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Knowledge Enclosures, Forced Specializations and Investment Crisis

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Abstract - Like land before the industrial revolution, much knowledge is being enclosed in private hands. These enclosures have become a major factor in specialization among firms and among countries: both are forced to specialize in the fields that are not restricted by the enclosures of the others. This forced specialization is highly asymmetric and involves strong self-reinforcing innovation patterns: we show that it is mainly driven by the existing knowledge enclosures, and that it polarizes investment opportunities among firms and, even more so, among countries. Moreover, also the world economy as a whole suffers from this restriction of investment opportunities, which, in our view, is one of the factors contributing to the present crisis.

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1. Introduction.

Since the 1994 TRIPS agreements, the global definition and enforcement of IPR has become much tighter. These new enclosures may initially have provoked a gold rush for the private appropriation of important fields of knowledge, but since then they have restricted opportunities for investment at both firm and country level. They have altered the comparative advantages of nations by restricting opportunities to specialize in processes that do not require rights owned by other nations. A virtuous circle of cumulative causation between intellectual property and investments may have arisen for countries rich with IPRs, while those poor in IPRs face the possibility of a vicious circle between investment and innovation opportunities. Whilst this restriction of investment opportunities is associated with a new sort of comparative advantage, and may lead to an increase in the level of international trade, it contributes to the overall depression of investment opportunities and, together with other causes, to the present crisis of the global economy.

In the next section of the paper we consider how a new economy based on intellectual monopoly and forced specialization patterns emerged after the end of the Cold War. In section 3 we elaborate on the relation between intellectual enclosures – that is, the increasingly private appropriation of knowledge – and the new restricted comparative advantage which has emerged. We compare this view of international trade with the standard theory of comparative advantage, as well as with the "modern theory" of the advantages of inter-industry trade, and argue that trade may instead stem from a restriction of investment opportunities due to intellectual monopoly. In section 4 we introduce a simple framework describing the theoretical basis for the empirical analysis. In section 5 we estimate the marginal effects of IPR endowments and investment efforts on each other by means of a system of simultaneous equations estimated using a three-stage least square procedure. We use data from 26 OECD countries over the 1978-2006 period and consider their specialization patterns in five industries. Our findings are twofold. First, we find that, on average, the within-country distribution of patents among industries determines the within-country distribution of investments among industries, and vice-versa. Second, we show that since the TRIPs agreements, the relation of causality from patent specialization to investment specialization has become more intense. In the concluding section we examine some policy implications of our analysis.

2. Intellectual monopoly and forced specialization patterns.

In 1994, the creation of the WTO, with the associated TRIPs agreements, marked a structural break in the world economy. By that time, the Cold War belonged to the past and the US had become the only superpower. In the same years, the fruits of the military effort were not evident in the political sphere alone; for in the new world under American dominance, internet and computers – to whose development military and public research had substantially contributed – became cheaply available, opening up numerous new technological possibilities. However, the technological generosity of the US did not last for long. The new world, unified by American political dominance and made small by the new information highways, could now give secure global intellectual ownership to the countries controlling scientific and technical knowledge. In this sense the TRIPs marked the beginning of a new era of capitalism: one of intellectual monopolies in which ideas themselves could be securely owned and become capital investments. The priority of ideas, which in the past had been associated with the "idealism" of Hegelian philosophy, was now a concrete reality. The firms and countries that owned ideas could use them in the production of material goods and of new ideas. By contrast, the countries that lacked ownership of these assets could easily fall into a vicious circle whereby skills were not developed because the country lacked the ownership of ideas, and ideas were not produced or acquired because the country lacked the requisite skills.

In this respect, the 1990s were different from the 1980s not only because of the absence of socialist countries. The change in the nature of capitalism had also changed the relations among all the other countries: both the relations among advanced and developed countries and the relations among major capitalist countries were now very different from those predominant during the Cold War.

In the framework of the mainstream view expressed by Solow's (1956) model, technological knowledge was available to all countries and would eventually lead to the convergence of the growth rates of all countries. Unfortunately, the only feature that knowledge shares with pure public goods is non-rival nature, whilst excluding others from knowledge is easily accomplished with various devices (such as secrecy and intellectual property rights). Moreover, the inclusion of others in the use of knowledge (that is, its transmission and diffusion) may be very costly. Thus, exclusion from the use of knowledge is not only feasible but also particularly costly for those excluded because its private ownership is meant to imply that only the first discoverers have the right to use it. Ironically, non-rival goods like ideas, which can be simultaneously used by many users without additional costs, cannot be replicated by other individuals in the same way as the other standard production inputs can. This circumstance generates two interrelated phenomena at micro and macro level or, to put it in another way, at firm level and country level.

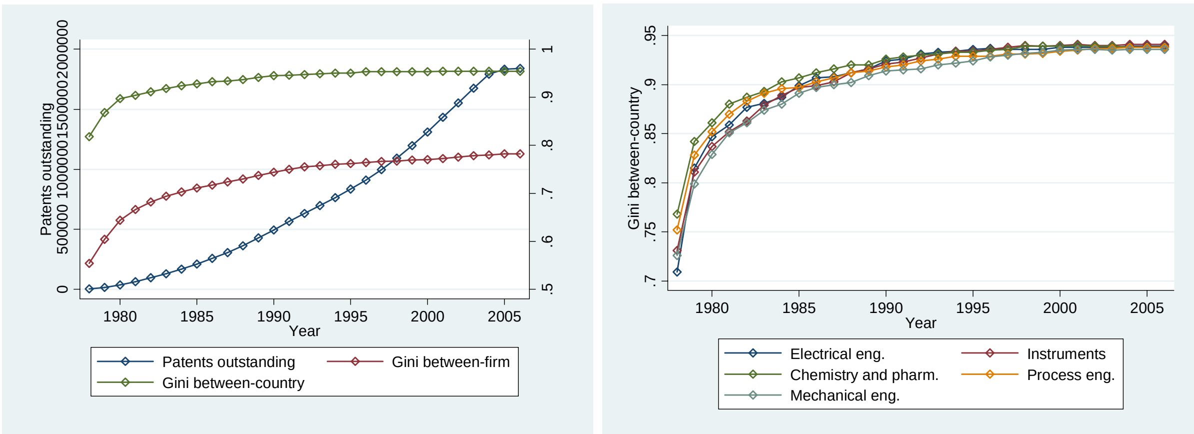
At micro level, each firm is forced to specialize its investments in the narrow field left free by the intellectual monopoly of other firms. In some cases, these specialization opportunities coincide with the shrinking fields, untouched by IPR, which are the modern equivalent of the common lands unaffected by the enclosures of the industrial revolution. In other cases, besides these shrinking commons, the field includes the firm's exclusive private intellectual property (which contributes to the narrowing of all the other possible fields of specialization). Some have maintained that, in the case of land, enclosures and private property prevented the over-exploitation of a resource being depleted by overcrowding. However, in the case of intellectual assets, it cannot be claimed that the modern counterpart of the enclosure movement has brought similar benefits. It does not save us from a tragedy of commons but may instead produce an anti-commons tragedy (Heller and Eisemberg, 1998): unlike farmland and pasturage, the fields of knowledge are not subject to overcrowding, but they may be greatly damaged when they are enclosed within narrow and rigid boundaries. When the access to knowledge is seriously limited by the fields privatized by others, the resulting forced specialization is likely to be associated with a dramatic squeeze of investment opportunities.

At macro level, the traditional theory of comparative advantage is based on the idea that each country acquires the specialization dictated by the natural endowments of the immobile resources enclosed in its geographical field. However, in the present global economy, the ownership of knowledge (potentially, the most mobile resource) generates an artificial field and a related comparative advantage. This artificial field includes the ideas owned by the country's production units and those under common ownership, while it is limited by the ideas owned by other nations. If a good like knowledge is moved from the public to the private sphere, the legal positions on intellectual property influence the comparative advantages of nations and cause patterns of asymmetric development (Pagano, 2007a). The legal ownership of knowledge that limits the liberty of some countries to enter certain specialization fields has consequences more drastic than those of tariffs. At most, tariffs can completely close the market of the country imposing them. By contrast, the IPRs imposed by a firm or by cluster of allied firms close global markets for all the other firms. While these clusters do not coincide with specific countries, they closely overlap with them, and as a consequence tend to create a new sort of national comparative advantage. However, although IPRs act like global tariffs, they cannot be reciprocated by other countries. Thus, unlike tariffs, they are associated with forced specialization and with increases in global trade. Countries which are prevented from specializing in certain fields must import goods or licenses from the holders of the legal rights on the related knowledge.

Both countries and firms are forced to specialize in restricted fields, the overall result being a global squeeze on investment opportunities. The restriction of productive opportunities, however, is highly asymmetric and path-dependent because it is closely conditioned by past endowments of intellectual assets. Since organizations owning more intellectual assets also own larger fields of investment and new patenting opportunities, a polarization arises in innovativeness (across firms as well as across countries). Moreover, if in all industries (albeit to different extents) technology is cumulative in nature, the same polarization dynamics should persist at sectoral level as well. A picture of these dynamics emerges rather sharply from Figure 1 (panel A and B).

Figure 1. World distribution of patents.

Panel A. All sectors. Panel B. Per sector.



Source: authors' calculations on European Patent Office data (EPO, 2008).

As will be seen from Figure 1, the degree of inequality in the distribution of patents increases over time both among firms and among countries. Moreover, the degree of polarization is shown to be constantly higher for countries than for firms. There are many reasons why this is so: for example, within the same country firms undertake joint research activities that are impossible across national borders, or they more easily engage in cross-licensing or alliances to fight rival patenting activities.[1] But the main reason is probably related to the fact that

[1] The market exclusion of competitors can be secured by pre-emptive patenting focusing on obvious and doubtful inventions which prevent potential innovators from following alternative research and patenting paths (Gueller, Martinez, Pluvia 2009). One strategy by which a cluster of firms, often

countries can wield different punishment devices in order to support, or defend, their national companies. Thus, at the micro level each firm has a sense of insecurity due to the fear that its investment strategies may be blocked by other firms. At the macro level, this sense of insecurity is exacerbated by differences among the political, military, and economic retaliation capabilities of countries.

Because of TRIPs, this cross-country polarization dynamic became sharper and affected the relative economic importance and power of the major capitalist countries. In spite of the scientific, political and military dominance of the US, the 1980s saw a remarkable challenge raised by West Germany against American capitalism. While the US relied on a science-based system of top-down innovation which had its counterpart in a detailed Fordist division of "flexible labour" at the bottom level, West Germany relied on an engineering-based system of bottom-up innovation and continuous quality improvement which privileged long-term labor relations. In a world of weak formal intellectual property rights, the American system was at an evident disadvantage: top-down formal science had to be expressed in fairly clear language and could be freely exploited by competent users, while bottom-up engineering improvements consisted much more of tacit knowledge embodied in humans, equipments and their relations, and they could not be easily used by competitors. The situation changed with the reinforcement of IPRs: top-down systems were better able to express their innovations in clear formulas which could be patented, while bottom-up systems saw the scope of their flexibility seriously restricted by the risk of infringing the IPRs of other countries. Thus the relative performances of the US and its main competitors reversed.

This dynamic is corroborated by the fact that, after the TRIPs, the US continued to increase – even at slightly increasing rates – their patent specialization in ICT technology. But Germany was forced (and has now succeeded) to adapt its patent specialization pattern to the new system, enhancing its patenting activity in ICT at the expense of its innovation activity in mechanical engineering (as shown in the figures A1 to A5 in Appendix A). However, it should also be noted that the positive effect of the TRIPs on the US's innovation performance did not last long, because the share of US patents (relative to the total of global patents) in all sectors entered progressive decline from around 2000. This recent worsening of the US's relative

belonging to the same national background, can defend themselves against pre-emptive patenting is by forming alliances (like AST, the Allied Security Trust) which operate under a catch and release model. They buy patents and give licences to the members of the Alliance and than resell the patents on the market. These big firms joined in alliances have many more investment and patenting opportunities than small firms (especially those isolated in backward countries). Besides their initial patenting endowments, the patenting opportunities and the innovation capabilities of firms also depend on many other factors, including the form of corporate governance and the safeguards provided for the individuals employed in the innovation activities (Belloc, 2010).

position may be the consequence of a reduction of investment opportunities for US firms due to the exacerbated fragmentation of IPRs in a country particularly strongly enforced intellectual monopolies as well as the result of successful industrial strategies of other countries.

