Innovation, Product Life Cycles and Intellectual Property Rights Protection: what is the best place to invent something?

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Abstract

This paper looks at the role that Intellectual Property Rights (IPR) protection plays for the decision of multinational corporations (MNCs) to locate their R&D activities. Do stronger IPRs attract more innovation? And if so, does it matter more for certain sectors than for others? Using a novel multi-country and multi-sector database gathering information on the innovation activity of more than 15,000 firms, we are able to distinguish among two types of innovation: innovation carried out in areas where the firm is present directly (or indirectly through a subsidiary) and research done in countries where the MNC only collaborates with local firms or inventors. We find that firms tend to locate the first type of activity in countries with strong IPR protection, and this is true especially in long life-cycle industries which rely longer on patents. In contrast, short life-cycle technologies with faster obsolescence rate are insensitive to IPR protection. The second type of innovative activity is not affected by patent protection, suggesting other motives behind location decisions.

Keywords: R&D, Innovation, Patents, Intellectual Property Rights, Product Life Cycle, External Innovation, Government Policy, Technological Change.

JEL Classification: D22, F23, L50, O30, O32, O38.

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1. Introduction

Innovation has been recognized as one of the key factors leading to social development and growth. Increase in productivity is crucial for a world with limited resources that wants to keep improving its living standard, and minimizing input demand. R&D activity is still mostly concentrated in developed countries, even if, in recent years, it has started to bloom in developing ones as well: for example China or India (see UNCTAD (2005), OECD (2008)). Location of inventions is crucial due to the tendency of R&D spillovers to be very localized (see Jaffe et al. (1993), Coe and Helpman (1995) and Helpman et al. (2007)), and spreading it globally is at the top of the agenda for most policy makers in the world. Multinational Corporations (MNCs), defined as firms with factories or other assets in at least one nation different from the home country, are responsible for the majority of the patenting activity across the globe: the 700 larger MNCs account for more than 70% of the world private R&D expenditures (UNCTAD, 2005; OECD, 2008). Therefore it is particularly important to attract innovative activities from MNCs. Innovation can easily be localized due to information on inventors' addresses which are publicly disclosed in patents records. IPR policies can help in attracting R&D into a given country: IPRs aim at protecting ideas incorporated into new products, the intensity of these ideas' protection could affect a firm's decision to innovate there (see Boldrin and Levine (2002) and Aghion et al. (2015)).

This paper analyses the effect of IPR in affecting MNCs decisions regarding where to locate their R&D activities. We use a newly-created dataset containing information on patenting activity of more than 15,000 multinationals undertaking research in 141 countries and 37 sectors in the years from 2004 to 2013. R&D location is identified by extracting inventors addresses out of patent data. We conduct analyse firm-level patents, further categorized by country and sector. Our identification strategy exploits the fact that IPRs are more important for certain sectors, namely sectors with long life cycles (e.g. metals and industrial production), than for those with short life-cycles (where products get obsolete faster) such as computer and other electronic equipments. Legal and socio-economic characteristics of a country affect patents protection levels, but not products' life-cycle lengths which only vary across industries. This enable us to capture a positive effect of IPR protection on R&D activities.

Two types of innovation are considered in this paper. Commercial innovation takes place in locations the MNC either has a subsidiary or undertakes production activities. External innovation, on the other hand, involves collaboration with foreign inventors, or firms, that are not part of the multinational itself. We find that there is a distinction between the two in the way they react to IPR intensity: the former values stronger IPR nations as better recipients while the latter appears more insensitive to the legal framework of the destination country. We believe that this is due to the fact that IPR strength matters more for commercialization rather than for innovation itself (see Smarzynska Javorcik (2004)). These findings are in line with the theoretical prediction of our model in Section 3. In this model we argue that while MNCs always prefer to locate their commercial innovation in countries with strong IPR (see Proposition 1), it cannot be established, a priori, whether they prefer countries with strong or weak IPR in external R&D location choices(see Proposition 3).

This works relates to three existing strands of literature. First, it relates to the theoretical studies on the relation between R&D and IPR (see Boldrin and Levine (2002) and Aghion et al. (2015)). Our results provide empirical evidence that MNCs prefer to innovate in countries with strong patent protection particularly for long life cycle products. Second, it relates to existing work which empirically evaluates the impact of IPRs on multinational activities, such as FDI, production or trade, and technology transfers (see Bilir (2014); Smarzynska Javorcik (2004); Branstetter et al. (2011, 2005)). Our analysis provides new insight on MNCs' innovative activity in a multi-country setting. Finally, this research is also linked to the international business literature on the globalisation of R&D (see Abramovsky et al. (2008), Defever (2006) and Defever (2012)). Compared to this literature, we add new insights by making a distinction between commercial and external R&D.

