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

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**Abstract**

We study the functional specialization whereby some countries contribute relatively more inventors vs. organizations in the production of inventions at a global scale. We propose a conceptual framework to explain this type of functional specialization, which posits the presence of feedbacks between two distinct sub-systems, each one providing inventors and organizations.

We quantify the phenomenon by means of a new metric, the "inventor balance", which we compute using patent data. We show that the observed imbalances, which are often conspicuous, are determined by several factors: the innovativeness of a country relative to its level of economic development, relative factor endowments, the degree of technological specialization and, last, cultural traits.

We argue that the "inventor balance" is a useful indicator for policy makers, and its routine analysis could lead to better informed innovation policies.

**JEL classification**: O31; O34; F21; F23; F29.

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

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## 1. Introduction

Inventions are typically produced by individuals who operate within organizations, most often, firms. Also, they are increasingly being produced at a global scale. Inventors and organizations can thus be considered inputs in the production of inventions. However, they are also outputs of complex processes, which are largely shaped by the global features of the economic system and by interactions between institutions and other actors. In a world where firms can obtain inventors and other relevant assets from abroad, some countries will possibly functionally specialize, e.g., contribute either relatively more inventors, or organizations. The study of the extent and motives of such "functional specialization", which so far has attracted scant and unsystematic attention, is the goal of this paper.

The salience of these considerations depends on the importance of internationally produced inventions. In fact, more than twenty years ago, inventive activities were an area of economic endeavour which was not highly internationalized (Patel and Pavitt, 1991). Nowadays, to the contrary, among scholars and practitioners there is consensus that R&D internationalization has made considerable inroads, and that the production of inventions often involves international collaborations of various types (see, e.g., Athreye and Cantwell, 2007). Anecdotal evidence abounds. For example, The Economist (2010) notes that "The world's biggest multinationals are becoming increasingly happy to do their research and development in emerging markets. Companies in the *Fortune* 500 list have 98 R&D facilities in China and 63 in India". Numerous case studies seem to confirm such anecdotal accounts.[2] Lewin et al. (2009) shows that one of the main reasons for US firms to offshore innovation is the lack of domestic inventors and skilled personnel (see also Athreye and Cantwell, 2007). Such process of internationalization thus seems to contemplate forms of functional specialization, which can be stylized as stemming from an asymmetry between industrialized countries, providing organizations (mostly, multi-national firms), and emerging markets, providing inventors.[3] We miss, however, a much-

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[2] The academic literature on the subject includes Patel and Vega (1999); Le Bas and Sierra, (2002); for wireless telecommunications, Di Minin and Bianchi (2011); for pharmaceuticals, Penner-Hahn and Shaver (2005); for biotech, Shan and Song, (1997); for semiconductors, Almeida (1996).

[3] For a study of how a new form of international "functional" division of labour emerged see also Fifarek and Veloso (2010).

needed, evidence-based comprehensive picture of such phenomenon, beyond what is afforded by case studies. To provide it is the first objective of our research.[4]

To interpret our empirical findings, which we present in Sections 3 to 5, we adopt a simple conceptual framework, which we describe in the next section. In a fashion similar to Coriat and Weinstein (2002), it brings together elements from theories that highlight the prominence of organizations (starting from the seminal work of Schumpeter, 1942) with theories focused on the role of institutions in innovation systems (Edquist, 1997; Lundvall, 1992; Nelson and Winter, 1982).

The framework can be conceptualized through two layers. At a first level, it hinges on the mutual relationships of what we describe as two sub-systems within a national economic system:[5] one providing organizations which are able to innovate internationally, and the other, inventors. At a second level, inventors and organizations match to produce inventions in what we call a "production function of inventions". Feedback loops operate between the two sub-systems, and between the production function of invention and the two sub-systems. For example, countries with productive and innovative organizations also have the resources to finance an advanced educational system, which provides inventors. Also, the supply of many inventors spurs the innovative activities of local firms.

The interdependence between the two sub-systems, however, is only partial: the reason is that the effects of feedbacks are lagged, and the two sub-systems also adjust to factors other than changes in the need for inventions' inputs. These two sub-systems are thus partially *decoupled*. In the "far from globalized" world of Patel and Pavitt (1991), the effects of such feedbacks would be stronger than in the case where the much of the production of inventions takes place internationally. In the latter case, countries would tend to specialize and to increase the imbalance in their contribution of inventors vs. organizations. In other words, greater internationalization would lead to a greater decoupling of the inventors and organizations sub-systems.

We discuss and consider these issues under the light of the empirical evidence

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4 Picci (2010) points out the relevance of the issue (see his comments of Figure 1 at p. 1075). Thomson (2013) reports data on what he defines "R&D offshoring", on which we will return in Section 4.

5 We refer to broad definition of a national "economic" system (similar in fashion to Edquist, 1997), rather than to "national system of innovation" for two reasons. First, the focus of the paper is on the quickly growing relevance of international production of knowledge, so that it would be more appropriate to talk about "international systems of innovation" (see Soete et al., 2010, Section 4.2 for a discussion), as we will clarify in Section 2. Second, we strictly focus on the inventive step, rather than on the whole innovation process.

that we gather. Using Patstat (European Patent Office, 2013, a, b), we measure inventive activities by means of patent data, which are particularly useful in the present context, since they list separately inventors, who are invariably persons, from applicants. While inventors are always individuals, applicants may be firms, universities and other research institutions, governmental organizations, non-profit organizations and, finally, also individuals. Available evidence (which we discuss below, see also Picci, 2010), however, allows us to conclude that almost always applicants are organizations, and very often they are firms, which we will assume to be the case, at the cost of some generalization.

When the objective is to assess a country's patent portfolio (that is, the number of patents produced in a country in a given lapse of time), the computation may be executed either by considering inventors ("inventor criterion") or applicants ("applicant criterion"). 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.[6]

We assess the functional specialization in the production of international patents by means of a new metric, the "inventor balance", which we illustrate in Section 3. It expresses the degree by which a country contributes relatively more inventors than applicants to the production of international patents. To fix ideas, we anticipate that it is equal to zero when there is no imbalance, and it ranges between –1 (in the extreme case where a country contributes only applicants, and no inventors) and + 1 (in the opposite extreme case). It can be computed both between pairs of countries, and also for a country with respect to the rest of the world.