Summing up, a tight international system of IPRs has three interrelated implications. First, it favors a virtuous circle of cumulative causation between intellectual property and investments for those countries rich in IPRs, while it depresses investment and innovation opportunities for countries poor in IPRs. Second, for countries rich in IPRs, it restricts both the investment and innovation opportunities of a country in the field where that country has proprietary monopoly knowledge. Finally, this restriction of investment opportunities is associated with a new sort of comparative advantage which is quite different from the standard comparative advantage considered in the Ricardian theory of international trade (and, as we shall see in the following section, also from the more recent theories of intra-industry trade).

3. IPR enclosures and restricted comparative advantage.

The traditional argument in favor of a tighter system of IPRs is that it fosters innovation, since it guarantees a monopolistic position (and monopolistic profits) to the innovator.[2] From a macro point of view, this argument has been translated into a strengthening of the IPRs system worldwide. While some authors argue that this should result in an increased aggregate R&D activity, because it positively affects the ability of firms to transfer technology abroad and go multinational (see, for instance, Taylor, 1994), others claim that a stronger IPR system may also give rise to an increasing differential in innovation rates across countries. For example, Helpman (1993) proposes a model with endogenous innovation and shows that the rates of innovation differ across countries whenever a given country has a stock of knowledge in inventive activity higher than that of the other countries, so that the more this country invests in innovation, the greater become its cumulative stock of knowledge and its subsequent innovation rates. A tighter system of IPRs thus has a negative effect on the innovation rates of the less developed countries, inasmuch as it reduces the South's possibilities to imitate the

[2] This is probably the most frequently cited purpose of patents. More generally, as Mazzoleni and Nelson (1998) put it, four arguments can be put forward in support of an IPR system: patents provide motivation for future inventions (Arrow, 1962; Nordhaus, 1962; Scherer, 1972); patents on inventions induce the investments needed to develop and commercialize them (Mueller, 1962); patents induce individuals to disclose their inventions (Machlup, 1958); and broad patents on prospect-opening inventions prevent competitors from wasting resources while racing the same goals (Kitch, 1977).

North's technology. Using a model similar to Helpman's (1993), Lai (1998) discusses different channels of international technology diffusion and maintains that stronger intellectual property protection depresses the rate of product innovation in less developed countries if production is transferred from the North to the South mainly through imitation.

Whilst this body of literature shows that stronger IPRs may produce a polarization in innovativeness by protecting countries already rich in knowledge and decreasing the international transfer of *existing* technology, it also assumes that stronger IPRs do not affect the costs of producing *new* technology.

In our opinion, this strand of analysis fails to acknowledge the fact that innovations build also on past proprietary innovations. In knowledge-intensive productions, indeed, new technology has a sort of IPR pedigree, so that the production of new technology requires an increasing number of proprietary intellectual assets (see Heller and Eisenberg, 1998, and Pagano and Rossi, 2004). As a consequence, a tighter system of IPRs increases the cost of producing innovation relatively more for countries with relatively lower endowments of IPRs. Thus, some countries enjoy security from owning knowledge and will invest in the relative skills and assets, which, in their turn, in a cumulative process, enable those countries to acquire the ownership of additional knowledge, thus generating a "snowball dynamic". Other countries may be trapped in a vicious circle whereby the lack of proprietary monopoly knowledge discourages investments in human capital and other related assets, whose absence discourages, in turn, the acquisition of intellectual property rights. In such contexts, countries poor in IPRs are unable to catch up with countries rich in IPRs.

A new perspective on comparative advantage thus emerges. In particular, each country is forced to specialize in those industrial fields in which it has a relatively larger initial IPRs endowment; in these fields, in turn, each country acquires increasing innovation and production capabilities.

The neoclassical "pure" theory of trade, as formulated in the Heckscher-Ohlin tradition, explains the relative specialization of countries by arguing that it is determined by relative factor endowments, where by 'factors' are meant immobile or physical resources (Heckscher, 1919, Ohlin, 1933). Despite the very large amount of studies that have further developed the standard approach to comparative advantage, this traditional understanding has also been strongly questioned by a more recent body of literature. A heterogeneous strand of economic analysis suggests that the determinants of specialization may lie at the institutional level, to the extent that national institutional architectures affect both production and transaction costs.[3]

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[3] See Dosi and Soete (1988) for a survey.

Dosi *et al*. (1988) argue that differences in patterns of technical change among countries are not due to differentials in physical resource endowments; or, at least, different factor endowments are not a sufficient condition for diverging innovation patterns to arise. They instead maintain that the fundamental international differences relate to country-specific conditions of technological learning and accumulation. Specifically, recalling the "local learning" intuition of Atkinson and Stiglitz (1969), Dosi *et al*. (1988) affirm that the degree of match/mismatch between sector-specific learning dynamics and technology-specific institutions at the country level determines the comparative advantages of nations.

More recently, Hall and Soskice (2001) have explained that national technological trajectories are strongly connected with national institutional systems and national systems of coordination among economic actors. On the one hand, in market forms of coordination (i.e. the Anglo-Saxon model), both the equity market and the labour market have a high degree of flexibility, which encourages the use of the "exit" option by the parties to contracts in economic relations. Hence liberal market economies should be better at supporting radical innovation, which requires a low asset specificity. On the other hand, non-market forms of coordination (i.e. the German model) favor long-term relationships among most actors within the economy, and they facilitate the development of highly specific assets which substantially characterize incremental innovation. Using a similar approach, Pagano (2007b) and Belloc and Bowles (2009) argue that international trade can be generated by comparative institutional advantage and can amplify institutional and cultural diversity.

We build on this literature by arguing that countries' initial conditions – physical resource endowments and national institutional settings – almost certainly have had a role in determining initial technological conditions and, hence, the initial distribution of proprietary intellectual assets. However, in the presence of a worldwide system of IPRs, the possession (or the lack) of proprietary knowledge assumes a crucial role in opening (or closing) opportunities for future investment. There ensues a progressive polarization of both patenting and investing activity, which stand in a two-way relationship. The effect of physical resource endowments, if any, disappears and institutions evolve to support the specialization dynamics.

While previous approaches to comparative advantage imply that technological specialization results from international trade openness and greater opportunities for economic exchange (since countries specialize in those sectors where they benefit from geographical or institutional advantages), from our perspective, paradoxically, countries are forced to specialize in response to a reduction of opportunities. Indeed, countries are pressured to specialize not by tighter competition, but rather by the advantages conferred by intellectual monopoly. Put differently, a fragmentation of intellectual property rights, in a context of cumulative knowledge production, precludes investment opportunities in a certain field for those countries which do not have IPRs in that field, and it forces them to invest in fields where they enjoy some proprietary intellectual assets.

Our approach also differs from the theory of inter-industry trade developed by Krugman (1980) by drawing on Dixit and Stiglitz's (1977) work on monopolistic competition where monopoly power makes it possible to recoup the set-up costs originating increasing returns, but free entry precludes the possibility of earning extra-profits. Under increasing returns to scale, there is a trade-off between product variety and the abatement of costs. Dixit and Stiglitz show that, under some conditions, markets can approximate the optimal variety of products. Building on their findings, Krugman argues that, for the selfsame reasons, countries specialize in different products, and that gains from trade arise from the fact that the opening of markets allows for a greater variety of products. Krugman's approach provides an adequate rationale for the very large amount of intra-industry trade among countries with similar factor endowments, which the traditional theory of comparative advantage fails to explain. However, it shares with the latter theory the assumption of free entry: monopolistic competition implies that intellectual monopoly and market closure cannot have important roles. In both cases, specialization follows from an enlargement of investment opportunities due to international trade. In this sense, our hypothesis is different from both these contentions. We maintain that specialization arises from a restriction of investment opportunities due to intellectual monopoly, and that increased trade may be an outcome of forced specialization. In our view, all three of these forces are at work in the present economy and it would be desirable to compare their relative abilities to explain different patterns of international trade. In this paper we take only a first step in this direction, trying to show that intellectual monopoly constraints can explain investment opportunities and specialization patterns.

4. IPR and investment specializations: a process of cumulative causation.

Before introducing the empirical analysis, in this section we specify our theoretical notion of the two-way relation between IPR and investment specializations.

At present, only few innovations are pioneering, while technologies are highly interdependent. Innovations undergo a gradual evolutionary development in which they are not only outputs but also inputs to the creative process, and in which they are therefore intimately interconnected both horizontally and vertically. The main consequence is that property rights on intellectual assets prevent unauthorized non-right-holders from reproducing the (proprietary) technology and from using it as an input for production. In other words, IPRs affect investment opportunities in such a way that only the IPR holder is entitled to invest in a certain technology, while others cannot. Therefore, when technologies are cumulative and interdependent, on the one hand, an individual devoid of IPRs is also unable to invest in those technologies that are based on proprietary knowledge owned by others; on the other hand, an individual owning some IPRs can invest only in those technologies that do not require IPRs other than his own, unless costly transactions of IPRs are undertaken in the intellectual assets market.

In this context, transaction costs entail that intellectual ownership matters and that it affects investment opportunities. The New Property Rights approach (Hart, 1995) has emphasized that, in a situation of incomplete contracts, everyone will under-invest because the fruits of each investment in human capital have to be shared with individuals making co-specific investments. In this situation, an efficient market for the ownership of assets can only partially close the gap with a "first best solution". Owners will invest more than non-owners, but both will under-invest because ownership can only guarantee the availability of assets which are not embodied in human beings. An efficient market for ownership can at most guarantee that the most capable investors are those who own the non-human assets. However an efficient market for ownership is unlikely to occur. The most capable investors could be the less wealthy, and it is hard to imagine that perfect capital and credit markets would move funds to these individuals to the extent that their capabilities deserved. Transaction cost are also high on these markets, and assets encounter great friction in moving from the hands of the wealthy to those of the most capable individuals. Instead of wealth moving to the most capable, the opposite could easily occur, because the wealthy finds the development of its capability protected by the ownership of production assets (Pagano and Rowthorn, 1994).

In the case of intellectual assets, this means that if transaction costs are zero, each IPR will be efficiently allocated to the party better able to exploit the technological potential of the given IPR, regardless of the initial allocation of the property rights. Put differently: that each party follows a certain investment-innovation path should not be a matter of concern, since such trajectories of technological development are efficient. Indeed, if at any time it is technologically efficient for some IPRs to be exchanged between two parties – for example on the basis of their technological competencies – this transaction will be executed.

However, transaction costs are particularly high in the IPR market, for several reasons (Pagano and Rossi 2004). First, in technologically active environments, the search to find the proprietary technology appropriate for a certain production is costly (Somaya and Teece, 2000). Second, technologies are subject to a technical and commercial uncertainty that may lead parties to substantially different beliefs about an IPR's value, and this can entail costs during licensing negotiations (Mergers and Nelson, 1990, 1994; Merges, 1994). Third, if the exact boundaries of the IPRs are unclear, the parties to an IPR transaction can use this uncertainty to their advantage, giving rise to a "hazard" in licensing contracts which in its turn results in further costs (Maskus, 1998; Somaya and Teece, 2000). Finally, all the traditional sources of transaction costs, such as wealth constraints, due to imperfect credit markets also hold for IPR exchanges.

The main direct consequence of positive transaction costs is that they stifle the IPR market and dissuade parties – at least to some extent – from undertaking efficient exchanges of proprietary intellectual assets. Innovators thus tend to invest in the development of new knowledge in the technological field where they enjoy some IPRs from the outset. This in turn induces them to acquire further IPRs in the same field, and so on.

While transaction costs characterize the within-country IPR market to a certain extent, they are likely to have a stronger effect in across-country transactions. Within the same country, transaction costs are reduced by the fact that firms can develop joint research activities which are more difficult across national borders; or they can more easily engage in cross-licensing or alliances to fight rival patenting activities. Countries should therefore tend to specialize both their investment and patenting efforts in those technical fields in which they already enjoy some proprietary technology. This generates, for each country, a process of cumulative causation between IPR and technology. Each country will tend to concentrate its investment effort in the field where it has a relatively larger IPR endowment; this in turn will make it develop new knowledge and acquire new IPRs in that field, which will be followed by further investments and intellectual assets, in a self-reinforcing process.