The remainder of the paper is structured as follows. In section 2, we deepen the literature review. Section 3 introduces the theoretical model. Section 4 describes the data sources. Section 5 presents the sample characteristics and the main descriptive statistics. In Section 6 we address our empirical strategy. Section 7 discusses the results and robustness checks of our estimation exercise. Finally Section 8 concludes.

2. Related Literature

The relation between IPR stringency and innovation is unclear. On the one hand it has been argued that extreme patent protection may interfere with the natural flow of information, blocking the development of other potentially useful inventions, and eventually suppressing competition (Boldrin and Levine, 2002, 2008). On the other hand it has been found that without IPR protection, any reward for the innovators would disappear, inducing a disincentive to do research (Aghion et al., 2015). Acemoglu and Akcigit (2012) observed that IPR protection should be discriminated across actors, granting stronger protection to technology leaders and laxer shield to the followers, in order to maximize the innovation outcome. However, none of these articles look at the across-sector variation of the impact of IPR on innovation. We use this variation for building an identification strategy to isolate the effect of IPR on R&D. To the best of our knowledge no research so far has made the distinction between commercial and external innovation in disentangling the effect of IPR protection, which is a major contribution of our paper.

A more recent stream of literature has developed the empirical analysis about the impact of IPRs on commercial activities of multinationals such as FDI, trade and production. In her latest work Bilir (2014) built an index of product life cycle length which reflects sectors' innovation intensity. She measures the length of time during which a specific patent continues to receive citations from subsequent patents. Products with shorter life-cycles, such as computers or electronic equipment, tend to become obsolete faster; on the other hand, long life-cycle technologies exhibit lasting relevance to future innovations. Firms operating in longer life-cycle sectors are found to be more responsive to the strength of the host-country patent protection. These results are in line with Smarzynska Javorcik (2004), who find that weak protection deters foreign investors in technology-intensive sectors, and also discourages them from undertaking local production. Similarly Smith (2001) finds a positive correlation between sales of US affiliates and IPR protection strength in the destination country. None of these studies, however, consider specifically R&D activity which is the main focus of our paper.

MNCs increasingly conduct innovation abroad, what Abramovsky et al. (2008) called innovation offshoring. They observe that R&D undertaken within a state is not only associated with companies from that nation, but also with foreign firms with subsidiaries based there (what we called commercial R&D) or foreign firms without any subsidiaries who are just collaborating with domestic companies or inventors (what we called external R&D). Innovation offshoring could be triggered by two kinds of factors (Kumar, 1995; Odagiri and Yasuda, 1996; Florida, 1997; Belderbos, 2001; von Zedtwitz and Gassmann, 2002; Harrison et al., 2004; Belderbos et al., 2005). The first one would be specific to the destination market, in which case the products of innovation are intended for the local factories of MNCs; this has been referred to in the literature as adaptive R&D. The second source of innovation offshoring would involve a ”techno-sourcing” motive, where the products of innovative activity are meant to be channelled back home. Kerr and Kerr (2015) studied collaborative patents[1]. They find a greater likelihood for them to be observed when a firm enters a new foreign country for innovative work, especially in settings where IPR protection is weak, which allows them to capture more easily the existing local knowledge. Even though the authors' definition of collaborative patents does not resemble ours for external innovation, as external R&D does not necessarily involve a domestic inventor, we believe that some external patents are indeed also collaborative ones. Then we don't expect external R&D to be driven by strong IPR protection as there is a higher probability for it to be associated with technology-seeking motives, rather than adaptive ones, since it has no association with local production activities. To the best of our knowledge, there is no study so far on the different rationales for commercial and external innovation. We will contribute to this question, showing that while IPR stringency is a key indicator for attracting commercial R&D, particularly for longer life cycle products' industries, it does not matter for external research.

[1] Collaborative patents are defined as patents where at least one inventor is located outside and one inventor inside the home country of the firm the patent belongs to, but no distinction is made for inventors based in countries where the MNC holds some productive activities and countries where it has no subsidiary at all.