In Section 4, we compute both metrics separately for families of technologies, for the period 1980-2009. Our data indicate that the extent of the functional specialization is considerable. Some countries, such as the United States and Switzerland, are specialized contributors of organizations, while others, such as

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[6] Firms typically file through their headquarters. See the discussion in Thomson (2013, Section 3) on the available evidence, and on why "intellectual property migration" should not affect significantly the use of patent statistics in the present context.

China, Italy, and the United Kingdom, mostly provide inventors. In between there is a group of countries which are weakly specialized overall, but may show specialization, in one direction or the other, in one or more technologies.

At the aggregate level, our results show that the observed imbalances tend to grow in time, possibly indicating a progressive decoupling of the sub-systems which guarantee the supply of organizations and of inventors. Such a progressive decoupling, we argue, may be both a consequence and a cause of the observed increase in the internationalization of inventive activities. However, within countries, we observe that the variation across technologies of the observed imbalances does not increase in time. In other words, if the decoupling is taking place, its effects play out at an aggregate country level, and not by making each technological sector more independent within countries.

In Section 5 we resort to econometric methods to identify a series of factors affecting the inventor balance. Countries which are not very innovative, relative to their level of economic development, tend to contribute more inventors than applicants, as do countries which have a high degree of technological specialization relative to the world average. The relative abundance of inventors and applicants is also a determinant of the inventor balance. Last, we find that also informal institutions, such as cultural traits, may have a role in explaining imbalances. In particular, countries where individualistic traits prevail tend to contribute relatively more inventors than applicants.

In the concluding section we discuss the policy relevance of our findings, arguing that the inventor balance is a useful indicator for policy makers, and that its routine analysis could lead to better informed innovation policies.

## 2. A Conceptual Framework

We develop a stylized conceptual framework which allows us to define a set of testable hypotheses on the determinants of the inventor balance. Such a framework will allow us to define a set of hypotheses, the first of which will be assessed in Section 3, while the others we test in Section 4.

Theories of innovation have followed two main paths: the first emphasizing the role of the organizational process in the production of inventions, the second stressing the global features of the economic systems and interactions between institutions and actors. Considering theories at the firm level, Coriat and Weinstein (2002) suggest that these two paths are complementary and that such a dichotomous approach should be taken over. In this wake, but on a different ground, we build our arguments on the idea that domestic organizational and institutional aspects are intertwined, and we propose an extended conceptual framework where the globalization of inventive activities plays a role.[7] Our core point is that distinct sets of institutions determine and shape the availability of inventors and organizations within an economic system. When international collaborations are included in the picture, foreign assets (inventors and organizations) may contribute to the production of inventions and thus influence the feedback between institutions, firms, and inventors. Throughout the section we will focus on the production of *inventions*, which in our empirical counterpart will be measured through patent data.

For the sake of clarity, we will first outline the case of domestic actors and no international collaborations, what as a first approximation may coincide with the "far from globalised" world described by Patel and Pavitt (1991).

### *2.1 A "far from globalised" invention system.*

The core actors of this framework are inventors and organizations. Inventors are always physical persons, while by organizations we mean firms, universities and other research institutes, governmental organizations, and non-profit organizations. Not only inventors and organizations are inputs in the production of inventions, but also they themselves are outputs of two complex processes, which we call the "inventors sub-system" and the "organizations sub-system" within the overall national economic system.

The two sub-systems may be seen as distinct sets of institutions whose combined interactions guarantee the supply of inventors and organizations potentially capable to invent. We define here institutions in a broad sense, both as formal (e.g. the architecture of specific bodies and systems, such as the higher-education system, and

[7] Our conceptual framework can also be viewed as a stylized "integrated model" where functions of innovation systems are features of the interplay between actors and institutions (see Markard and Truffer, 2008; Bergek et al., 2008).

laws) and informal (customs, traditions and social norms).[8]

Within the *inventors sub-system*, educational institutions play a prominent role. The *organizations sub-system* comprises a more diverse set of institutions including, e.g., agencies and bodies determining innovation processes and policies (the "knowledge infrastructure", Smith, 1998), coordination mechanisms among institutions (Nelson and Rosenberg, 1993), the intellectual property right system, labour market laws and other aspects of the national invention system.

Figure 1 depicts such constructs. Its top part represents the supply of inventors and of organizations.

**[Figure 1 about here]**

In the central part of Figure 1, solid-line elements show that domestic inventors and organizations match in order to produce inventions. The different elements of the model are linked by feedbacks operating at two levels: among sub-systems; between the sub-systems and the invention production function.

Let us consider first the likely feedbacks between the two sub-systems. For the time being, we assume that internationalization is absent, which corresponds to assuming away the bottom part of Figure 1. At the aggregate level, only a country endowed with an organizations sub-system which fosters the proliferation of many productive and innovating firms will have the resources to finance a higher-education system able to produce many inventors. Also, the presence of innovative firms contributes to the supply of skilled personnel through training on the job. The presence of a good school system, in turn, is one of the prerequisites for a country to have a richly textured productive structure, including innovating firms.

The second set of feedbacks operates at the level of the production of inventions. To appreciate their nature, we discuss what we may loosely define as the "invention production function", that is, how the two types of inputs (inventors and organizations) combine to produce inventions. Within a given production process, there may be a degree of substitutability between factors of production. For example, a firm facing scarcity of inventors to some extent may substitute them with more

[8] Our definition thus encompasses a wide set of constructs: a large literature discusses such point and the actual definition of "institutions", see e.g. Coriat and Weinstein (2002), Edquist and Johnson (1997), North (1990), Freeman (1987).

capital goods: better instruments, computers, working conditions, etc. However, at the aggregate level, relative imbalances in the two inputs most likely would not result much in 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. For example, a country where there is abundance of potential inventors might specialize in forms of process (vs. product) innovations, which perhaps can be successfully performed also in the absence of formal R&D labs.

Therefore, while inventors and organizations are amenable to some degree of substitution, particularly so in the aggregate, any relative imbalances in those inputs will also reverberate backward to the two sub-systems. For example, a scarcity of capable inventors may be the results of a more general scarcity of skilled personnel, and as such may spur adjustments in the inventors sub-system. In practice, this happens by modifying vocational choices, i.e. by inducing young people to pursue careers in sectors affected by relative scarcity. Also, inasmuch as scarcity in skilled personnel hampers the activities of firms, some of them would disappear, so as to reduce their relative over-supply.