In order to formalize the mechanism underlying this process we will consider as given an international system of IPRs where patent lifetimes last for m periods (with $m > 1$). However, to simplify the argument, we will start by considering a two-period production framework, and we will later generalize our results. We also assume a world with only two countries, A and B, which are able to produce in two sectors, i and j, and that productivity can be improved by industrial research. Investments at t_0 are a positive function of the production value at t_0 (V_{to}), i.e. the funds available at t_0, and a negative function of the unit cost of the capital at t_0 (c_{to}):

$$I_{t_0}^{A,i} = q\left(V_{t_0}^{A,i}, c_{t_0}^{A,i}\right) \; ; \; I_{t_0}^{A,j} = q\left(V_{t_0}^{A,j}, c_{t_0}^{A,j}\right) \; ; \; I_{t_0}^{B,i} = q\left(V_{t_0}^{B,i}, c_{t_0}^{B,i}\right) \; ; \; I_{t_0}^{B,j} = q\left(V_{t_0}^{B,j}, c_{t_0}^{B,j}\right) \qquad (1)$$

Assume also that production values at t_0 are greater than zero and equal across countries and sectors (i.e. industries have the same initial size). The unit cost of the capital, c_{to}, can be expressed as follows:

$$c_{t_0}^{A,i} = k^{A,i} + (g+h)P_{t_0}^{B,i} + gP_{t_0}^{A,i} \ ; \ c_{t_0}^{A,j} = k^{A,j} + (g+h)P_{t_0}^{B,j} + gP_{t_0}^{A,j} \ ;$$
$$c_{t_0}^{B,i} = k^{B,i} + (g+h)P_{t_0}^{A,i} + gP_{t_0}^{B,i} \ ; \ c_{t_0}^{B,j} = k^{B,j} + (g+h)P_{t_0}^{A,j} + gP_{t_0}^{B,j} \quad (2)$$

where the first component k – per country and sector – identifies the unit cost of the non-proprietary technology used in production (including both physical and human capital) which accounts for a country's relative factor endowments, P_{t0} indicates the initial endowments of patents at t_0 (per country and sectors), while g and h are, respectively, the unit cost of the royalties paid by country A (or B) to use the proprietary technology necessary for production held by country B (or A) and the unit transaction cost of contracting on such usage of the other's proprietary technology (including the risk that the transaction may not take place and all the other disincentives faced by non-owners). Note that, in equations (2), the unit cost of capital for a given country in a given sector depends also on the patents that the same country holds in the same sector, because the corresponding royalties represent the opportunity-cost of using those patents for production rather than licensing them to others. For simplicity, we assume that k is time invariant, and that both the unit royalty cost g and the unit transaction cost h are time invariant and equal across sectors.

Suppose that patents result from investment activity after one period according to a positive function:

$$P_{t_1}^{A,i} = f\left(I_{t_0}^{A,i}\right) \ ; \ P_{t_1}^{A,j} = f\left(I_{t_0}^{A,j}\right) \ ; \ P_{t_1}^{B,i} = f\left(I_{t_0}^{B,i}\right) \ ; \ P_{t_1}^{B,j} = f\left(I_{t_0}^{B,j}\right) \quad (3)$$

where P_{t1} indicates the number of patents at t_1 (per country and sectors). Indeed, it is reasonable to assume that the more a given country invests, the more the new technological knowledge – and therefore the patents – that the same country obtains when the production process is completed.

Suppose, finally, that the value of the production of a given country in a certain sector is a positive function of the number of patents which that same country holds in that sector. The rationale behind this is simple: patents guarantee monopoly profits to the inventor; moreover, if inventors license their proprietary technology, then the more inventors patent, the more they are able to license, and the larger the royalty income that they obtain. The production value at t_1 for the two countries in the two sectors can therefore be written as:

$$V_{t_1}^{A,i} = r\left(P_{t_1}^{A,i}\right) \; ; \; V_{t_1}^{A,j} = r\left(P_{t_1}^{A,j}\right) \; ; \; V_{t_1}^{B,i} = r\left(P_{t_1}^{B,i}\right) \; ; \; V_{t_1}^{B,j} = r\left(P_{t_1}^{B,j}\right) \qquad (4)$$

We will now articulate our argument into three steps: we will consider how different patent endowments influence specialization in the *first period production*; how in the second period the influence becomes greater in the *second period production*; and finally how the argument can be generalized to a *multi-period production* where the process of cumulative causation between patent and investment specialization becomes very evident. We will conclude the section by re-stating out intuition in terms of our simple model.

Production in the first period.

Suppose that, in t_0, the only feature that differentiates countries is the initial endowment of patents, as follows:

$$P_{t_0}^{A,i} > P_{t_0}^{A,j} \; ; \; P_{t_0}^{B,i} < P_{t_0}^{B,j} \; ; \; P_{t_0}^{A,i}, P_{t_0}^{A,j}, P_{t_0}^{B,i}, P_{t_0}^{B,j} > 0 \qquad (5)$$

Using relations (2), inequalities (5) imply that:

$$c_{t_0}^{A,i} < c_{t_0}^{A,j} \; ; \; c_{t_0}^{B,i} > c_{t_0}^{B,j} \qquad (6)$$

when transaction costs are sufficiently high, i.e. when:

$$h > \frac{\left(k^{A,i} - k^{A,j}\right)}{P_{t_0}^{B,j} - P_{t_0}^{B,i}} - g\left(1 + \frac{P_{t_0}^{A,i} - P_{t_0}^{A,j}}{P_{t_0}^{B,i} - P_{t_0}^{B,j}}\right) \quad \text{and} \quad h > \frac{\left(k^{B,j} - k^{B,i}\right)}{P_{t_0}^{A,i} - P_{t_0}^{A,j}} - g\left(1 + \frac{P_{t_0}^{B,j} - P_{t_0}^{B,i}}{P_{t_0}^{A,j} - P_{t_0}^{A,i}}\right) \qquad (7)$$

that, if at t_0 the relative endowments of patents across sectors are symmetric between countries (i.e. if $(P^{A,i} - P^{A,j}) = (P^{B,j} - P^{B,i})$), more simply:

$$h > \frac{\left(k^{A,i} - k^{A,j}\right)}{P_{t_0}^{B,j} - P_{t_0}^{B,i}} \quad \text{and} \quad h > \frac{\left(k^{B,j} - k^{B,i}\right)}{P_{t_0}^{A,i} - P_{t_0}^{A,j}} \qquad (7')$$

In words, even when it is technically efficient for country A to produce in sector *j* relatively more than in sector *i* (i.e. when $k^{A,i} > k^{A,j}$), country A faces a lower (overall) unit cost of the capital in sector *i* if the transaction costs *h* are higher than the differential between the costs of the (non proprietary) technology weighted by the within-country B differential of patents across sectors. Vice-versa for country B. It follows straightforwardly that when the unit cost of the non-proprietary technology is equal across sectors (i.e. when $k^{A,i} = k^{A,j}$ and $k^{B,i} = k^{B,j}$), conditions (6) are satisfied for any positive value of transaction costs.

As shown in relations (1), countries invest relatively more in the sector where the unit cost of the capital is relatively lower, i.e. (if transaction costs are higher than the threshold levels (7)):

$$I_{t_0}^{A,i} > I_{t_0}^{A,j} \;;\; I_{t_0}^{B,i} < I_{t_0}^{B,j} \tag{8}$$

which can be written in terms of relative intensity of investments as:

$$\frac{I_{t_0}^{A,i}}{I_{t_0}^{A,j}} > 1 \;;\; \frac{I_{t_0}^{B,i}}{I_{t_0}^{B,j}} < 1 \tag{9}$$

Using relations (3), relations (8) imply that:

$$P_{t_1}^{A,i} > P_{t_1}^{A,j} \;;\; P_{t_1}^{B,i} < P_{t_1}^{B,j} \tag{10}$$

and that:

$$V_{t_1}^{A,i} > V_{t_1}^{A,j} \;;\; V_{t_1}^{B,i} < V_{t_1}^{B,j} \tag{11}$$

Production in the second period.

At the end of the period t_1, countries A and B can exploit both the patents held in t_0 and those obtained in t_1. Consequently, the unit cost of investment (per country and sector) at t_1 is:

$$c_{t_1}^{A,i} = k^{A,i} + (g+h)\left(P_{t_0}^{B,i} + P_{t_1}^{B,i}\right) + g\left(P_{t_0}^{A,i} + P_{t_1}^{A,i}\right) \;;$$
$$c_{t_1}^{A,j} = k^{A,j} + (g+h)\left(P_{t_0}^{B,j} + P_{t_1}^{B,j}\right) + g\left(P_{t_0}^{A,j} + P_{t_1}^{A,j}\right) \;;$$
$$c_{t_1}^{B,i} = k^{B,i} + (g+h)\left(P_{t_0}^{A,i} + P_{t_1}^{A,i}\right) + g\left(P_{t_0}^{B,i} + P_{t_1}^{B,i}\right) \;;$$

$$c_{t_1}^{B,j} = k^{B,j} + (g+h)\left(P_{t_0}^{A,j} + P_{t_1}^{A,j}\right) + g\left(P_{t_0}^{B,j} + P_{t_1}^{B,j}\right) \tag{12}$$

Given relations (5), (10) and (12), the following inequalities hold:

$$c_{t_1}^{A,i} < c_{t_1}^{A,j} \;;\; c_{t_1}^{B,i} > c_{t_1}^{B,j} \tag{13}$$

when transaction costs are above a certain threshold level as follows:

$$h > \frac{\left(k^{A,i} - k^{A,j}\right)}{\left(P_{t_0}^{B,j} - P_{t_0}^{B,i}\right) + \left(P_{t_1}^{B,j} - P_{t_1}^{B,i}\right)} - g\left[1 + \frac{\left(P_{t_0}^{A,i} + P_{t_1}^{A,i}\right) - \left(P_{t_0}^{A,j} + P_{t_1}^{A,j}\right)}{\left(P_{t_0}^{B,i} + P_{t_1}^{B,i}\right) - \left(P_{t_0}^{B,j} + P_{t_1}^{B,j}\right)}\right] \text{ and}$$

$$h > \frac{\left(k^{B,j} - k^{B,i}\right)}{\left(P_{t_0}^{A,i} - P_{t_0}^{A,j}\right) + \left(P_{t_1}^{A,i} - P_{t_1}^{A,j}\right)} - g\left[1 + \frac{\left(P_{t_0}^{B,j} + P_{t_1}^{B,j}\right) - \left(P_{t_0}^{B,i} + P_{t_1}^{B,j}\right)}{\left(P_{t_0}^{A,j} + P_{t_1}^{A,j}\right) - \left(P_{t_0}^{A,i} + P_{t_1}^{A,j}\right)}\right] \tag{14}$$

Again, if at t_1 the relative endowments of patents across sectors are symmetric between countries, thresholds (14) become more simply:

$$h > \frac{\left(k^{A,i} - k^{A,j}\right)}{\left(P_{t_0}^{B,j} - P_{t_0}^{B,i}\right) + \left(P_{t_1}^{B,j} - P_{t_1}^{B,i}\right)} \quad \text{and} \quad h > \frac{\left(k^{B,j} - k^{B,i}\right)}{\left(P_{t_0}^{A,i} - P_{t_0}^{A,j}\right) + \left(P_{t_1}^{A,i} - P_{t_1}^{A,j}\right)} \tag{14'}$$

where it is to be noted that the threshold levels are lower than those of the first period (t_0). It follows that at t_1, country A again invests relatively more in sector *i*, while country B invests relatively more in sector *j*. Moreover, it can be shown that:

$$\frac{c_{t_0}^{A,i}}{c_{t_0}^{A,j}} > \frac{c_{t_1}^{A,i}}{c_{t_1}^{A,j}} \;;\; \frac{c_{t_0}^{B,i}}{c_{t_0}^{B,j}} < \frac{c_{t_1}^{B,i}}{c_{t_1}^{B,j}} \tag{15}$$

and so that:

$$\frac{I_{t_0}^{A,i}}{I_{t_0}^{A,j}} < \frac{I_{t_1}^{A,i}}{I_{t_1}^{A,j}} \;;\; \frac{I_{t_0}^{B,i}}{I_{t_0}^{B,j}} > \frac{I_{t_1}^{B,i}}{I_{t_1}^{B,j}} \tag{16}$$

As a consequence:

$$\frac{P_{t_1}^{A,i}}{P_{t_1}^{A,j}} < \frac{P_{t_2}^{A,i}}{P_{t_2}^{A,j}} \; ; \; \frac{P_{t_1}^{B,i}}{P_{t_1}^{B,j}} > \frac{P_{t_2}^{B,i}}{P_{t_2}^{B,j}} \tag{17}$$

In words, given an initial distribution of patents according to which A enjoys IPRs relatively more in sector *i* while B enjoys IPRs relatively more in sector *j*, inequalities (16) and (17) show that country A increases both its investment and patent specialization in sector *i* and that, symmetrically, country B increases both its investment and patent specialization in sector *j*.

Multiple periods and specialization paths.