Recently Griffith and Macartney (2010) have studied the impact of employment protection legislation on innovation. Our paper builds heavily on the framework of Griffith and Macartney, but it focuses on the role of IPR, rather than labour protection. Additionally it introduces multi-sector analysis and the distinction between commercial and external innovation, which was not present in the original setting.

3. Theoretical Framework

To better analyse our problem we frame a partial equilibrium model which captures its main characteristics.

A firm i innovating in sector s in a foreign country c, wants to maximize its return from R&D, Π:

$$\Pi_{i,s,c} = (\pi_{i,s,c} + k_{i,s,c}) MIN(t_s, m_c) + \Sigma_{z \neq i} k_{z,c,s} [T_{max} - MIN(t_s, m_c)] + \varepsilon_{i,s,c} \quad (1)$$

where π is a fixed profit which the company is going to realize, every year, from the sales of the R&D products in sector s in the country c until it becomes obsolete (at time t), or imitation occurs from competitors (at time m); m is associated with IPR protection: the stronger the IPR, the more difficult it would be for competitors to imitate a technology, and thus the bigger is m. k_i is the firm's own knowledge in that industry which it is able to protect until the invention becomes obsolete or the idea is stolen by competitors, depending on what comes first. k_i represents value of knowledge protection to the firm: without flowing of information, the MNC protects its know-how, indirectly gaining from it (this can be attributed to the adaptive innovation rational). $\Sigma_{z \neq i} k_z$ is the knowledge of all the other competitors of firm i present in country c and innovating in the same sector[2]. This know-how becomes accessible only after the innovative products turn obsolete (at time t), unless a possibility for imitation arises first (at time m). In this view having a laxer IPR protection system (or lower m) would be beneficial for firm i which can access its competitors

[2] All the following derivations consider the scenario where a unique competitor j is present in both countries, nonetheless our results extend easily to the case of a multi-competitor scenario where the firm has more than just one rival in the foreign market.

information sooner (this can be attributed to the technology-seeking rational). Following Bilir (2014) we believe that the obsolescence time t is an industry-specific characteristic, as different sectors have different life-cycle length. T_{max} is the maximum obsolescence period. $\varepsilon_{i,s,c}$ accounts for possible unobservables at firm, country and sectoral level, it justifies the fact that we observe innovation in all countries and sectors both with strong and low IPR. This component is drawn independently across country-sector pairs according to a known distribution.

Firm i can observe everything, except for the imitation factor: it doesn't know when imitation will occur, it only knows that in countries with higher IPR protection, there is a lower possibility of early arrival, compared to laxer countries.

Assumption 1 – *The imitation time m in country c is uniformly distributed:* $m_c = U\left(0, \overline{m}_c\right)$*;* $\overline{m}_c$ *is the upper limit for m in c.*

Firm i can decide between locating its R&D in two countries, North (N) and South (S), which are perfectly symmetric, with the same π and k, and only differ on the level of IPR protection

Assumption 2 – *North has stronger law enforcement and therefore a lower probability of imitation, while South has laxer protection, and thus imitation can arise sooner:* $\overline{m}_N > \overline{m}_S$*.*

When comparing the firm's expected returns from R&D in these 2 countries we find[3]:

$$E\left(\Pi_{i,N,s}\right) - E\left(\Pi_{i,S,s}\right) = \left(\frac{1}{\overline{m}_S} - \frac{1}{\overline{m}_N}\right)\left[\frac{t_s^2}{2}\left(\pi_{i,s} + k_{i,s}\right) - \frac{k_{j,s}t_s^2}{2}\right] \tag{2}$$

Proposition 1 – *For sufficiently high commercial profits (π), we find that* $E\left(\Pi_{i,N,s}\right) > E\left(\Pi_{i,S,s}\right)$ *implying that a multinational always decides to locate its innovation in the country with the strongest IPR protection, no matter whether it is pursuing adaptive or technology-seeking R&D.*

In order to find which industry s the firm prefers to offshore in terms of R&D, it maximizes (1)

[3]For simplicity the two countries are assumed symmetric, therefore $\pi_{i,N,s} = \pi_{i,S,s} = \pi_{i,s}$, $k_{i,N,s} = k_{i,S,s} = k_{i,s}$ and $k_{j,N,s} = k_{j,S,s} = k_{j,s}$. For a better understanding of the resolution mechanism, please refer to Appendix B.

over the sectoral time maturity t finding a threshold level:

$$t^* = \overline{m}_c \tag{3}$$

it chooses to offshore all sectors with $t_s \leq t^*$. It is reasonable to think that innovation offshoring for products with high t is more prone to imitation than those with shorter life-cycles, putting at risk the return from sales of the company.