We expect that the effects of these feedbacks may be delayed, as we clarify by means of an example. Consider a negative shock affecting a given country's chemical sector. As vocational choices are influenced by expectations of future employment possibilities, fewer students would pursue careers in chemistry. However, to the extent that the shock had been unexpected, it would take several years for changes in vocational choice to be observed. In addition, the needed reduction in the supply of education in chemistry would take time, since it is not feasible to close or downsize university programs and research departments overnight. Similar reasoning would apply to other types of feedbacks.

Besides being delayed, any adjustments of imbalances between inventors and organizations probably would also be weak. Consider that both sub-systems cater to needs which go beyond the mere production of inventions, or of inventive organizations. As a result, a relative imbalance between inventors and organizations may be justified by the different roles played both by highly skilled personnel and by organizations.

As an example, consider a country with many firms active in a high-tech domain, which however are not themselves very innovative, so that they demand only few inventors. Being numerous, their production process requires many highly skilled professionals, generating a feedback on the education system to supply them. Among all these specialists, there will be relatively many potential inventors who, however, will be oversupplied – and persistently so – with respect to the needs of domestic firms. Only few of them will find a job as inventors for domestic firms, while most will likely work as generic specialists. The fact that potential inventors might be usefully employed as generic specialists implies that any adjustments to an oversupply of "inventor grade" specialists would not only be slow to materialize, but also, quite likely, rather weak.

In conclusion, both the weak nature of the feedbacks and the delayed timing of their effects would likely ensure that imbalances in the supply of inventors and organizations would self-adjust only partially. This is so for more than one reason. First, there likely is a degree of substitutability between inventors and organizations, as they match to produce inventions. Also, organizations might choose production processes of inventions which are more compatible with the available mix of inputs, and any adjustments would take time to materialize. Last, those adjustments would likely be rather weak, in part because the two sub-systems' outcome may target not only the innovation system.

### *2.2 An international invention system: hypotheses.*

So far we have only considered interactions between domestic actors. We now admit the possibility of international collaborations in inventive activities, which in the bottom part of Figure 1 we represent with dashed lines. If the inputs of the production function can be sourced also abroad, domestic potential inventors are also employable by foreign firms, and domestic firms may also hire foreign inventors. As a consequence, the feedbacks from the invention production function to the two sub-systems would be even weaker than in the previous case.

Increased internationalization in the production of inventions would then be associated with a progressive *decoupling* of the inventors and organizations sub-systems. *Internationalization* and *decoupling* of sub-systems will thus co-evolve: 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-system and might further increase imbalances. In other words, internationalization and functional specialization would possibly reinforce each other.

Our reasoning leads to the following hypothesis:

*H1: An increase in the internationalization of inventive activities is associated with an increase in countries relative imbalances in the contribution of inventors vs. organizations.*

We now ask which factors explain the observed imbalances. We discussed above that the inventors sub-system caters to the more general needs of specialized personnel, most of which is not employed in R&D labs. The demand for inventors relative to generic specialized professionals thus varies across countries, depending on the degree of innovativeness and economic development. Countries which are highly innovative, relative to their degree of economic development, would need relatively more inventors, compared to the numbers which are domestically supplied, possibly employing foreign inventors. Other countries (or sectors within a country) which are less innovative may demand fewer inventors, even after we control for their level of economic development. The following hypothesis captures the above considerations.

*H2: The inventor balance depends negatively on countries innovativeness, relative to their degree of economic development.*

Previous works (e.g. Cantwell and Vertova, 2004) suggest that re-organization of MNEs has led them to prefer sourcing of technologies abroad in those sectors where foreign countries have a relative advantage. Under the light of the discussion of *H2*, 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. Such considerations lead to the next hypothesis.

*H3: The inventor balance depends positively on the degree of technological specialization of country i and negatively from that of country j.*

We now consider the motivations for an applicant from country *j* to collaborate with an inventor from country *i*. These might include augmenting the home-base capabilities through specific know-how which is available only abroad, or it is available abroad on advantageous term. A well-known taxonomy (Kuemmerle, 1997) distinguishes between "home-base augmenting" motivations, aimed at obtaining abroad strategic assets that are complementary with those already available, as opposed to "home-base exploiting" motivations, whose goal is to exploit already developed assets, delivering inventions that are mostly of the adaptive type.[9]

Our first contention is that, when deciding where to carry out their inventive activities, *everything else being equal*, firms take into consideration the relative availability of inventive resources. If the mass of country *i*'s inventors is small, country *i* will be more likely to act as a provider of organizations and outsource inventors from country *j*. Analogously, if country *j*'s mass of inventors is large, country *i* is more likely to source inventors from country *j*. Calling $Inv_i$ the inventory mass of country *i,* we thus spell out our hypothesis as:

*H4: The inventor balance depends positively on* $Inv_i / Inv_j$.

Also, we consider the effect of the overall organizational inventory in the home country (*i)* and in the foreign country (*j)*. On the basis of standard labour market competition arguments, for a given pool of inventors in country *i*, the larger is the mass of country *i*'s organizations, the more expensive it will be to hire inventors from country *i*. Tougher competition in the home country has two effects: first, home country organizations will be pushed to hire inventors abroad. Secondly, organizations from country *j* will find it difficult to hire inventors in country *i*. Both effects would result in an inventor deficit for country *i*. Similar considerations hold if we consider country *j*. There, for a given overall supply of inventors, the presence of many local organizations would lead to much competition for the scarce human resources. Organizations in country *j* would have an incentive to hire inventors abroad, and organizations in country *i* not to hire inventors in country *j.* Both effects would lead to an inventor surplus for country *i*. Calling $App_i$ the organizational inventory of country *i*, these considerations lead to formulate the following hypothesis:

9 Patel and Vega (1999) and Le Bas and Sierra (2002) provide evidence in support of this perspective. See also Vernon (1966) for an early product-cycle rationale of this argument.

*H5: The inventor balance depends negatively on $App_i / App_j$.*

Hypotheses *H1* to *H5* are the core implications of our conceptual framework. We add further considerations regarding two more factors which also could be of relevance and that, as such, we contemplate in the empirical analysis. As we mentioned, the sub-systems include also formal institutions, such as the legal system, and informal ones, such as a country's cultural traits (Edquist and Johnson, 1997).