If patent lifetimes last until time t_m, in a continuous-time context, it is straightforward to obtain:

$$\frac{\int_{t_0}^{t} P_{t_r}^{A,i}\left(I_{t_r-1}^{A,i}\right) d\left(t-t_0\right)}{\int_{t_0}^{t} P_{t_r}^{A,j}\left(I_{t_r-1}^{A,j}\right) d\left(t-t_0\right)} > \frac{\int_{t_0}^{t-1} P_{t_h}^{A,i}\left(I_{t_h-1}^{A,i}\right) d\left((t-1)-t_0\right)}{\int_{t_0}^{t-1} P_{t_h}^{A,j}\left(I_{t_h-1}^{A,j}\right) d\left((t-1)-t_0\right)} \; ;$$

$$\frac{\int_{t_0}^{t} P_{t_r}^{B,j}\left(I_{t_r-1}^{B,j}\right) d\left(t-t_0\right)}{\int_{t_0}^{t} P_{t_r}^{B,i}\left(I_{t_r-1}^{B,i}\right) d\left(t-t_0\right)} > \frac{\int_{t_0}^{t-1} P_{t_h}^{B,j}\left(I_{t_h-1}^{B,j}\right) d\left((t-1)-t_0\right)}{\int_{t_0}^{t-1} P_{t_h}^{B,i}\left(I_{t_h-1}^{B,i}\right) d\left((t-1)-t_0\right)} \qquad \forall t \in [t_0, t_m] \tag{18}$$

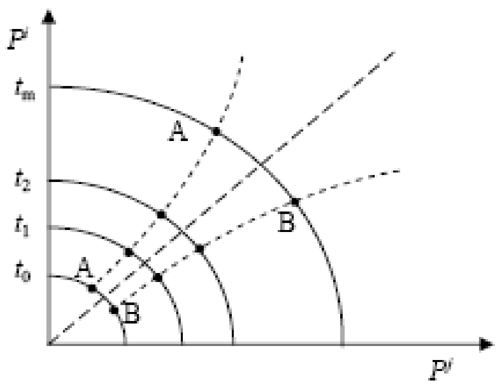
where t_r is a generic time between t_0 and t, and t_h is a generic time between t_0 and t-1. In turn:

$$\frac{I_t^{A,i}\left(\int_{t_0}^{t} P_{t_r}^{A,i} d\left(t-t_0\right)\right)}{I_t^{A,j}\left(\int_{t_0}^{t} P_{t_r}^{A,j} d\left(t-t_0\right)\right)} > \frac{I_{t-1}^{A,i}\left(\int_{t_0}^{t-1} P_{t_h}^{A,i} d\left((t-1)-t_0\right)\right)}{I_{t-1}^{A,j}\left(\int_{t_0}^{t-1} P_{t_h}^{A,j} d\left((t-1)-t_0\right)\right)} \; ;$$

$$\frac{I_t^{B,j}\left(\int_{t_0}^{t} P_{t_r}^{B,j} d\left(t-t_0\right)\right)}{I_t^{B,i}\left(\int_{t_0}^{t} P_{t_r}^{B,i} d\left(t-t_0\right)\right)} > \frac{I_{t-1}^{B,j}\left(\int_{t_0}^{t-1} P_{t_h}^{B,j} d\left((t-1)-t_0\right)\right)}{I_{t-1}^{B,i}\left(\int_{t_0}^{t-1} P_{t_h}^{B,i} d\left((t-1)-t_0\right)\right)} \qquad \forall t \in [t_0, t_m] \tag{19}$$

Inequalities (18) express the patent specialization paths of countries A and B over m periods, and indicates that a country's specialization increases in each period with respect to the preceding one. Without specifying the exact values of relations (18), we cannot draw patent specialization patterns exactly, but their general trend can be represented graphically as in Figure 2.

Figure 2. Patent specialization paths.



In Figure 2, the arches represent the innovation frontiers of countries A and B at different periods (from t_0 to t_m), while the dashed curves represent countries' innovation paths. After m periods, both countries A and B have increased their patent specialization, respectively, in sectors i and j, with respect to their patent specialization at t_0.

Concluding remarks.

The model shows under what conditions IPRs can undo the standard comparative advantage which stems from resource endowments. Here trade arises from the fact that other countries' patents force a country to restrict its production in a limited production field and must import the goods which are not included in that field. It may be associated with "unequal gains from trade" in the sense that one pattern of specialization may yield higher monopoly profits associated with intellectual property. Because of the cumulative causation between investment and IPR specialization, countries which invest first in a certain field are likely to specialize in that field, and the specialization pattern becomes increasingly difficult to change even by means of targeted national policies.

5. Estimating IPR constraints on investment opportunities.

5.1 Estimation Strategy.

Our argument is that the amount of intellectual assets (protected by IPR) that a given country owns in a certain sector positively affects the investment opportunities which that same country is able to exploit in the same sector, while, simultaneously, the higher the country's investment effort in a given sector, the more intense its patenting in that sector becomes. Empirical investigation of our hypothesis poses two difficulties.

The first difficulty relates to the need for valid inter-country comparisons. As usual when dealing with cross-country analysis, omitted variables bias is likely to occur, because accounting for all the relevant country characteristics is virtually impossible. As a consequence, a traditional cross-country methodology would make it difficult to interpret the correlations observed in a causal sense. To solve this problem, we rely on the methodology proposed by Rajan and Zingales (1998) and we make predictions about within-country differences in investment levels between industries based on a measure of patent activity outcomes that varies with both country and industry. As Rajan and Zingales (1998) point out, in so doing, we are able to correct for country and industry characteristics in ways that traditional cross-country studies are unable to correct for and that are less subject to criticism about omitted variable bias or model misspecification.

A second problem concerns the investigation of a two-way relation between country patenting and country investing and, in particular, the existence of complementarities between these two variables. An equation-by-equation estimation would not enable us to detect causal relations, while the time structure of patents (yearly) data is not well-suited to time series analysis. For this reason, we develop a system of two equations, in which we explicitly model the two-way relationship.

Formally, we consider the following baseline two-equation system:

$$\frac{I_t^{k,i}}{I_t^k} = \beta_0 + \beta_1 \cdot \frac{\sum_{t_0}^{t} P_{t_r}^{k,i}}{\sum_{t_0}^{t} P_{t_r}^{k}} + \beta_{2\ldots K} \cdot \mathbf{C}_k + \beta_{K+1\ldots N} \cdot \mathbf{S}_i + \beta_{N+1\ldots Z} \cdot \mathbf{T}_t + \varepsilon_{i,k,t} \qquad \text{(I)}$$

$$\frac{\sum_{t_0}^{t} P_{t_r}^{k,i}}{\sum_{t_0}^{t} P_{t_r}^{k}} = \delta_0 + \delta_1 \cdot \frac{I_{t-1}^{k,i}}{I_{t-1}^{k}} + \delta_{2 \ldots K} \cdot \mathbf{C}_k + \delta_{K+1 \ldots N} \cdot \mathbf{S}_i + \delta_{N+1 \ldots Z} \cdot \mathbf{T}_t + \delta_{Z+1} \cdot \vartheta_{i,k,t} + \eta_{i,k,t} \qquad \text{(II)}$$

where the terms $\left(I_t^{k,i} / I_t^k\right)$ and $\left(I_t^{k,i} / I_t^k\right)$, which we call *Investment Specialization*$_{i,k,t}$ and *Investment Specialization*$_{i,k,t-1}$, measure the share of country *k*'s investments in industry *i* over the total of country *k*'s investments in manufacturing at time *t* and *t-1*, and where the term $\left(\sum_{t_0}^{t} P_{t_r}^{k,i} \Big/ \sum_{t_0}^{t} P_{t_r}^{k}\right)$, which we call *Patent Specialization*$_{i,k,t}$, measures the share of country *k*'s patents in industry *i* over the total of country *k*'s patents held at time *t*, where t_r is a generic time between t_0 and *t*. Furthermore, $\mathbf{C}_k$, $\mathbf{S}_i$, and $\mathbf{T}_t$ are vectors of, respectively, country, sector and time dummy indicators; $\vartheta_{i,k,t}$ is an excluded instrument that enables us to meet identification requirements; β_0 and δ_0 are the two model constants; $\varepsilon_{i,k,t}$ and $\eta_{i,k,t}$ are idiosyncratic disturbances that change across *i*, *k*, and *t*. In words, what we estimate is whether the within-country distribution of patents between industries determines the within-country distribution of investments between industries, and whether, in turn, the amount of a given country's patents in a certain industry is affected by the previous investments undertaken by that country in that industry.

We jointly estimate the two equations using a three-stage least square procedure (3SLS hereafter). The three steps in the 3SLS method are the following. The first step is identical to the first step of a two-stage procedure (2SLS): the predicted values of each endogenous variable on all the exogenous regressors are obtained. In the second step, we substitute the predictions of the patent specialization found in the first step in place of *Patent Specialization*$_{i,k,t}$ on the right-hand-side of equation (I) and applied OLS. The residuals are then used to obtain an estimate of the covariance matrix of the error terms of the two equations. In the third step, the estimate of the cross-equation correlation matrix is used as a weighting matrix to calculate the generalized least square estimator (GLS). The last two steps are iterated over the estimated disturbance covariance and parameter estimates until the parameter estimates converge.

An empirical strategy of this kind has three advantages over a traditional cross-section methodology for cross-country analysis. First, it makes it possible to estimate a two-way relationship between patent activity and investments by exploiting multilevel information (per country, industry, year) in a simultaneous equations model; therefore, we are confident that we are estimating correlations in a causal sense. Second, by relating within-country differences between industries to within-country explanatory variables and to country, time and industry fixed effects, we reduce the number of controls on which we rely, along with the risk of multicollinearity. Third, we do not incur the problem of limited degrees of freedom, since we use multiple observations per country over five industries and 29 years, as we will discuss below.

5.2 Data and variables.

In order to estimate our model, we need appropriate and comparable measures of investments and patent activity.

Data on investments are obtained from the levels of gross fixed capital formation provided by the OECD's Structural Analysis Database – STAN – (OECD, 2009) which, in its turn, relies on the Official Annual National Accounts obtained directly from national sources. The data are classified by International Standard Industrial Classification (ISIC) code. Data on patents are obtained from the European Patent Office Database (EPO, 2008). Patent data are provided at the highest possible disaggregation level, because information on all the individual patents registered at the EPO are included.

In order to make patents and investments data comparable, we aggregate them through a consistent classification at the country (*i*), industry (*ii*) and time (*iii*) level.

(*i*) While investment data are already available at the country level, for patent data we perform an aggregation procedure. We use the applicant's nationality to determine the patent's nationality. When more than one applicant is related to one patent, we count the patent once in each applicant's country (for instance, if two German firms had applied for the same patent, the patent is counted once for Germany, but if a German and a French firm had applied for the same patent, the patent is then counted once for Germany and once for France). By this means we have information on both patents and investments for 26 OECD countries.[4]

(*ii*) At the industry level, on the one hand, investments data are classified according to 4-digit ISIC codes, on the other, patents data are organized in a 30 classes International Patent Classification (IPC) System, which enables us to work at a high disaggregation level. Nevertheless, some economic activities are characterized by a very low number of patents, so that the inter-country comparison may not be reliable in some cases. To circumvent this problem, we aggregate both investments and patents data according to the 5-industry ISI-

[4] Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, South Korea, Spain, Sweden, United Kingdom, United States.

INIPI-OST Classification System (elaborated by the German Fraunhofer Institute of Systems and Innovation Research – ISI – the French Patent Office – INIPI – and the Observatoire des Sciences and des Techniques – OST –). See Table 1 for a summary description of our final classification.

(*iii*) As a time structure, we use yearly data. In particular, for patents data we consider the year of the application at the EPO of published patents.

Note that, in order to calculate the patent specialization, we cumulate the number of patents year after year for each country's industry; indeed, our focus is on the endowment of patents that countries progressively accumulate in a two-way relation with their investment efforts.

Table 1. OST/INPI/ISI-technology Classification.