Lemma 1 – *Assumption 1 combined with the optimality condition in (3) entails that the country with stronger IPR protection can host innovative activity for a wider variety of sectors:* $t_N^* > t_S^*$.

From Lemma 1 it follows that there is an interval of sectors $t_N^* > t_s > t_S^*$ for which location in North is crucial, as their R&D would be offshored to North but not to South.

Proposition 2 – *Location of R&D in nations with stronger IPR protection matters more for long product life-cycle sectors rather than short life-cycle ones.*

Now we move on to the case of external R&D. As highlighted before, this is the case when the MNC does not have any production activity in the country where it decides to locate R&D. This translates into:

$$\pi^x_{i,s,c} = 0 \tag{4}$$

where the superscript x indicates all variables referring to external innovation. In this context equation 2 reads:

$$\Pi^x_{i,N,s} - \Pi^x_{i,S,s} = \left(\frac{1}{\overline{m}_S} - \frac{1}{\overline{m}_N}\right) \frac{t_s^2 \left(k^x_{i,s} - k^x_{j,s}\right)}{2} \tag{5}$$

Proposition 3 – *It cannot be established, a priori, whether a multinational prefers to locate its external R&D in countries with stronger or weaker IPRs; this decision is influenced by the nature of the innovation itself, which can be more adaptive or more technology-sourcing oriented.*

4. Data Sources

Our dataset merges four types of information: 1) firm-level data, which are used to build the group structure of each enterprise, and identify countries where the company is present directly or indirectly through a subsidiary, 2) patent data, which identify innovation and, more specifically, innovation location, 3) country level data, which captures countries' characteristics, and lastly 4) sectoral level data, which add industry-specific life-cycle information.

Firm-level Characteristics We access micro-level data on firms from Orbis of Bureau van Dijck, a commercial database which contains information on more than 120 million companies around the world[4], and focuses on the biggest players in the market, which are also the most active ones in terms of research activity. We restrict our selection to MNCs with at least one granted[5] patent between 2004 and 2013[6]. A multinational typically consists of a group's headquarters and some subsidiaries of which, at least one, needs to be located in a different country from the parent. The subsidiaries represent an extension of the firm itself and they are a possible means through which the holding company conducts its activities, including R&D investments. For this reason, we used Orbis to re-build the ownership structure of each innovating company. Since not all subsidiaries are of the same importance to a firm, we restrict our attention to those with an ownership share of more than 25%[7]. With this approach we are also able to identify in which countries the corporation is present and conducts some production activities, which will help us to distinguish between commercial and external innovation.

Innovation Orbis provides information on patents, held by a firm, through the European Patent Office (EPO) PATSTAT dataset. It provides us information on the names and addresses of the inventors that collaborated in the creation of patents. The inventor's address is of particular

[4]Last update as of December 2015.

[5]Granted patents are typically a higher value measure for innovation rather than just patent application which contains also patents refused or withdrawn (Guellec and Pottelsberghe de la Potterie, 2000; Zuniga et al., 2009).

[6]This is the period for which we have available data on IPR protection in each state.

[7]For a detailed explanation on the process of data extraction from Orbis and sample creation please refer to Appendix C.

importance in our analysis since it enables us to geographically localize the invention. A major advantage of using Orbis is that it harmonizes all inventors' names in order to merge them with business-related data, therefore information is presumably more precise. In order to remove equivalent patents[8] from the sample, we build our analysis on the priority date[9] rather than on the application date[10].

Country Characteristics To capture the IPR protection in each country we use the World Economic Forum index. It is an index built with an Executive Opinion Survey which is a survey of a representative sample of business leaders in their respective nations. Each of them is called to answer the following question: *"In your country, how strong is the protection of intellectual property, including anti-counterfeiting measures? (1 = extremely weak; 7 = extremely strong)"*. We believe that this index gives a fair representation of the perception of the firm about the patent protection in each state. Additionally, it presents the advantage of an extensive geographical coverage, it is therefore appropriate for our multi-country study. The main drawback is that it only dates back to 2004. We uses the Ginarte and Park (1997) updated index for robustness checks at the end of the analysis. As a control we also include information on the GDP level per capita, which we gather from the World Bank's Development Indicators.