To account for formal institution, we consider 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 headquarters in the home country (see for discussion Thomson, 2013; Picci, 2010). 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. However, there could be a further effect, reflecting itself in a bias of sort in our data: in countries with weak IPR, innovations would be protected by means other than patents (e.g. trade secret), and as such would not be reflected in our statistics. Both effects would lead to the following:

*H6:The inventor balance depends negatively on the degree of IPR protection of country i.*

Finally, we consider the possibility that countries' cultural characteristics influence the inventor balance. A large literature (since, e.g., Johnson, 1992) considers the role of culture on innovation. Recent studies have found that the degree of individualism of a society has a positive effect on the level of output and on patents across countries (Gorodnichenko and Roland, 2010, 2011) and also across regions within the same country (in the United States, Gorodnichenko et al., 2011; in China, Talhelm at 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 lead to a bias towards analytical reasoning, which in turn enhances novelty and creativity. This bias is typically mediated by what in our conceptual framework is the inventors sub-system.

In our case, 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 (for example, more individualist countries could fuel relatively more the inventors sub-system), determining the provision of the two factors, and also, on the probability that, for a given supply of organizations and inventors, they may be felicitously matched. On the basis of the existing literature (Gorodnichenko and Roland, 2010; 2011), we surmise that individualism is the most important cultural dimension that facilitates the provision of inventors. When individualism is not moderated by other factors, it could lead to an imbalance in the provision of inventors, rather than organizations (where team-work, coordination and cooperative play a central role). Such considerations lead to the following:

*H7: The inventor balance depends positively on the degree of individualism of country i.*

We anticipate that, in terms of the measure of individualism that we use (Hofstede, 2001), the United States are both the most individualistic country and the historical home-base of world-leading innovation organizations. We thus expect our empirical results to be strongly influenced by the US, a case which certainly would contradict *H7*.

## 3. The Data and the Inventor balance

We use the Patstat database (European Patent Office, 2013a, 2013b) and we consider all priority applications of 34 countries filed at any of a group of 50 patent offices from 1980 to 2009, representing the virtual totality of worldwide patenting activity. We employ the methodology presented in De Rassenfosse et al. 2013,[10] and

[10] The methodology takes full advantage of the fact that Patstat allows us to track multiple applications in different offices that claim the right to priority for the same invention, and to avoid double counting within patent families. Considering patent *applications*, instead of granted patents, allows for the analysis of more recent data (since the granting process may take several years). 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,

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. Nevertheless, the type of internationalization of inventive activity which we observe is determined, by and large, by the behaviours of multi-national enterprises (MNEs), and we will interpret our results accordingly.[11] We define a patent to be "international" if at least one of its inventors and/or applicants resides, or is headquartered, in a country different from that of the others.[12] In our population of 16.212.708 patents we do not identify the nature of the applicant, because it would be prohibitively costly to do so.

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

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

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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.

11 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.

12 The term "international" is here used purely out of convenience, and with no reference to where the first filing occurred – nationally, to a regional office such as the European Patent Office, or via the so called "international route".

13 These computations also are done fractionally, so that patents with multiple codes belonging to more than one macro-technology are counted appropriately. See Appendix A.2 for a detailed description of the constituent technologies in terms of the IPC classification, and how they are aggregated to form the five macro-technologies.

(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 and 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 terms of number of patents. It witnesses the very high number of Japanese patents, a well-known fact that has been explained in part by noting that Japanese patents have relatively narrow scopes (Coehn et al., 2002; 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 provides a glance at the increase in the degree of internationalization in the production of innovative activities, a phenomenon also documented in Picci (2010) and Thomson (2013), among others. It reports, for a small group of important countries, *InvApp|Inv*, one of the relative measures of internationalization introduced by Picci (2010).[14] From the available evidence it appears that the degree of internationalization is such to make our interest in the inventor balance *a priori* potentially relevant.

**[Figure 1 about here]**

The "inventor balance" metric allows appreciating the divergence between country patent portfolios computed according to the applicant or inventor criterion. We consider this measure both between pairs of countries, and also between one country and the rest of the world. We define the former, which we call the bilateral inventor balance, when $InvApp_{ij}$>0 or $InvApp_{ji}$>0, as:

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

For any pair of countries (*i*, *j*), it is equal to the relative imbalance in inventors vs. applicants in the collaborative inventive activities involving country *i*'s inventors and country *j*'s applicants. $InvBal_{ij}$ ranges from -1 to +1. It is equal to zero if there is no imbalance between country *i* and country *j*. If $InvBal_{ij}$>0, we say that country *i* displays an "Inventor Surplus" (or "Applicant Deficit"), i.e. it contributes relatively more inventors than applicants compared to country *j*. Likewise, if $InvBal_{ij}$<0, country *i* displays an "Inventor Deficit" (or "Applicant Surplus"). The lower bound ($InvBal_{ij}$= -1) corresponds to the 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 inventors surplus, country *j* displays an inventor deficit of the same entity, i.e. $InvBal_{ij} = -InvBal_{ji}$. $InvBal_{ij}$ can be computed both for all technological sectors, and also separately for

[14] The upper bound of such measure is 0.5 (or 50%), corresponding to the maximum possible degree of internationalization. Intuitively, this is so because it 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.

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, $InvBal_{i,ROW} = +1$ when 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.[15] It is the normalization needed to assure that $-1 \leq InvBal_{i,ROW} \leq +1$.

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[15] If every patent were produced by entities residing, or being headquartered, in the same country, 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's "net R&D offshoring", which, using our notation, equals $(App_i - Inv_i)/Inv_i$ (see his Table 3, 3rd column).

## 4. Descriptive analysis of the inventor balance

In Table 2 we show the inventor balance, both with respect to the rest of the world and bilateral, 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 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*, comprising countries whose $InvBal_{i,ROW} < -1/3$. (Switzerland, South Korea, The Netherlands, and the United States).
2. *Specialized inventor providers*, including 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).

Columns 4-15 of Table 2 show the bilateral inventor balance for all technologies. In considering them, we should keep in mind that $InvBal_{i,ROW}$ may be seen as a weighted average of the various $InvBal_{ij}$, so that, for example, a "specialized

Our measure differs from Thompson'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 lacks symmetry around zero.

applicant provider" is expected to have bilateral applicant surpluses vis-à-vis most other countries. We observe such fact in the countries belonging to this group, and whenever we observe a negative value, it is with respect to another country belonging to the same group, with South Korea and Switzerland, displaying an applicant deficit vis-a-vis Taiwan, as exceptions. The case of the United States stands out, both for the size of its economy and for the extent of its innovative activities. In the next section, where we research the determinants of the inventor balance, we shall comment upon such an instance of "American exceptionalism".