I. Electrical Engineering	II. Instruments	III. Chemestry and Pharmaceuticals	IV. Process Engineering	V. Mechanical Engineering
Electrical machinery and apparatus, electrical energy	Optics	Organic fine chemistry, macromolecular chemistry, polymers	Chemical engineering	Machine tools, engines, pumps, turbines, mechanical elements
Audio-visual technology	Analaysis, measurement, control technology	Pharmaceuticals, cosmetics	Surface technolgy, coating, meterials, metallurgy	Transport, space technology, weapons
Telecommunications and information technology	Medical technology	Agriculture, food chemestry	Materials processing, textiles, paper, handling, printing	Consumer goods and equipment
Semiconductors	Nuclear engineering	Chemical and petrol industry, basic materials chemistry	Agricultural and food processing, machinery and apparatus, and environmental technology	Civil engineering, building, mining

As said, we add country, industry and time indicators in both equations by means of three vectors of dummies in order to estimate country, industry and time fixed effects. More specifically, country fixed effects refer to the country-specific characteristics that can affect both patent and investment specialization (such as countries' comparative advantage due to physical and human factor endowments, and to institutional features); industry fixed effects soak up the data variability due to technology differences across sectors, according to which some sectors exhibit patenting (or investment) activity more intensely than the others, keeping investment (or patenting) activity equal. Finally, time fixed effects explain the variation in the response variables due to unobservable time-specific factors (e.g., changes in the international IPRs standards), which may underlie both patent and investment specialization patterns in a way virtually constant across countries. Hence we do not really need to include additional explanatory variables (see Rajan and Zingales, 1998). Nonetheless, as a robustness check, we estimate further model specifications in which we include two control variables (possibly) relevant to explaining country investment specialization across industries: the industry-relative share of the value of goods produced in a year (*Production Specialization*$_{i,k,t}$), which we consider to be a proxy for expected profits as well as for funds available at the industry level; and a measure of the industry's trade openness (*Trade Specialization*$_{i,k,t}$) calculated as the sum of industry exports and imports over the sum of the total country imports and exports in order to allow for the potential relationship between the degree of industry-level trade openness and investment specialization.

We also include the industry-relative share of the wages paid in a year (*Labour Specialization*$_{i,k,t}$) as one of the determinants of the patent specialization in equation (II), in order to meet identification requirements (i.e. *Labour Specialization*$_{i,k,t}$ is the excluded instrument $\vartheta_{i,k,t}$). In knowledge intensive productions, employees are a crucial part of innovation programs. For example, Grossman and Helpman (1994) argue that the probability of R&D success is proportional to the labor employed in the research project; and, more recently, Hall (2002) reports that fifty per cent or more of R&D spending consists in the wages and salaries of highly educated scientists and engineers.

The three variables *Production Specialization*$_{i,k,t}$, *Trade Specialization*$_{i,k,t}$ and *Labour Specialization*$_{i,k,t}$ are obtained from the STAN database (OECD, 2009).

When all the control variables are included, and the excluded instrument made explicit, the operative two-equation system that we estimate takes the following augmented form:

$$\frac{I_t^{k,i}}{I_t^k} = \beta_0 + \beta_1 \cdot \frac{\sum_{t_0}^{t} P_{t_r}^{k,i}}{\sum_{t_0}^{t} P_{t_r}^{k}} + \beta_{2\ldots K} \cdot \mathbf{C}_k + \beta_{K+1\ldots N} \cdot \mathbf{S}_i + \beta_{N+1\ldots Z} \cdot \mathbf{T}_t + \beta_{Z+1} \cdot \frac{V_t^{k,i}}{V_t^k} + \beta_{Z+2} \cdot \frac{M_t^{k,i} + E_t^{k,i}}{M_t^k + E_t^k} + \varepsilon_{i,k,t} \quad \text{(I')}$$

$$\frac{\sum_{t_0}^{t} P_{t_r}^{k,i}}{\sum_{t_0}^{t} P_{t_r}^{k}} = \delta_0 + \delta_1 \cdot \frac{I_{t-1}^{k,i}}{I_{t-1}^k} + \delta_{2\ldots K} \cdot \mathbf{C}_k + \delta_{K+1\ldots N} \cdot \mathbf{S}_i + \delta_{N+1\ldots Z} \cdot \mathbf{T}_t + \delta_{Z+1} \cdot \frac{L_t^{k,i}}{L_t^k} + \eta_{i,k,t} \quad \text{(II')}$$

where the terms $\left(V_t^{k,i} / V_t^k\right)$, $\left(\left(M_t^{k,i} + E_t^{k,i}\right) / \left(M_t^k + E_t^k\right)\right)$, $\left(L_t^{k,i} / L_t^k\right)$ indicate, respectively, *Production Specialization*$_{i,k,t}$, *Trade Specialization*$_{i,k,t}$, and *Labour Specialization*$_{i,k,t}$.

5.3 Results.

Table 2 reports the estimation results. While the first column reports the variables, the remaining columns set out the estimated parameters of different model specifications.

Our two-way relation argument finds strong support in the data. The parameter estimates confirm the positive and statistically significant effect (at the 1% level) of patent specialization on investment specialization – in particular, the estimated effect is greater than one – also controlling for country, industry and time fixed effects. In turn, one-year-lagged investments positively affect patent activity. Hence the investment opportunities of countries and their patent endowments are shown to be statistically related in a complementarity relationship. Moreover, the results obtained from models (2) and (4) show that the relative share of the value of goods produced in a given industry positively influences investment activity in the same industry, while models (3) and (4) reveal that the degree of trade openness does not affect investment specialization in a statistically significant way.

Table 2. Cross-country panel estimation (1978-2006 period): results.

	(1)	(2)	(3)	(4)
	3SLS	3SLS	3SLS	3SLS
	[Baseline model]	[Partially augmented model – version *a*]	[Partially augmented model – version *b*]	[Fully augmented model]
Variable	*Investment Specialization$_{i,k,t}$*	*Investment Specialization$_{i,k,t}$*	*Investment Specialization$_{i,k,t}$*	*Investment Specialization$_{i,k,t}$*
Patent Specialization$_{i,k,t}$	1.483 (0.148) ***	1.201 (0.198) ***	1.414 (0.309) ***	1.214 (0.278) ***
Production Specialization$_{i,k,t}$		0.266 (0.083) ***		0.248 (0.045) ***
Trade Specialization$_{i,k,t}$			0.082 (0.145)	0.023 (0.130)
Constant	0.222 (0.055) ***	0.030 (0.044)	-0.072 (0.070)	0.156 (0.042) ***
Country dummies	yes	yes	yes	yes
Industry dummies	yes	yes	yes	yes
Time dummies	yes	yes	yes	yes
Variable	*Patent Specialization$_{i,k,t}$*	*Patent Specialization$_{i,k,t}$*	*Patent Specialization$_{i,k,t}$*	*Patent Specialization$_{i,k,t}$*
Investment Specialization$_{i,k,t-1}$	0.477 (0.041) ***	0.521 (0.049) ***	0.481 (0.056) ***	0.515 (0.057) ***
Labour Specialization$_{i,k,t}$	0.211 (0.045) ***	0.119 (0.043) ***	0.183 (0.032) ***	0.113 (0.057) ***
Constant	-0.120 (0.043) ***	-0.046 (0.048)	0.055 (0.043)	-0.091 (0.039) **
Country dummies	yes	yes	yes	yes
Industry dummies	yes	yes	yes	yes
Time dummies	yes	yes	yes	yes

Note: significance level ("*" = 10%, "**" = 5%, "***" = 1%). All regressions include country, industry and time fixed effects (coefficient estimates not reported). Standard errors are reported in parentheses.

Finally, we perform a diagnostic analysis whose results are reported in Table 3. First, we check the relevance of the instruments used in the estimation by examining the first stage R-square. In our model specifications we obtain a first stage R-square always greater than 0.3 (i.e. the conventionally used acceptance threshold, Shea, 1997). Second, we verify the model's identifiability by means of the Anderson canonical correlation statistic and the Sargan test of overidentifying restrictions. These allow us to consider the instruments as adequate in identifying the model. Then, as an overall diagnostic procedure, we perform the Wald test, which leds us to reject the null hypothesis of joint non-statistical significance of all the parameters, and this finally validates our estimation results.

Table 3. Diagnostic analysis.

Statistical details	(1)	(2)	(3)	(4)
R-square of Eq. (1)	0.518	0.674	0.564	0.673
R-square of Eq. (2)	0.541	0.540	0.539	0.538
Wald Test of Eq. (1): p-value	0.000	0.000	0.000	0.000
Wald Test of Eq. (2): p-value	0.000	0.000	0.000	0.000
Anderson Statistic (p-value)	94.953 (0.000)	16.123 (0.000)	14.782 (0.000)	10.175 (0.006)
Sargan Statistic (p-value)	1.667 (0.196)	0.477 (0.489)	0.212 (0.645)	0.014 (0.905)
Number of Observations	682	682	675	675

We also check the robustness of the estimation results presented in Table 2 to a different estimation method. For this purpose, we perform an estimation of the investment specialization equation (I) and of the patent specialization equation (II) using a traditional two-stage procedure (2SLS) for panel data. Note that, in this estimation context, equation (II) is the first stage equation, while equation (I) is the second stage equation.

As the estimation results reported in Table 4 show, we again find that the relationship between patent specialization and investment specialization is a two-way relationship.

Table 4. Robustness checks: two-stage cross-country panel estimation.

	(1)	(2)
Variable	Investment Specialization equation	Patent Specialization equation
Patent Specialization$_{i,k,t}$	1.445 (0.143) ***	
Investment Specialization$_{i,k,t-1}$		0.390 (0.083) ***
Labour Specialization$_{i,k,t}$		0.382 (0.129) ***
Constant	-0.132 (0.041) ***	0.042 (0.033)
Country-Industry-Year FE	Yes	Yes
I stage R-square	--	0.460
II stage R-square	0.604	--
F (prob > F)	--	110.35 (0.000)
Wald $\chi 2$ (prob > $\chi 2$)	2712.96 (0.000)	--
Number of Observations	682	682

Note: significance level ("*" = 10%, "**" = 5%, "***" = 1%). Standard errors are reported in parentheses.

Table 5 reports the estimation results obtained by using two sub-sets of observations: the first set contains observations referring to the 1978-1994 sub-period (before the TRIPs agreement), while the second contains observations referring to the 1995-2006 sub-period (under the TRIPs agreement). In this way we explore whether (and how) the marginal effect of the patent specialization on investment specialization has been affected by the TRIPs agreement. Model specifications (1a) and (1b) do not contain explanatory variables in equation (1) other than *Patent Specialization*$_{j,k,t}$ and industry, country and time dummies; in model specifications (2a) and (2b) we included also the two variables *Production Specialization*$_{j,k,t}$ and *Trade Specialization*$_{j,k,t}$.

Table 5. Cross-country panel estimation (1978-1994 and 1995-2006 sub-periods): results.

	(1a) 3SLS	(1b) 3SLS	(2a) 3SLS	(2b) 3SLS
	Before TRIPs (1978-1994)	Under TRIPs (1995-2006)	Before TRIPs (1978-1994)	Under TRIPs (1995-2006)
Variable	*Investment Specialization*$_{j,k,t}$	*Investment Specialization*$_{j,k,t}$	*Investment Specialization*$_{j,k,t}$	*Investment Specialization*$_{j,k,t}$
Patent Specialization$_{j,k,t}$	1.024 (0.159) ***	1.289 (0.127) ***	0.680 (0.150) ***	1.050 (0.179) ***
Production Specialization$_{j,k,t}$			0.575 (0.140) ***	0.213 (0.066) ***
Trade Specialization$_{j,k,t}$			-0.023 (0.159)	0.026 (0.050)
Constant	-0.089 (0.034) ***	0.081 (0.053)	0.049 (0.044)	0.047 (0.043)
Country dummies	yes	yes	yes	yes
Industry dummies	yes	yes	yes	yes
Time dummies	yes	yes	yes	yes
Variable	*Patent Specialization*$_{j,k,t}$	*Patent Specialization*$_{j,k,t}$	*Patent Specialization*$_{j,k,t}$	*Patent Specialization*$_{j,k,t}$
Investment Specialization$_{j,k,t-1}$	0.752 (0.116) ***	0.505 (0.044) ***	0.837 (0.130) ***	0.557 (0.053) ***
Labour Specialization$_{j,k,t}$	0.122 (0.062) **	0.318 (0.065) ***	-0.064 (0.089)	0.210 (0.066) ***
Constant	0.062 (0.051)	-0.069 (0.045)	-0.134 (0.064) **	-0.028 (0.039)
Country dummies	yes	yes	yes	yes
Industry dummies	yes	yes	yes	yes
Time dummies	yes	yes	yes	yes

Note: significance level ("*" = 10%, "**" = 5%, "***" = 1%). All regressions include country, industry and time fixed effects (coefficient estimates not reported). Standard errors are reported in parentheses.

In both cases, the estimation results reveal an increase in the strength of the effect of patent specialization on investment activity. In particular, the estimated effect of the former on the latter grows from 1.024 to 1.289 (i.e. by about 25%) according to models (1a) and (1b), and from 0.680 to 1.050 (i.e. by about 54%) according to models (2a) and (2b). Furthermore, it remains statistically significant at the 1% level in both cases.

Again, as shown in Table 6, the diagnostic analysis induces us never to reject the statistical validity of our estimation results.

