98.

Lewin, A., Massini S., Peeters C., 2009. Why are companies offshoring innovation? The emerging global race of talent, Journal of International Business Strategy, 40: 901-925.

Lundvall, B. A., ed., 1992, National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning, London: Pinter.

Mathews, J. A., Hu, M. C., 2007. Enhancing the role of universities in building national innovative capacity in Asia: the case of Taiwan. World Development, 35(6), 1005-1020.

Nelson, R., Winter, G.W., 1982, An Evolutionary Theory of Economic Change, Cambridge (MA): Harvard University Press.

Nelson, R. R., Rosenberg, N., 1993. Technical innovation and national systems, pp. 1 -21 in Richard R. Nelson (eds), National innovation systems: A comparative analysis. Oxford University Press: New York.

North, D., 1990. Institutions, Institutional Change and Economic Performance. Cambridge University Press, Cambridge, New York.

Padilla-Pérez, R., Gaudin, Y., 2014. Science, technology and innovation policies in small and developing economies: The case of Central America. Research Policy, 43(4), 749-759.

Park, W.G., 2008. International patent protection: 1960–2005. Research Policy 37 (4), 761–766.Picci, L., 2010. The Internationalization of inventive activity: A gravity model using patent data. Research Policy, 39(8), 1070-1081.

Sa, C.M., Litwin, J., 2011. University–industry research collaborations in Canada: the role of federal policy instruments. Science and Public Policy, 38 (6), 425–435.

Sakakibara, M., Branstetter, L. 2001. Do Stronger Patents Induce More Innovation? Evidence from the 1988 Japanese Patent Law Reforms. The RAND Journal of Economics 32, 1, 77-100.

Schmoch, U., 2008. Concept of a technology classification for country comparisons. Final report to the World Intellectual Property Organisation (WIPO). Available online: http://www.wipo.int/export/sites/www/ipstats/en/statistics/patents/pdf/wipo_ipc_technology.pdf accessed online: 21 December 2016.

Smith, K., 1998. Economic Infrastructure and Innovation Systems. Systems of Innovation. Technologies, Institutions and Organizations. Pinter, London, Washington.

Soete, L., Verspagen, B., er Weel, B., 2010. Systems of innovation, CPB discussion paper, n. 138.

Talhelm, T. , Zhang, X., Oishi, S. Shimin, C., Duan, D. , Lan, X., Kitayama, S., 2014. Large-Scale Psychological Differences Within China Explained by Rice Versus Wheat Agriculture, Science, 344: 603-607.

Thomson, R., 2013. National scientific capacity and R&D offshoring. Research Policy 42, 517-528.

Toivanen, H., Suominen, A., 2015. The Global Inventor Gap: Distribution and Equality of World-Wide Inventive Effort, 1990–2010. PLoS ONE 10(4):

e0122098. doi:10.1371/journal.pone.0122098.

WIPO, 2011. International Patent Classification (IPC), www.wipo.int/classifications/ipc/en/ accessed online: 18 January 2015.

Wooldridge, J.M. 2002. Econometric Analysis of Cross Section and Panel Data. Cambridge: MIT Press.

Zanatta, M., Strachman, E., Carvalho, F., Varrichio, P. C., Camillo, E., Barra, M. 2008. National Policies to Attract FDI in R&D. An Assessment of Brazil and Selected Countries, UNU-WIDER Research Paper (2008-69).

Zeschky M., Winterhalter S., Gassmann O., 2014. From cost to frugal and reverse innovation: mapping the field and implications for global competitiveness, Research Technology Management, 57(4), 1-8.

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 (*1,2, ... P*) 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, which expresses the share of international patents in a country's portfolio, and it is defined as:

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

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 and methodology: European Patent Office (2013a, 2013b). See the methodological description in Section 3. Patstat allows for the tracking of multiple applications claiming the right to priority for the same invention in different offices, and for avoiding double count 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 ½, so that each patent always counts as one, regardless of whether the inventor or the applicant criterion is chosen.

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.

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".

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. Two groups of countries are considered: a smaller one, of 12 countries: Canada, China, France, Germany, Italy, Japan, Netherlands, South Korea, Switzerland, Taiwan, United Kingdom, United States of America. A bigger one, of 27 countries, also includes: Australia, Austria, Belgium, Czech Republic, Denmark, Finland, Hungary, India, Ireland, Mexico, Norway, Poland, Spain, Sweden, Turkey.