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

Within each group there are countries which are very different among themselves in other dimensions. In this respect we observe a logical difference between the first and the third group. Among specialized applicants providers we find only mature industrialized countries (South Korea, by now, belonging to this category). These are invariably countries which both have a richly textured economic structure, and also a strong educational sector which is able to supply inventors. Within specialized inventor providers, instead, we observe an emerging country such as China grouped with 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. The same cannot be said of Canada, Italy or the UK, which belong to the same group as China.

Inquiring into the trajectories which have led to the current pattern of functional specialization is not our primary goal, but in Table 3 we at least provide some useful indications in this respect, by showing $InvBal_{i,ROW}$ both at an aggregate level and 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 does not vary across sectors, with some noteworthy exceptions. Taiwan experienced a surge in the applicant surplus in the second decade, which was reversed later. Germany saw its inventor balance progressively improving over time from a deficit to a surplus. A clear trend is evidenced for China, whose inventor surplus became more pronounced in time, as it was increasingly targeted by multinational firms as a R&D location. In other words, if for transition economies the presence of an inventor surplus could be a transient phase, as they develop an industrial base with the muscles needed to be proactive abroad, the data for China does not show (yet) a turnaround.[16]

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. There are however some exceptions to this tendency. For example, Japan's inventor balance is roughly in equilibrium over 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 reverse 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 increase in internationalization which we observed was accompanied by a progressive decoupling of the supply of organizations and of inventors (our hypothesis *H1*). Such a decoupling could manifest itself through an increase in time of imbalances, 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[17] is a

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

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

follows: 0.4062 (1980-1989), 0.4592 (1990-1999), and 0.4713 (2000-2009). The observed increase in the overall amplitude of imbalances is coherent with the presence of a progressive decoupling of the two sub-systems. When we look within countries and across technological sectors, however, we do not observe an increase in the imbalances. The last column of Table 3 shows a measure of dispersion, measured for each decade, of the sectoral inventor imbalances. The average values are 0.0739 (1980-1989), 0.0619 (1990-1999), and 0.0754 (2000-2009). Our findings thus provide partial support for hypotheses *H1*, indicating a the presence of a progressive decoupling across countries, at least at the cross-country level.

## 5. Empirical strategy and results

To test our hypotheses from *H2* to *H7* we resort to inferential methods. With the purpose of providing robust results, we test, in more than one way, for the significance of a set of factors in explaining the inventor balance. First, we consider a series of 30 yearly cross-section regressions to explain $InvBal_{i,ROW}$, the inventor balance with respect to the Rest of the World. Such an approach has limitations, the most important being a certain paucity of degrees of freedom, since we explicitly decide not to pool observations in order to carry out this analysis at the level of individual countries. We consider all countries with a world share of patents at least greater than 0.1% in 2009, for a total of 27, accounting together for a world share of patents of about 99%.[18] On the plus side, this approach, which explains countries overall imbalances, allows us to appreciate general tendencies and how they may vary in different years.

We aggregate the results, which are shown in Table 4, in the following way. For the 30 (one for each year) estimated coefficients relative to each variable, we

[18] We have information on patents with inventors and applicants from a total of 52 countries, but the contribution of some is marginal and in some cases negligible. We thus consider countries for which we have sizeable data for internationalization for all the period in consideration (1980 – 2009). The number of observations for which we have international collaborations ranges from 24 in 1980 (due to lack of internationalization for China; Czech Republic (at the time communist Czechoslovakia); Turkey) to 27 in 2009. Some countries, such as the Russian Federation, are not present in our dataset on internationalization in the early 1980s and were thus not included. The 27 countries are: Australia, Austria, Belgium, Canada, China, Czech Republic, Denmark, Finland, France, Germany, Hungary, India, Ireland, Italy, Japan, Mexico, Netherlands, Norway, Poland, South Korea, Spain, Sweden, Switzerland, Taiwan, Turkey, United Kingdom, United States of America.

report the median value. To appreciate the overall statistical significance of the estimated coefficients, we report 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*.[19]

In our second estimation strategy, the dependent variable is the bilateral inventor balance, $InvBal_{ij}$. The structure of the data is analogous to that familiar in the estimation of the gravity model. However, what we estimate is not a gravity model, because the dependent variable does not represent the intensity of a bilateral flow (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 include a given regressor $x$ twice, once relative to country $i$ ($x_i$ ) and once to country $j$ ($x_j$ ), the two estimated coefficients will be exactly one the opposite of the other. Because of the symmetric nature of the problem, we obtain exactly the same result if we include only one regressor $x' = x_i - x_j$, as we do. A positive estimated coefficient will imply that $x'$ has a positive impact on the inventor balance, when present in $i$, and a negative one, of exactly the same magnitude, when present in $j$.

Since, particularly in the early years of the sample, we record many missing values for the dependent variables, corresponding to cases where there was no bilateral collaboration between a given pair of countries, we adopt Heckman's Lambda Method (Wooldridge, 2002).[20]

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 illustrated in Table 4, and in Panel B, for the smaller group of 12

[19] 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.

[20] We include in the selection equation the 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 (see Appendix A.3 for data description). 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.

countries with a world share of patents at least greater than 0.5% in 2009.[21] Details on all variables considered are presented in Appendix A.3.

For each sample, we present results both using all available years and also limited to the 1990-2009 and 2000-2009 periods. For each estimation approach, we also report results which exclude the United States, for reasons which will become clear shortly. Table 4 and 5 report our results, which we discuss 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 of countries i and j*, in the empirical model of Table 5.

The data used to estimate the cross-sections, whose results are shown in Table 4, are also amenable to pooling and to estimation using fixed effects. However, caution should be exercised in adopting such an estimation technique. First, a fixed effects panel estimate identifies its 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, a fixed effects estimator does not admit variables which are constant in time, because they are indistinguishable from the fixed effects. In our case in particular, most of the regressors are of this type. These limitations notwithstanding, we also estimated a fixed effects model on the pooled data, and will report the results for the two time-varying variables whose effect it allows estimating.