Table 6. Diagnostic analysis.

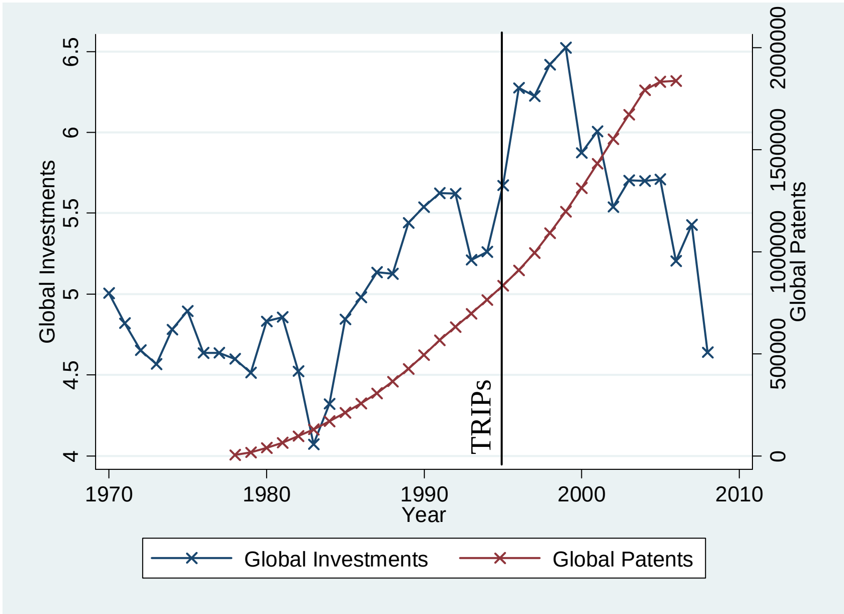
Statistical details	(1a)	(1b)	(2a)	(2b)
R-square of Eq. (1)	0.832	0.671	0.923	0.772
R-square of Eq. (2)	0.776	0.491	0.772	0.489
Wald Test of Eq. (1): p-value	0.000	0.000	0.000	0.000
Wald Test of Eq. (2): p-value	0.000	0.000	0.000	0.000
Anderson Statistic (p-value)	38.381 (0.000)	94.929 (0.000)	13.525 (0.001)	16.021 (0.000)
Sargan Statistic (p-value)	0.053 (0.817)	1.621 (0.202)	0.082 (0.775)	0.955 (0.328)
Number of Observations	196	486	189	486

6. Conclusion.

A tight worldwide system of IPRs forces countries to specialize in those sectors where from the outset they have possessed some proprietary monopoly knowledge enabling them to acquire the ownership of additional knowledge and new investment opportunities. Countries poor in IPRs are unable to compete effectively in product markets unless they are characterized by low labor costs in the diminishing fields left free by the intellectual monopoly of other countries. This is shown by the fact that, while in the 1990s China and America boomed (the former thanks to low wages, the latter thanks to a large endowment of IPRs), other capitalist economies stagnated, either because they were relatively poor in intellectual monopoly assets or because they had relatively high labor costs, or for both these reasons (this being the case of Italy, among others). At the same time, however, also in countries rich in IPRs, firms have a growing sense of insecurity due to the fear that their development of new technology may be blocked by other firms. As a consequence, strong IPRs not only concentrate investment opportunities in the hands of a few, but also decrease overall investment possibilities, and are therefore one of the factors contributing to the current recession (Pagano and Rossi, 2009).

Figure 3 shows that total world investments increased for about five years after the TRIPs, while they have been continuously declining since 1999.

Figure 3. Global patents and global investments.



Source: authors' calculations on data from the European Patent Office (EPO, 2008) and OECD (2009). Global investments are expressed as a percentage of global production (gross output) and refer to the 1970-2008 period; global patents are the total world's patents outstanding and refer to the 1978-2006 period.

Patent pools and pre-emptive patenting (Gueller, Martinez and Pluvia, 2009) have created a situation in which only some large interconnected firms are able to limit the damage caused by intellectual monopoly and, in particular, by patent trolls[5]. Recently, 11 firms, including Sun Microsystems, Motorola, Hewlet-Packard, Verizon Communications, Cisco Systems, Google and Ericsson, have become members of AST (Allied Security Trust), a joint trust which is a patent holding company that helps protect members against patent infringement lawsuits. Allied Security Trust (2010) claims that:

> *AST operates under a "catch and release" model that is unique among defensive patent organizations. AST members purchase patents for defensive purposes, secure the necessary licenses to ensure freedom of operation, and then return the patents to the marketplace for sale. These sale proceeds help to reimburse AST members for their investment in acquiring a license. Under the rules of Trust, AST or its affiliated companies seek to sell all acquired patents within one year of the date of acquisition.*

If companies of the size of those that have joined AST consider it useful to join forces to avoid specialization restrictions and "to ensure freedom of operation", it is not hard to imagine the difficulties encountered by small companies, especially when they belong to the periphery of the industrial world.

The knowledge economy is characterised by a *property paradox* (Pagano and Rossi, 2010): the intensive use of a non-rival capital good like knowledge implies that many firms should be simultaneously able to use this input at low cost: small scale production should be highly competitive, and a world of open markets of worker-owned firms should prevail. However we have seen that the present arrangements of the world economy favour a world of closed proprietary science which involves a high degree of intellectual monopoly (Boldrin and Levine 2008) and closed markets, and which restricts the investment opportunities of firms, countries, and the world economy as a whole. In other words, the *property rights paradox* is connected to the present crisis, and one of the ways to re-launch the economy is to alter the balance between closed science and open science and, at the same time, the balance between open science and open markets.

Institutional change and Keynesian policies should go together: more investment in public research is necessary to deal with the problem of free-riding among countries. A WRO (a World Research Organization) should balance the WTO and the TRIPS agreement. Moreover, in some important cases, the public authorities should do for all firms what AST does for its powerful and wealthy members by moving some knowledge from the private to the public sphere. This policy could generate a supermultiplier (Pagano and Rossi, 2010) which couples the expansionary effects of the standard Keynesian multiplier with the efficiency gains due to the multiplying virtues that a non-rival good displays when it is moved from the private to the public sphere. Productive specialization should no longer be driven by market enclosures but rather by the enlargement of investment opportunities in open international markets.

[5] The term is used to indicate a person or company that enforces patents against alleged infringers in a manner considered unduly aggressive or opportunistic, often with no intention of manufacturing or marketing the patented invention.

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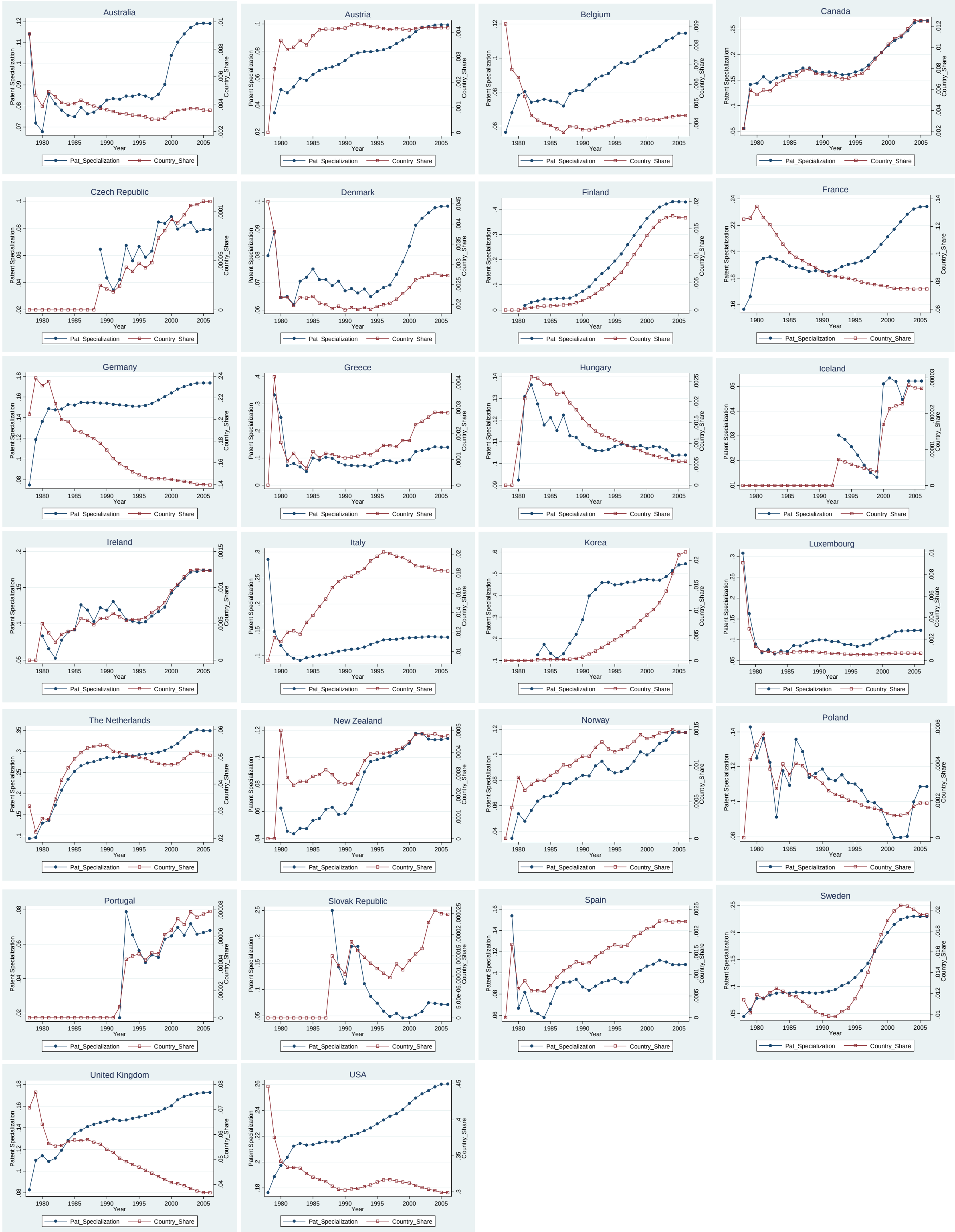
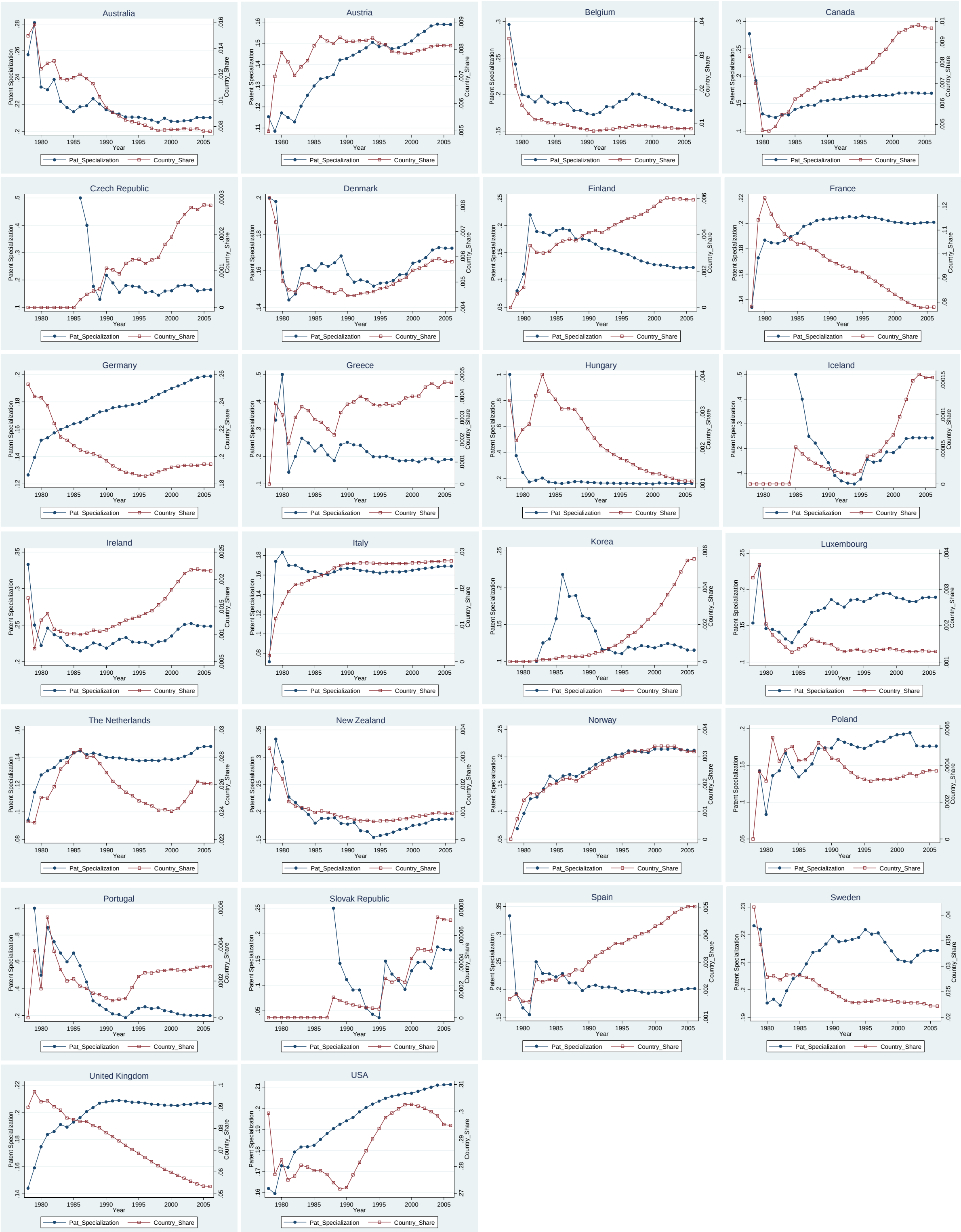
Appendix A: patent specialization patterns of OECD countries.