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

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 Ethnologe 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	-0.4	-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		-0.68	0.70	0.61
Instr	-0.37	-0.44	0.39	0.23	0.60	0.31	0.42	0.00	**NL**	-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		0.14	-0.44
Instr	-0.48	-0.20	0.73	-0.13	0.89	1.00	0.81	0.98	0.49	**TW**	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		-0.87
Instr	-0.33	-0.60	-0.09	-0.44	0.58	0.62	-0.94	-0.84	-0.48	-0.10	**UK**	-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	0.83	
Electr	0.57	0.27	0.87	0.51	0.40	0.91	0.01	-0.32	-0.61	0.44	0.87	
Instr	0.79	-0.36	0.76	0.56	0.57	0.90	0.07	-0.14	-0.17	0.50	0.77	**US**
Chem	0.81	-0.25	0.72	0.53	0.32	0.74	0.43	0.00	0.33	0.71	0.74	
Mech	0.61	-0.67	0.85	0.69	0.77	0.88	-0.10	0.39	0.23	0.83	0.86	
Other	0.70	-0.34	0.67	0.74	0.50	0.93	0.41	0.33	-0.07	0.79	0.78	

Note: Countries with world share of patents > 0.5%.
Country *i*: horizontal, first row. Country j: 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: 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	0.168***	0.0578	-0.402**	0.160**	0.0552	-0.432**
	(0.0466)	(0.0600)	(0.131)	(0.0516)	(0.0652)	(0.139)
Log(inv-national)	1.663***	1.238***	1.330***	1.727***	1.229***	1.256***
	(0.0863)	(0.103)	(0.201)	(0.0989)	(0.116)	(0.219)
Log(app-national)	-1.785***	-1.266***	-0.958***	-1.831***	-1.248***	-0.852***
	(0.0899)	(0.110)	(0.204)	(0.104)	(0.124)	(0.220)
IPR	-0.00947	-0.0123	0.00626	-0.0139	-0.0146	0.0151
	(0.00743)	(0.00857)	(0.0122)	(0.00874)	(0.0102)	(0.0155)
Tech specialization	0.289***	0.119	0.0360	0.280***	0.134	0.0383
	(0.0491)	(0.0702)	(0.126)	(0.0572)	(0.0786)	(0.134)
Individualism	-1.331***	-2.273***	-5.503***	0.0871***	0.0804***	0.0000937
	(0.369)	(0.493)	(1.117)	(0.00913)	(0.0110)	(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: Bilateral Inventor Balance (eq. 2)	(3) All countries (n=12)			(4) Excluding the US		
	1980-2009	1990-2009	2000-2009	1980-2009	1990-2009	2000-2009
Innov|GDP	-0.251***	-0.382***	-0.621**	-0.321***	-0.452***	-0.751***
	(0.0762)	(0.0903)	(0.192)	(0.0889)	(0.104)	(0.211)
Log(inv-national)	0.755***	0.776***	1.436***	0.428	0.423	1.279**
	(0.185)	(0.210)	(0.399)	(0.224)	(0.244)	(0.458)
Log(app-national)	-0.554**	-0.457*	-0.851	-0.168	-0.0520	-0.566
	(0.183)	(0.210)	(0.451)	(0.226)	(0.249)	(0.520)
IPR	0.0167	-0.0229	-0.0857***	0.00780	-0.0365*	-0.105***
	(0.0132)	(0.0144)	(0.0208)	(0.0165)	(0.0182)	(0.0288)
Tech specialization	0.317***	0.0187	-0.0504	0.361***	0.101	0.0722
	(0.0844)	(0.112)	(0.273)	(0.101)	(0.130)	(0.300)
Individualism	-5.064***	-5.936***	-7.567***	0.0478***	0.0361*	-0.00461
	(0.589)	(0.711)	(1.727)	(0.0138)	(0.0162)	(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**	0.0472	-0.460***	0.181*	0.0372	-0.494***
	(0.0689)	(0.0864)	(0.131)	(0.0758)	(0.0932)	(0.138)
Log(inv-national)	1.466***	1.146***	1.248***	1.497***	1.131***	1.178***
	(0.127)	(0.121)	(0.175)	(0.139)	(0.132)	(0.190)
Log(app-national)	-1.613***	-1.168***	-0.831***	-1.624***	-1.140***	-0.726***
	(0.138)	(0.140)	(0.179)	(0.153)	(0.154)	(0.192)
IPR	-0.0136	-0.0154	0.00484	-0.0191	-0.0184	0.0123
	(0.0111)	(0.0100)	(0.0130)	(0.0129)	(0.0118)	(0.0166)
Tech specialization	0.284***	0.120	0.0542	0.281**	0.139	0.0563
	(0.0747)	(0.0865)	(0.112)	(0.0863)	(0.0950)	(0.120)
Individualism	-1.147	-2.324**	-5.969***	0.0924***	0.0784***	-0.00754
	(0.586)	(0.735)	(1.148)	(0.0146)	(0.0177)	(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	-0.367**	-0.652***	-0.304*	-0.467**	-0.774***
	(0.124)	(0.133)	(0.166)	(0.143)	(0.155)	(0.178)
Log(inv-national)	0.580**	0.553*	1.054**	0.352*	0.307	0.949*
	(0.212)	(0.241)	(0.351)	(0.237)	(0.261)	(0.407)
Log(app-national)	-0.413	-0.258	-0.472	-0.117	0.0605	-0.255
	(0.254)	(0.275)	(0.388)	(0.292)	(0.308)	(0.446)
IPR	0.00838	-0.0315	-0.0881***	-0.000.	-0.0441	-0.113***
	(0.0224)	(0.0179)	(0.0224)	(0.0274)	(0.0230)	(0.0321)
Tech specialization	0.269*	-0.00973	-0.0536	0.307*	0.0777	0.0332
	(0.119)	(0.138)	(0.209)	(0.140)	(0.152)	(0.230)
Individualism	-0.0944***	-0.0962***	-0.102***	0.0938***	0.0203	-0.0164
	(0.0209)	(0.0201)	(0.0237)	(0.0220)	(0.0298)	(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 *i*	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	-0.35	- .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 A.2.