**[Table 4. about here]**

**Determinants of Inventor balance. Rest of the World. Ordinary Least Squares**

**[Table 5. about here]**

**Determinants of Bilateral Inventor balance. Heckman's Lambda Method**

To test *H2* (see Section 2), we include among the regressors a measure of a country innovativeness, relative to its level of economic development:

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

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

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. This measure is disputable, since the numerator depends crucially on the propensity to patent, which varies across countries (see, however, De Rassenfosse and de la Potterie, 2009).

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, on the other hand, unambiguously indicate a significant negative impact of *Innov|GDP* on the inventor balance. Pieced together, our results indicate that *H2* is verified: economies which are highly innovative, relative to their level of economic development, tend to have an applicant surplus.

All results testing the effect of a measure of technological specialization indicate that it has a positive and significant effect, thus corroborating *H3*. The pooled fixed effects model also indicates a positive effect, with an estimated coefficient equal to 0.341, significant at 5% level.

All our results unambiguously indicate a significant effect of patent inventories: positive, when adopting the inventor criterion, and negative, when looking at applicants. Please note that to express these measures we only employed *national* patents, a feature which is possible because of the type of measures which we adopt. In other words, these measures do not include data which are also included in the definition of the dependent variables, and as such are legitimate for the purpose of testing *H4* and *H5*, which are confirmed by our results.

This concludes the analysis of the main assumptions which we derived from our conceptual framework. We also controlled for two possible further factors which may affect the inventor balance. First, we find no evidence (or contrasting evidence) on the relevance of the degree of IPR protection (*H6*) in the larger group of countries, while we find a negative and statistically significant effect in the last two decades for the smaller group countries (both excluding and including the US). The evidence on *H6* is then mixed.

Second, we consider a possible effect of culture on the inventor balance. We focus on the cultural dimension of individualism. Our results depend on whether we consider the United States, which both has the highest value for the individualism, and a strong applicant surplus. We start by considering the results using the

Heckman's estimator (Table 5). When we include the United States, we find a negative and significant effect of both cultural variables in all cases (Panels A.1 and B.1 of Table 5). This might be due to the fact that the United States rank first among individualistic countries, and at the same time have a prominent position as applicants in determining bilateral inventor balances. In fact, when we exclude the United States, in the larger group of countries the results are reversed and significant for the whole periods 1980-2009 and 1990-2009 (Panel A.2), thus confirming *H7*. In the case of the smaller group of countries (Panel B.2), when excluding the US the coefficients are always positive, but not significant.

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.

We conclude that *H7* is verified, but only when taking into account 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.

## 6. Discussion and conclusions

We have studied a type of international functional specialization in the production of innovations at a global scale. In a situation where most innovations are the product of a matching between organizations, which are typically firms, and inventors, some countries may specialize in providing the former, while others, the latter. We have shown that the magnitude of the observed imbalance is often considerable, and that it has increased on average during the last three decades. We interpreted this result as evidence of a progressive "decoupling", as the degree of internationalization in the production of innovations increases, of two sub-systems supplying respectively inventors and organizations. With the help of a dedicated conceptual model, we tested a series of hypotheses on the determinants of such imbalances. In this concluding section we would like to briefly comment upon the possible policy relevance of our findings.

The presence of the strong imbalances which we have found poses problems and opportunities to policy makers. Consider the case of a country displaying an important applicant deficit. Such a situation could be accompanied by a strong productive base which is however not very innovative. In this case, that country's educational system would provide inventors both to the need of the "domestic" productive sector, which demands technicians but not inventors, and to the R&D labs controlled by foreign entities. However, much of the value added by new inventions would arguably be captured by those firms, and possibly siphoned off abroad. Such a country would risk a hollowing-out of its productive base, which in turn would imperil the resources needed to run its educational system, with long-run negative effects on the very provision of much-needed skilled labour.

On the other side, the presence of functional specialization could offer an opportunity to increase efficiency, particularly for developing countries, which could in this way attract foreign investments and foster economic development. For example, an interesting question left for future research regards the determinants of the share of foreign direct investments which would actually feedback to the inventors sub-system (thus reinforcing the decoupling) or rather to the organizations sub-system, thus having a re-balancing effect (on similar issues, see also Lewin et al., 2009; Athreye and Cantwell, 2007).

Our analysis also represents an attempt to re-frame the debate on innovation systems under the light of internationalization of inventive activities (see also Carlsson, 2006). While keeping some elements of the original framework of national systems of innovation (for example, the domestic nature of the inventors and organizations sub-systems), we have proposed a conceptual framework where international feedbacks are crucial for the definition of the domestic systems. Certainly, we 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 assumption is consistent with evidence showing that innovation systems, even though increasingly internationalized, still rely on country-specific institutions (Carlsson, 2006). To some extent, this is only a useful simplification of a more complex reality. For example, the higher echelons of the education system might be able to directly attract talented students from abroad (for similar considerations see Soete et al., 2010).

The presence of the rich set of international interdependencies which we have discussed, suggests that purely national innovation policies may come short of expectations. In particular, in a world of yore where innovations were almost exclusively national, these preoccupations would have been addressed by the playing of adjustment mechanism between the inventors and the organizations sub-systems. We have however argued that a progressive decoupling between them may be in place, going hand in hand with the deepening of internationalization, and weakening reciprocal feedbacks. This, in turn, calls for a heightened attention by policy makers.

In a sense, we are confronting yet another case where the internationalization of economically relevant activities complicates the prospects of success of policies which are purely national in scope. Consequently, forms of supranational action, either by suitable institutions – the case of the European Union coming to mind as an obvious example - or resulting from the coordination of national actors, would be called for (see e.g., Gregersen and Johnson, 1997 for an early discussion of factors hindering the emergence of an European innovation system). What these policies should concretely aim at would require further research. Certainly, a constant monitoring of the inventor balance, both in the aggregate and a the level of individual technologies, would be a prerequisite for any action, aimed at avoiding that the opportunities arising from the international matching of inventors and organizations result in undesired long-term effects for some of the countries involved.