Sector Characteristics By employing the concordance tables from Lybbert and Zolas (2012) we are able to match each patent's International Patent Classification (IPC) code with their sector/s of use. Finally with the inclusion of Bilir's index[11] it is possible to control for different life-cycle lengths at the sector level. This index is built using information on patent citations in the US, which we assume should not differ systematically from the rest of the world. It covers 37 industries from the 1987 3-digits Standard Industrial Classification (SIC) classification. Table 1 shows the sectors with the longest and shortest product life cycle lengths. Electronics and computer related sectors are the ones which get obsolete faster, while metals and hardware products,

[8]A patent family which includes all patent documents sharing exactly the same priority patent.

[9]The priority date is the first absolute date of patent filing everywhere in the world

[10] The application date is the date of patent filing in a specific patent office.

[11]See Bilir (2014).

Table 1: Product Life Cycle Lengths by Sector

Short Life Cycle Sectors	Life-cycle length (T)	Long Life Cycles Sectors	Life-cycle length (T)
Electronic Machinery	6.73	Fabricated Structural Metal Products	10.25
Watches, Clocks and Clockwork Operated Devices	7.37	Cutlery, Handtools and General Hardware	10.41
Computer and Office Equipment	8.38	Screw Machine Products, Bolts, Nuts and Screws	10.42
Agricultural Chemicals	8.69	Metal Cans and Shipping Containers	10.63
Electronic Components and Accessories	8.83	Heating Equipment, except Electric	10.89

Table 2: Notes: The table is taken from Bilir (2014) and it shows the products life cycle lengths for the top and bottom five industries in the sample.

on average, have a longer patent citation lag.

5. Descriptive Trends

Our main sample includes around 1.2 million patents granted to almost 15,000 MNCs in 141 countries and 37 sectors across 10 years. Only 30% of this innovation can be classified as offshored: 94% of total offshored R&D takes the form of commercial R&D, while the remaining 6% is external.

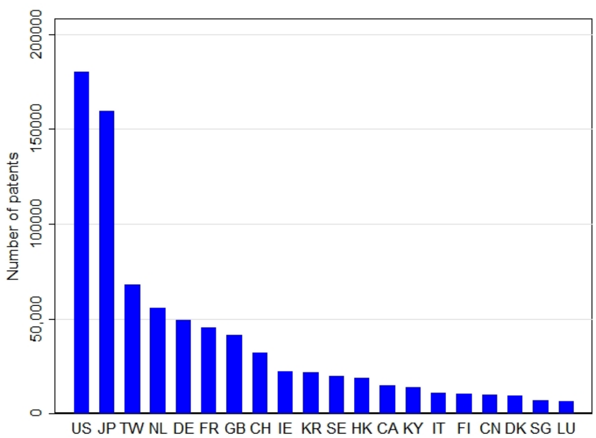
Figure 1 shows the home countries with the top innovative firms, while Figure 2 plots the destination countries for innovation by the top innovative firms. In both cases a distinction is made between commercial (see Figure a) and external innovation (see Figure b).

While origin countries for innovative companies don't differ significantly across both, with the most active ones being the United States and Japan, the divergence in Figure 2 points to differences in the composition of the destination country group. Commercial innovation is concentrated in few bigger countries such as the US, China or Germany, where the probability for the MNC to hold a subsidiary is larger. On the contrary, external innovation is dispersed across smaller or more remote economies[12], where the probability of establishing a subsidiary is much lower.

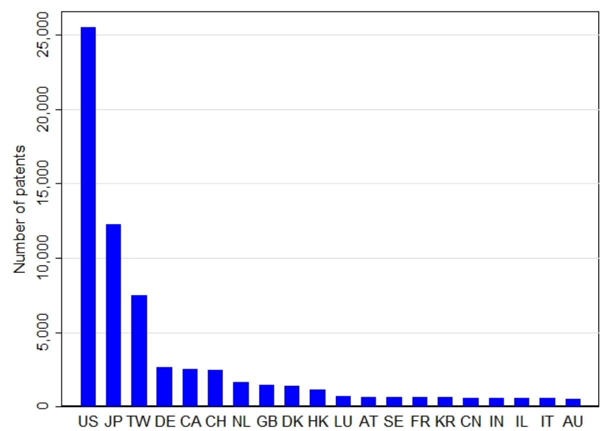
We now turn to analyse bilateral relations, established among countries, for R&D location. Figure 3 shows the top 20 dyads, where the first 2-digits ISO code represents the MNC's home country

[12] Among the biggest recipient countries for external innovation there, for example, Austria, Spain, New Zealand, Australia and South Africa.

while the second one refers to the innovation recipient country. We acknowledge a much wider variety of destination countries for external innovation (see Figure 3(b)), while commercial R&D exhibits more standardized links which reflect well established commercial connections (see Figure 3(a)).