Figure A1. Patent specialization patterns: electrical engineering.



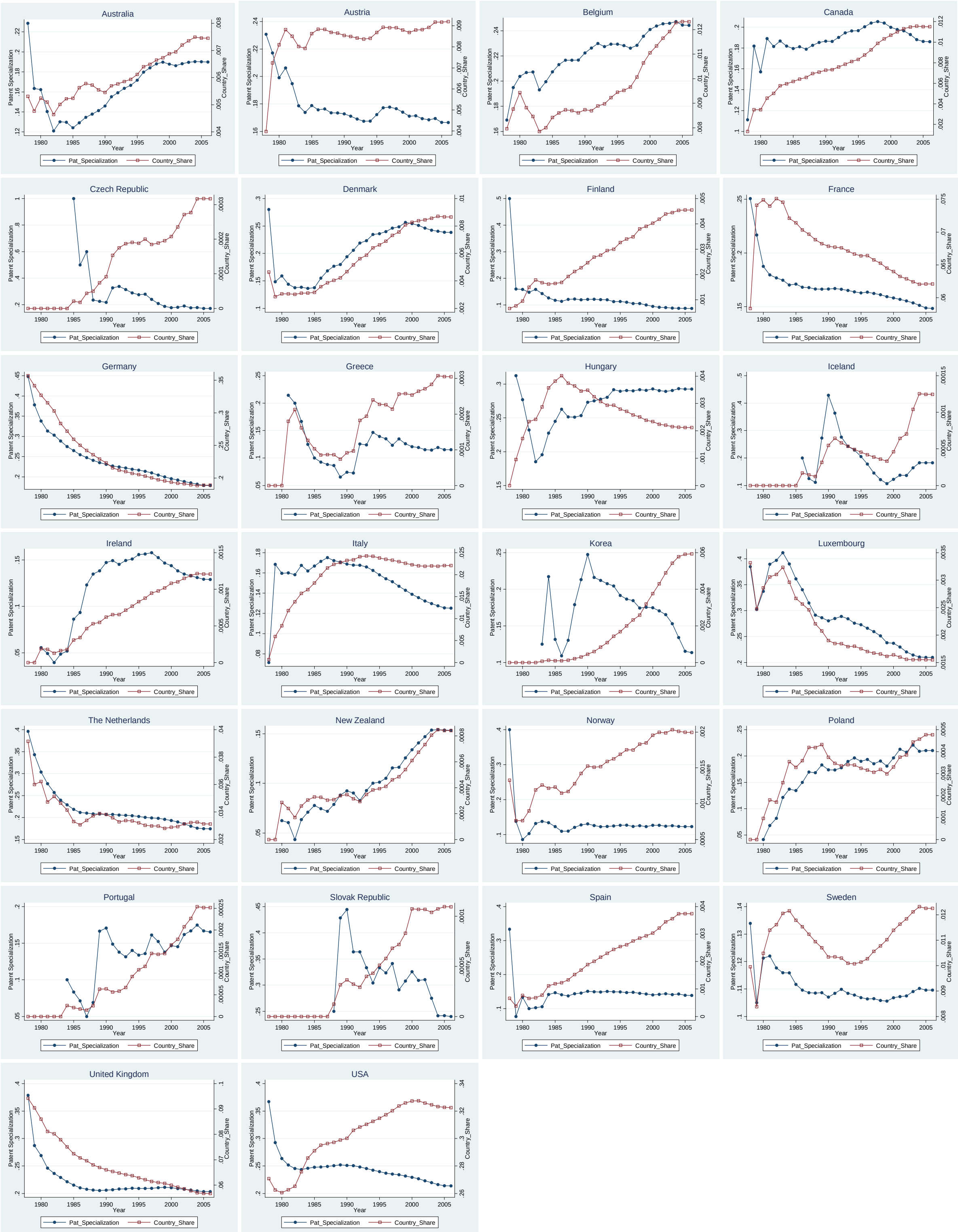
Source: authors' calculations on data from the European Patent Office (EPO, 2008). Patent specialization (blue line) is defined as the share of country *k*'s patents in industry *j* over the total of country *k*'s patents; the country's patent share (red line) is defined as the share of country *k*'s patents in industry *j* over the total of world's patents in industry *j*. See Table 1 in the paper for details of the industry classification that we use.

Figure A2. Patent specialization patterns: instruments.



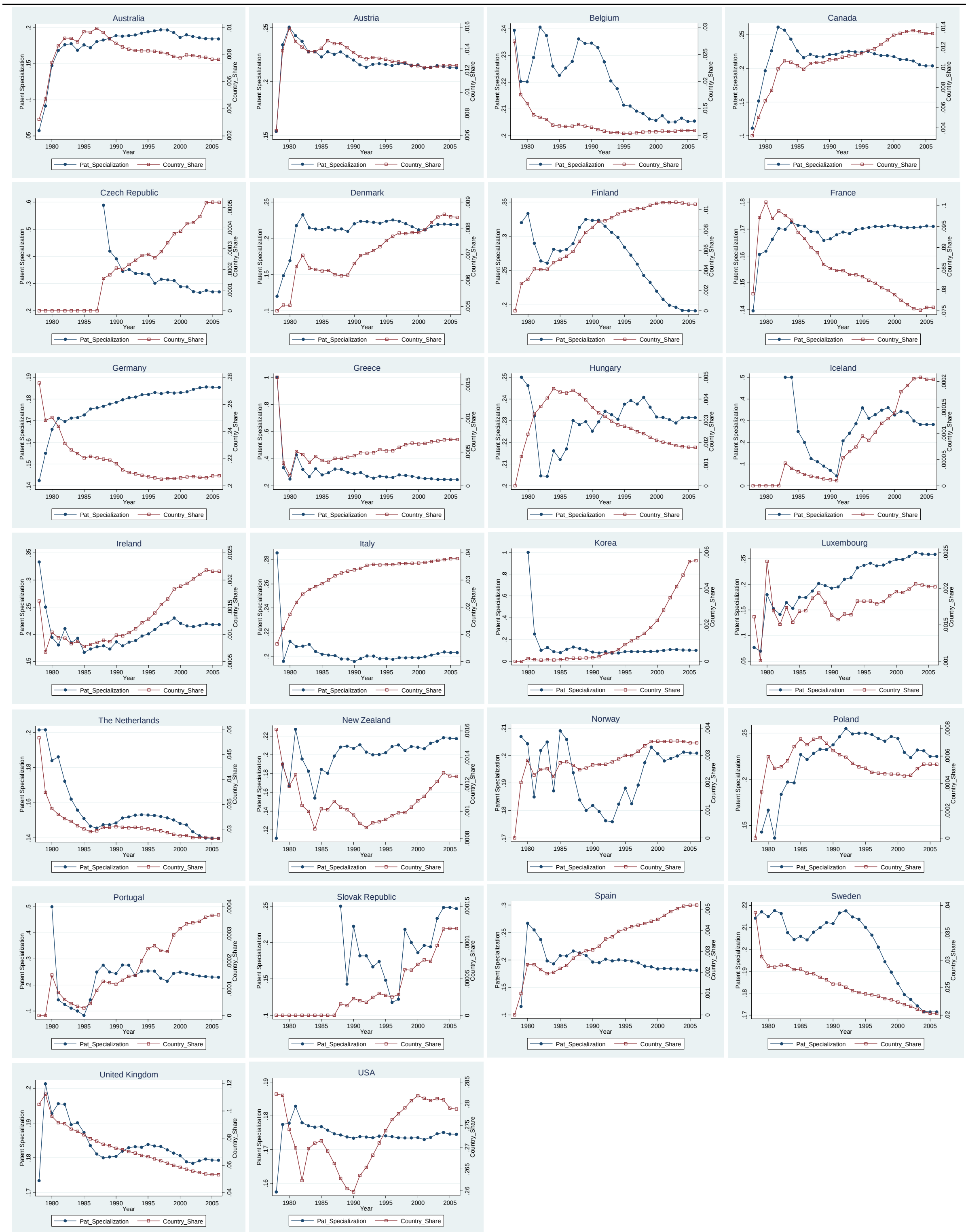
Source: authors' calculations on data from the European Patent Office (EPO, 2008). Patent specialization (blue line) is defined as the share of country k's patents in industry j over the total of country k's patents; the country's patent share (red line) is defined as the share of country k's patents in industry j over the total of world's patents in industry j. See Table 1 in the paper for details of the industry classification that we use.

Figure A3. Patent specialization patterns: chemistry and pharmaceuticals.



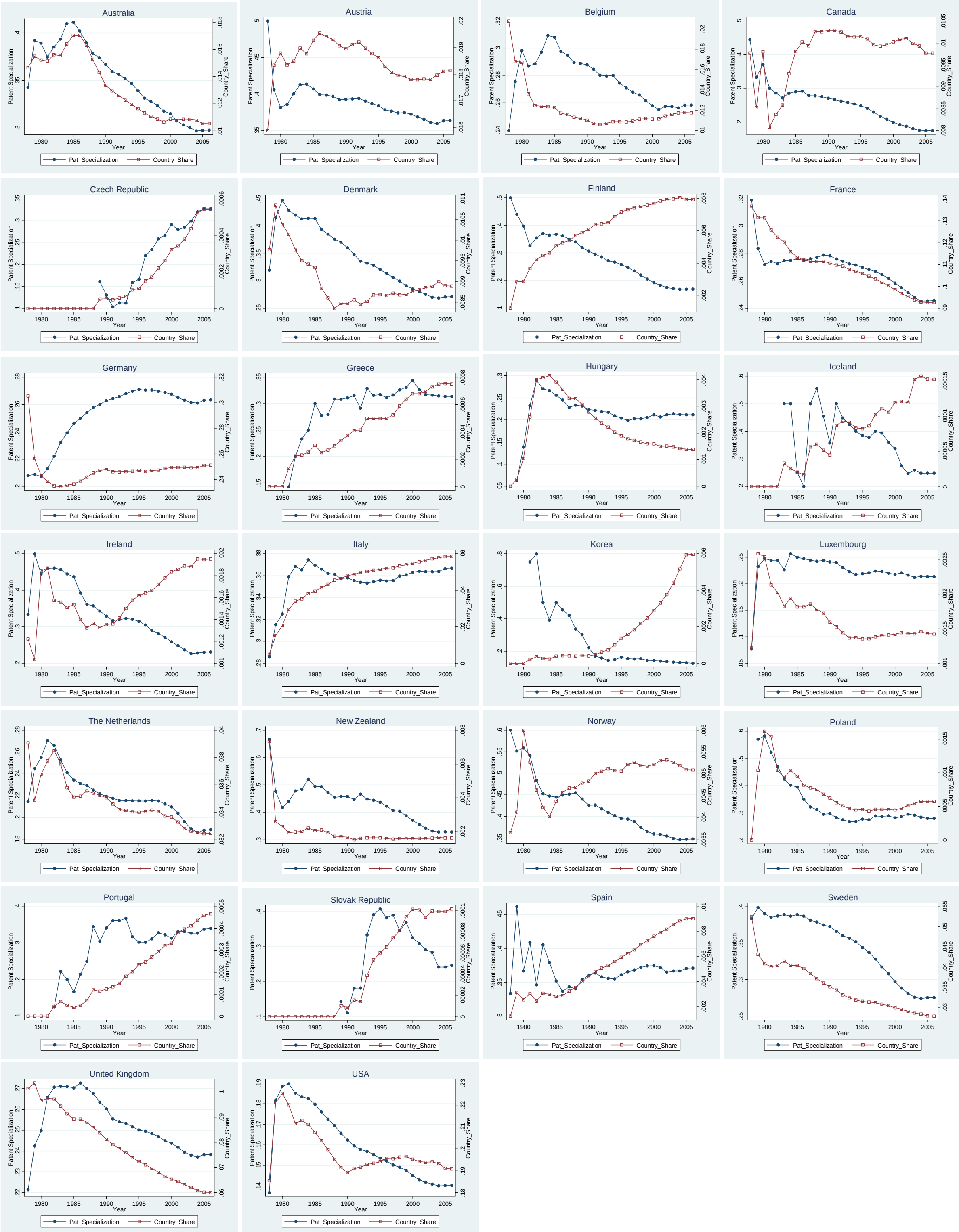
Source: authors' calculations on data from the European Patent Office (EPO, 2008). Patent specialization (blue line) is defined as the share of country *k*'s patents in industry *j* over the total of country *k*'s patents; the country's patent share (red line) is defined as the share of country *k*'s patents in industry *j* over the total of world's patents in industry *j*. See Table 1 in the paper for details of the industry classification that we use.