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	Individualism
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	Individualism
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 ≥ x (if x > 15), or ≤ 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: Bilateral inventor balance (eq. 2)	(a) All countries (n=27)			(b) Excluding the US		
	(1) 1980-2009	(2) 1990-2009	(3) 2000-2009	(4) 1980-2009	(5) 1990-2009	(6) 2000-2009
Innov|GDP	0.193***	0.0472	-0.460***	0.181***	0.0372	-0.494***
	(0.0439)	(0.0577)	(0.127)	(0.0483)	(0.0624)	(0.134)
Log(inv-national)	1.466***	1.146***	1.248***	1.497***	1.131***	1.178***
	(0.0743)	(0.0916)	(0.185)	(0.0833)	(0.101)	(0.201)
Log(app-national)	-1.613***	-1.168***	-0.831***	-1.624***	-1.140***	-0.726***
	(0.0817)	(0.102)	(0.188)	(0.0925)	(0.113)	(0.202)
IPR	-0.0136	-0.0154	0.00484	-0.0191*	-0.0184	0.0123
	(0.00713)	(0.00823)	(0.0118)	(0.00832)	(0.00970)	(0.0148)
Tech specialization	0.284***	0.120	0.0542	0.281***	0.139	0.0563
	(0.0473)	(0.0673)	(0.121)	(0.0547)	(0.0751)	(0.129)
Individualism	-1.147**	-2.324***	-5.969***	0.0924***	0.0784***	-0.00754
	(0.352)	(0.479)	(1.083)	(0.00856)	(0.0105)	(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: Bilateral Inventor Balance (eq. 2)	(c) All countries (n=12)			(d) Excluding the US		
	(7) 1980-2009	(8) 1990-2009	(9) 2000-2009	(10) 1980-2009	(11) 1990-2009	(12) 2000-2009
Innov|GDP	-0.221**	-0.367***	-0.652***	-0.304***	-0.467***	-0.774***
	(0.0694)	(0.0865)	(0.182)	(0.0811)	(0.100)	(0.199)
Log(inv-national)	0.580***	0.553**	1.054***	0.352*	0.307	0.949**
	(0.138)	(0.170)	(0.315)	(0.158)	(0.189)	(0.351)
Log(app-national)	-0.413**	-0.258	-0.472	-0.117	0.0605	-0.255
	(0.146)	(0.176)	(0.357)	(0.170)	(0.200)	(0.398)
IPR	0.00838	-0.0315*	-0.0881***	-0.000	-0.0441**	-0.113***
	(0.0126)	(0.0137)	(0.0194)	(0.0155)	(0.0171)	(0.0266)
Tech specialization	0.269***	-0.00973	-0.0536	0.307**	0.0777	0.0332
	(0.0805)	(0.107)	(0.252)	(0.0954)	(0.123)	(0.273)
Individualism	-0.0944***	-0.0962***	-0.102***	0.0938***	0.0203	-0.0164
	(0.0113)	(0.0125)	(0.0202)	(0.0126)	(0.0198)	(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