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## Appendix

### A.1 Measures of internationalization in Picci (2010).

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

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

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

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

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

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

### A.2 Taxonomy of technologies (Schmoch, 2008).

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

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

*Chem* (Chemistry)
14 - Organic fine chemistry: C07B, C07C, C07D, C07F, C07H, C07J, C40B, A61K8, A61Q.
15 - Biotechnology: C07G, C07K, C12M, C12N, C12P, C12Q, C12R, C12S.
16 - Pharmaceuticals: A61K, A61K8, A61P (added, not present in WIPO document).
17 - Macromolecular chemistry, polymers: C08B, C08C, C08F, C08G, C08H, C08K, C08L
18 - Food chemistry: A01H, A21D, A23B, A23C, A23D, A23F, A23G, A23J, A23K, A23L, C12C, C12F, C12G, C12H, C12J, C13D, C13F, C13J, C13K.

19 - Basic materials chemistry: A01N, A01P, C05, C06, C09B, C09C, C09F, C09G, C09H, C09K, C09D, C09J, C10B, C10C, C10F, C10G, C10H, C10J, C10K, C10L, C10M, C10N, C11B, C11C, C11D, C99Z.
20 - Materials, metallurgy: C01, C03C, C04, C21, C22, B22.
21 - Surface technology, coating: B05C, B05D, B32, C23, C25, C30.
22 - Micro-structure and nano-technology: B81, B82.
23 - Chemical engineering: B01B, B01D0, B01D1, B01D2, B01D, B01D41, B01D5 (added, not clear in WIPO document), B01D8 (added, not clear in WIPO document), B01D9 (added, not clear in WIPO document), B01D43, B01D57, B01D59, B01D6, B01D7, B01F, B01J, B01L, B02C, B03, B04, B05B, B06B, B07, B08, D06B, D06C, D06L, F25J, F26, C14C, H05H.
24 - Micro-structure and nano-technology: A62D , B01D45 , B01D46 , B01D47 , B01D49 , B01D50 , B01D51 , B01D52 , B01D53, B09, B65F, C02, F01N, F23G, F23J, G01T, E01F8, A62C.

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

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

### A.3 Data description

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

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

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

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

*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.

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## Tables and Figures

### Table 1. 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 (n=52) | 294408 | 100.0 | 548300 | 100.0 | 652650 | 100.0 |

**Note:** Patent counts are rounded numbers, computed according to the applicant criterion. Total 52 refers to the whole set of 52 countries considered 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 | | .53 | -.02 | .04 | .23 | -.36 | .47 | .77 | -.28 | .17 | -.66 | .65 |
| CH | 10 | -.56 | -.53 | | -.57 | -.55 | -.88 | -.82 | -.57 | .20 | -.38 | -.14 | -.65 | -.18 |
| CN | 1 | .77 | .02 | .57 | | .69 | .41 | -.38 | .26 | .65 | .55 | .81 | .50 | .84 |
| DE | 6 | .19 | -.04 | .55 | -.69 | | .00 | -.51 | .30 | .45 | .20 | -.24 | -.53 | .60 |
| FR | 3 | .36 | -.23 | .88 | -.41 | .00 | | -.18 | .65 | .77 | .69 | .93 | .29 | .47 |
| IT | 0 | .66 | .36 | .82 | .38 | .51 | .18 | | .19 | .82 | .49 | .15 | .57 | .88 |
| JP | 6 | .07 | -.47 | .57 | -.26 | -.30 | -.65 | -.19 | | .84 | .72 | .45 | -.80 | .08 |
| KR | 10 | -.34 | -.77 | -.20 | -.65 | -.45 | -.77 | -.82 | -.84 | | -.74 | .83 | -.78 | -.14 |
| NL | 7 | -.35 | .28 | .38 | -.55 | -.20 | -.69 | -.49 | -.72 | .74 | | .57 | -.63 | -.26 |
| TW | 8 | -.01 | -.17 | .14 | -.81 | .24 | -.93 | -.15 | -.45 | -.83 | -.57 | | -.29 | .56 |
| UK | 3 | .63 | .66 | .65 | -.50 | .53 | -.29 | -.57 | .80 | .78 | .63 | .29 | | .83 |
| US | 8 | -.49 | -.65 | .18 | -.84 | -.60 | -.47 | -.88 | -.08 | .14 | .26 | -.56 | -.83 | |

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

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

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

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

**Table 4. Determinants of Inventor Balance. Rest of the World. Ordinary Least Squares.**

## Panel A: All countries

| | 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

| | 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 $\geq x$ (if $x > 15$), or $\leq x$ (if $x < 15$) in 30 draws of a binomial random variable where the probability of success equals one half.

**Table 5. Determinants of Bilateral Inventor Balance. Heckman's Lambda Method.**

## Panel A. Countries with world share of patents > 0.1%.

| | (1) All countries (n=27) | | | (2) Excluding the US | | |
|---|---|---|---|---|---|---|
| | 1980-2009 | 1990-2009 | 2000-2009 | 1980-2009 | 1990-2009 | 2000-2009 |
| Innov\|GDP | -0.121*** | -0.147*** | -0.433*** | -0.176*** | -0.206*** | -0.484*** |
| | (0.0437) | (0.0537) | (0.113) | (0.0501) | (0.0598) | (0.123) |
| Log(inv-national) | 1.637*** | 1.413*** | 1.541*** | 1.669*** | 1.408*** | 1.493*** |
| | (0.0884) | (0.101) | (0.183) | (0.105) | (0.117) | (0.207) |
| Log(app-national) | -1.502*** | -1.237*** | -1.118*** | -1.462*** | -1.167*** | -1.013*** |
| | (0.0908) | (0.106) | (0.192) | (0.110) | (0.125) | (0.213) |
| IPR | 0.0102 | -0.0123 | -0.0102 | 0.00353 | -0.0215** | -0.00557 |
| | (0.00684) | (0.00772) | (0.0106) | (0.00883) | (0.0101) | (0.0147) |
| Tech specialization | 0.313*** | 0.190*** | 0.0304 | 0.400*** | 0.297*** | 0.0230 |
| | (0.0469) | (0.0647) | (0.122) | (0.0561) | (0.0737) | (0.135) |
| Individualism | -0.397*** | -0.440*** | -0.659*** | 0.00362*** | 0.00424*** | -0.000687 |
| | (0.0378) | (0.0491) | (0.108) | (0.00102) | (0.00115) | (0.00205) |
| Observations | 18,750 | 12,750 | 6,500 | 17,280 | 11,760 | 6,000 |
| of which, censored | 12,106 | 7,358 | 3,270 | 11,918 | 7,286 | 3,246 |
| Wald test, p-value | 0.966 | 0.958 | 0.986 | 0.949 | 0.931 | 0.975 |