Figure A4. Patent specialization patterns: process engineering.



Source: authors' calculations on data from the European Patent Office (EPO, 2008). Patent specialization (blue line) is defined as the share of country *k*'s patents in industry *j* over the total of country *k*'s patents; the country's patent share (red line) is defined as the share of country *k*'s patents in industry *j* over the total of world's patents in industry *j*. See Table 1 in the paper for details of the industry classification that we use.

Figure A5. Patent specialization patterns: mechanical engineering.



Source: authors' calculations on data from the European Patent Office (EPO, 2008). Patent specialization (blue line) is defined as the share of country *k*'s patents in industry *j* over the total of country *k*'s patents; the country's patent share (red line) is defined as the share of country *k*'s patents in industry *j* over the total of world's patents in industry *j*. See Table 1 in the paper for details of the industry classification that we use.

Appendix B: Transaction costs thresholds.

B.1. Transaction costs thresholds in the first period's production. In this subsection we show that the first of inequalities (6) in the text (i.e. $c_{t_0}^{A,i} < c_{t_0}^{A,j}$) holds when transaction costs (*h*) are above the threshold level shown in the first of inequalities (7) in the text.

Inequality $c_{t_0}^{A,i} < c_{t_0}^{A,j}$ can be written as:

$$k^{A,j} + (g+h)P_{t_0}^{B,j} + gP_{t_0}^{A,j} > k^{A,i} + (g+h)P_{t_0}^{B,i} + gP_{t_0}^{A,i} \qquad \text{(B1)}$$

which, in turn, can be rewritten as:

$$h\left(P_{t_0}^{B,j} - P_{t_0}^{B,i}\right) > k^{A,i} - k^{A,j} + g\left(P_{t_0}^{A,i} - P_{t_0}^{A,j}\right) - g\left(P_{t_0}^{B,j} - P_{t_0}^{B,i}\right) \qquad \text{(B2)}$$

that is:

$$h > \frac{k^{A,i} - k^{A,j}}{P_{t_0}^{B,j} - P_{t_0}^{B,i}} + g\frac{P_{t_0}^{A,i} - P_{t_0}^{A,j}}{P_{t_0}^{B,j} - P_{t_0}^{B,i}} - g \qquad \text{(B3)}$$

and then:

$$h > \frac{k^{A,i} - k^{A,j}}{P_{t_0}^{B,j} - P_{t_0}^{B,i}} - g\left(1 + \frac{P_{t_0}^{A,i} - P_{t_0}^{A,j}}{P_{t_0}^{B,i} - P_{t_0}^{B,j}}\right) \qquad \text{(B4)}$$

If at t_0 the relative endowments of patents across sectors are symmetric between countries (i.e. if $(P^{A,i} - P^{A,j}) = (P^{B,j} - P^{B,i})$, we have that:

$$\frac{P_{t_0}^{A,i} - P_{t_0}^{A,j}}{P_{t_0}^{B,i} - P_{t_0}^{B,j}} = -1 \qquad \text{(B5)}$$

and obtain:

$$h > \frac{k^{A,i} - k^{A,j}}{P_{t_0}^{B,j} - P_{t_0}^{B,i}} \qquad \text{(B6)}$$

that is, the first of inequalities (7') in the text. Similarly, the second of inequalities (7') can be obtained for country B.

B.2. Transaction costs thresholds in the second period's production. In this subsection we show that the first of inequalities (13) in the text (i.e. $c_{t_1}^{A,i} < c_{t_1}^{A,j}$) holds when transaction costs (*h*) are above the threshold level shown in the first of inequalities (14) in the text.

Inequality $c_{t_1}^{A,i} < c_{t_1}^{A,j}$ can be written as:

$$k^{A,j} + (g+h)\left(P_{t_0}^{B,j} + P_{t_1}^{B,j}\right) + g\left(P_{t_0}^{A,j} + P_{t_1}^{A,j}\right) > k^{A,i} + (g+h)\left(P_{t_0}^{B,i} + P_{t_1}^{B,i}\right) + g\left(P_{t_0}^{A,i} + P_{t_1}^{A,i}\right) \qquad \text{(B7)}$$

which, in turn, can be rewritten as:

$$h\left[\left(P_{t_0}^{B,j} + P_{t_1}^{B,j}\right) - \left(P_{t_0}^{B,i} + P_{t_1}^{B,i}\right)\right] > k^{A,i} - k^{A,j} + g\left[\left(P_{t_0}^{A,i} + P_{t_1}^{A,i}\right) - \left(P_{t_0}^{A,j} + P_{t_1}^{A,j}\right)\right] - g\left[\left(P_{t_0}^{B,j} + P_{t_1}^{B,j}\right) - \left(P_{t_0}^{B,i} + P_{t_1}^{B,i}\right)\right] \quad \text{(B8)}$$

that is:

$$h > \frac{\left(k^{A,i} - k^{A,j}\right)}{\left(P_{t_0}^{B,j} + P_{t_1}^{B,j}\right) - \left(P_{t_0}^{B,i} + P_{t_1}^{B,i}\right)} + g\,\frac{\left(P_{t_0}^{A,i} + P_{t_1}^{A,i}\right) - \left(P_{t_0}^{A,j} + P_{t_1}^{A,j}\right)}{\left(P_{t_0}^{B,j} + P_{t_1}^{B,j}\right) - \left(P_{t_0}^{B,i} + P_{t_1}^{B,i}\right)} - g \qquad \text{(B9)}$$

and then:

$$h > \frac{\left(k^{A,i} - k^{A,j}\right)}{\left(P_{t_0}^{B,j} - P_{t_0}^{B,i}\right) + \left(P_{t_1}^{B,j} - P_{t_1}^{B,i}\right)} - g\left[1 + \frac{\left(P_{t_0}^{A,i} + P_{t_1}^{A,i}\right) - \left(P_{t_0}^{A,j} + P_{t_1}^{A,j}\right)}{\left(P_{t_0}^{B,i} + P_{t_1}^{B,i}\right) - \left(P_{t_0}^{B,j} + P_{t_1}^{B,j}\right)}\right] \qquad \text{(B10)}$$

If at t_1 the relative endowments of patents across sectors are symmetric between countries, we have that:

$$\frac{\left(P_{t_0}^{A,i} + P_{t_1}^{A,i}\right) - \left(P_{t_0}^{A,j} + P_{t_1}^{A,j}\right)}{\left(P_{t_0}^{B,i} + P_{t_1}^{B,i}\right) - \left(P_{t_0}^{B,j} + P_{t_1}^{B,j}\right)} = -1 \qquad \text{(B11)}$$

and obtain:

$$h > \frac{\left(k^{A,i} - k^{A,j}\right)}{\left(P_{t_0}^{B,j} - P_{t_0}^{B,i}\right) + \left(P_{t_1}^{B,j} - P_{t_1}^{B,i}\right)} \qquad \text{(B12)}$$

that is, the first of inequalities (14') in the text. Similarly, the second of inequalities (14') can be obtained for country B.

Appendix C: empirical model derivation.

To obtain the joint density function of patent specialization and investment specialization observations, we use a sequential factorization. Let us call $\mathbf{I}^{k,i}$ the vector of investment specialization values, $\mathbf{P}^{k,i}$ the vector of investment specialization values, $\mathbf{I}_0^{k,i}$ and $\mathbf{P}_0^{k,i}$ their initial values, $\mathbf{I}_{t-1}^{k,i}$ and $\mathbf{P}_{t-1}^{k,i}$ their values obtained up to time *t-1*, θ the vector of parameters. We have:

$$f\left(\mathbf{I}^{k,i},\mathbf{P}^{k,i}\middle|\mathbf{I}_0^{k,i},\mathbf{P}_0^{k,i};\boldsymbol{\theta}\right)=\prod_{t_0}^{t} f\left(\frac{I_t^{k,i}}{I_t^k},\frac{\sum_{t_0}^{t} P_{t_r}^{k,i}}{\sum_{t_0}^{t} P_{t_r}^{k}}\middle|\mathbf{I}_{t-1}^{k,i},\mathbf{P}_{t-1}^{k,i};\boldsymbol{\theta}\right) \tag{C1}$$

The joint density function for individual observations, in turn, can be factorized as follows:

$$f\left(\frac{I_t^{k,i}}{I_t^k},\frac{\sum_{t_0}^{t} P_{t_r}^{k,i}}{\sum_{t_0}^{t} P_{t_r}^{k}}\middle|\mathbf{I}_{t-1}^{k,i},\mathbf{P}_{t-1}^{k,i};\boldsymbol{\theta}\right)=f\left(\frac{I_t^{k,i}}{I_t^k}\middle|\frac{\sum_{t_0}^{t} P_{t_r}^{k,i}}{\sum_{t_0}^{t} P_{t_r}^{k}},\mathbf{I}_{t-1}^{k,i},\mathbf{P}_{t-1}^{k,i};\boldsymbol{\theta}\right)\times f\left(\frac{\sum_{t_0}^{t} P_{t_r}^{k,i}}{\sum_{t_0}^{t} P_{t_r}^{k}}\middle|\mathbf{I}_{t-1}^{k,i},\mathbf{P}_{t-1}^{k,i};\boldsymbol{\theta}\right) \tag{C2}$$

Bearing this in mind, the model to be estimated can be written in the following basic form:

$$\frac{I_t^{k,i}}{I_t^k}=\beta\cdot\frac{\sum_{t_0}^{t} P_{t_r}^{k,i}}{\sum_{t_0}^{t} P_{t_r}^{k}}+\varepsilon_{i,k,t} \tag{C3}$$

$$\frac{\sum_{t_0}^{t} P_{t_r}^{k,i}}{\sum_{t_0}^{t} P_{t_r}^{k}}=\delta\cdot\frac{I_{t-1}^{k,i}}{I_{t-1}^{k}}+\eta_{i,k,t} \tag{A4}$$

$$\begin{pmatrix}\varepsilon_{i,k,t}\\ \eta_{i,k,t}\end{pmatrix}\sim IN\left(0;\begin{pmatrix}\sigma_{11} & \sigma_{12}\\ \sigma_{21} & \sigma_{22}\end{pmatrix}\right) \tag{C5}$$

Substituting (A4) in (A3), we obtain the joint generation process of patent and investment specialization, conditional to their past values:

$$\begin{pmatrix}\dfrac{I_t^{k,i}}{I_t^k}\\ \dfrac{\sum_{t_0}^{t} P_{t_r}^{k,i}}{\sum_{t_0}^{t} P_{t_r}^{k}}\end{pmatrix}=\begin{pmatrix}\beta\delta\\ \delta\end{pmatrix}\frac{I_{t-1}^{k,i}}{I_{t-1}^{k}}+\begin{pmatrix}\upsilon_{i,k,t}^{'}\\ \upsilon_{i,k,t}^{''}\end{pmatrix} \tag{C6}$$

$$\begin{pmatrix}\upsilon_{i,k,t}^{'}\\ \upsilon_{i,k,t}^{''}\end{pmatrix}\sim IN\left(0;\begin{pmatrix}\sigma_{11}+\beta^2\sigma_{22}+2\beta\sigma_{12} & \sigma_{12}+\beta\sigma_{22}\\ \sigma_{21}+\beta\sigma_{22}, & \sigma_{22}\end{pmatrix}\right) \tag{C7}$$