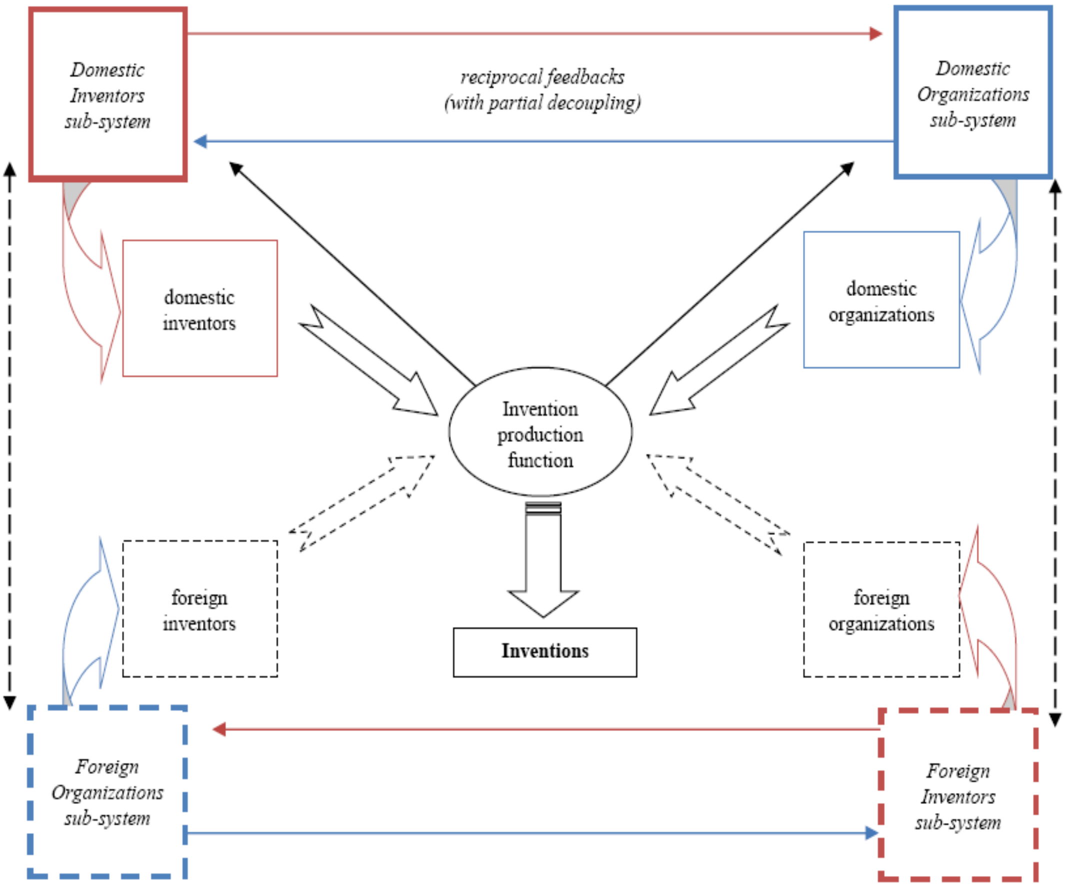

Figure 2. InvApp/Inv relative measure of internationalization for FR, DE, JP, UK and US. 1980-2009.