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

| | (1) All countries (n=12) | | | (2) Excluding the US | | |
|---|---|---|---|---|---|---|
| | 1980-2009 | 1990-2009 | 2000-2009 | 1980-2009 | 1990-2009 | 2000-2009 |
| Innov\|GDP | -0.473*** | -0.484*** | -0.430** | -0.588*** | -0.617*** | -0.532*** |
| | (0.0646) | (0.0771) | (0.172) | (0.0762) | (0.0879) | (0.193) |
| Log(inv-national) | 1.280*** | 1.284*** | 1.829*** | 0.996*** | 1.029*** | 1.761*** |
| | (0.177) | (0.202) | (0.379) | (0.216) | (0.239) | (0.440) |
| Log(app-national) | -0.885*** | -0.850*** | -1.439*** | -0.506** | -0.483** | -1.265*** |
| | (0.175) | (0.201) | (0.419) | (0.219) | (0.242) | (0.488) |
| IPR | 0.0219* | -0.0231* | -0.0766*** | 0.00356 | -0.0485*** | -0.0934*** |
| | (0.0122) | (0.0138) | (0.0189) | (0.0163) | (0.0185) | (0.0269) |
| Tech specialization | 0.395*** | 0.166* | -0.267 | 0.520*** | 0.311*** | -0.200 |
| | (0.0753) | (0.0994) | (0.265) | (0.0933) | (0.117) | (0.293) |
| Individualism | -0.710*** | -0.722*** | -0.612*** | 0.000402 | 0.000622 | 0.00139 |
| | (0.0550) | (0.0668) | (0.171) | (0.00139) | (0.00161) | (0.00306) |
| Observations | 3,300 | 2,200 | 1,100 | 2,700 | 1,800 | 900 |
| of which, censored | 1,036 | 458 | 98 | 1,014 | 458 | 98 |
| Wald test, p-value | 0.945 | 0.930 | 0.941 | 0.940 | 0.932 | 0.942 |

**Note:** Estimation method: Heckman's lambda method. First-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. All dependent variables are computed as the difference of values for *i* and *j* countries. 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**

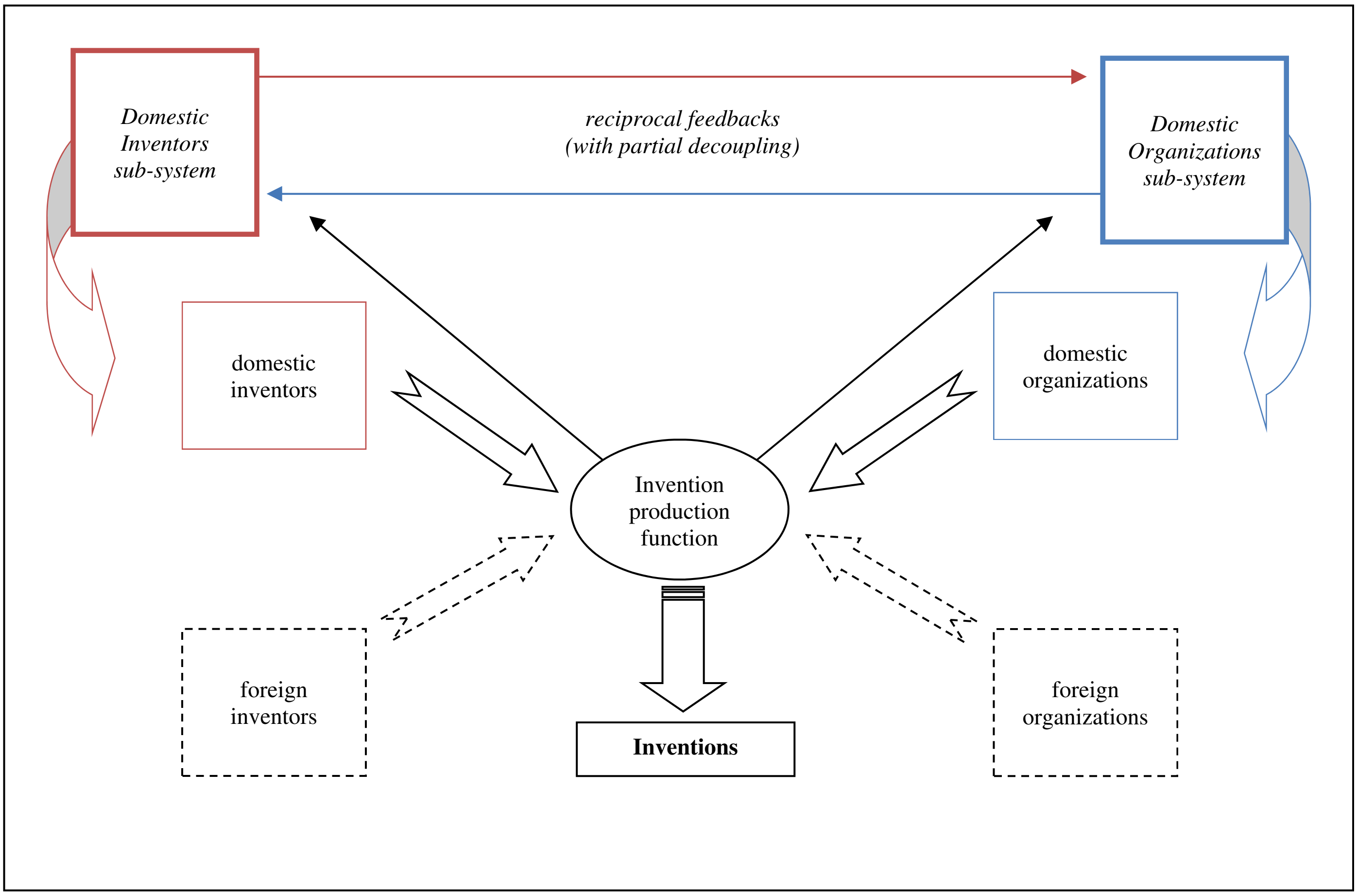

**Figure 2.** InvApp/Inv relative measure of internationalization for FR, DE, JP, UK and US. 1980-2009.