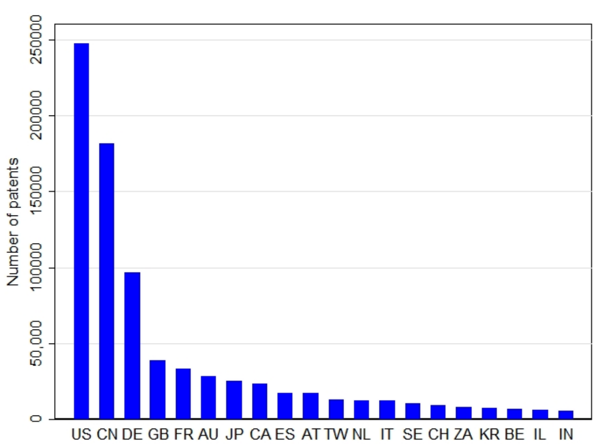


(a) Commercial Innovation

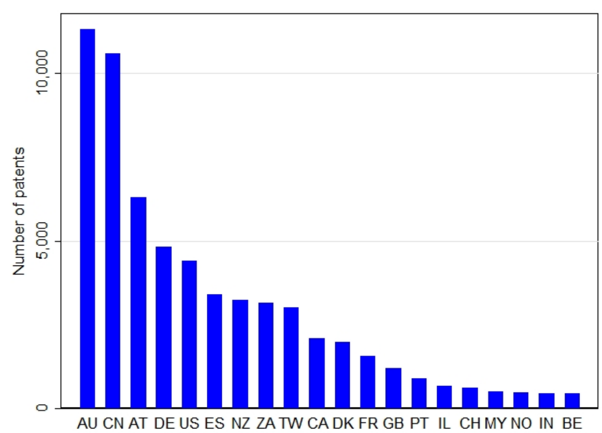


(b) External Innovation

Figure 1: Top 20 home countries for innovation



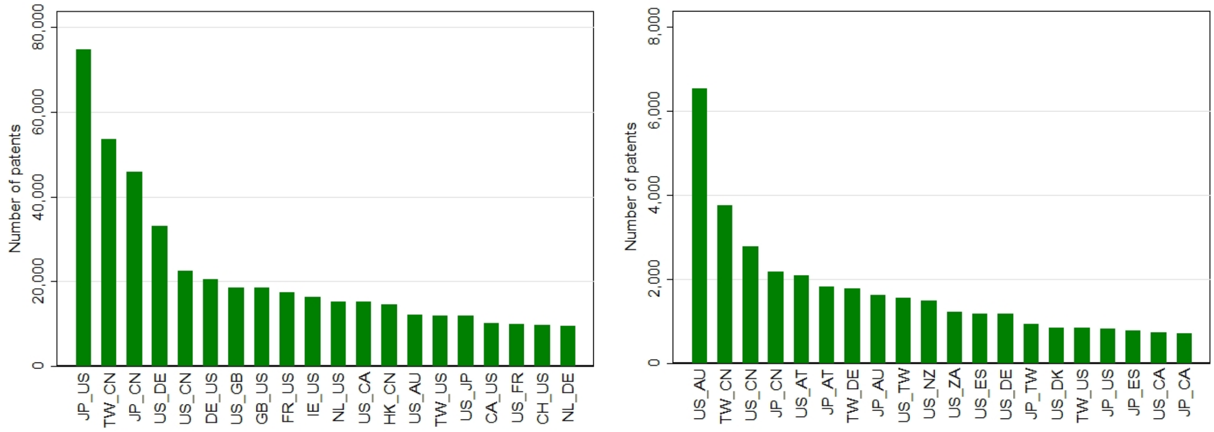
(a) Commercial Innovation



(b) External Innovation

Figure 2: Top 20 destination countries for innovation

Figure 5 compares the average IPR strength of the destination country for commercial and external

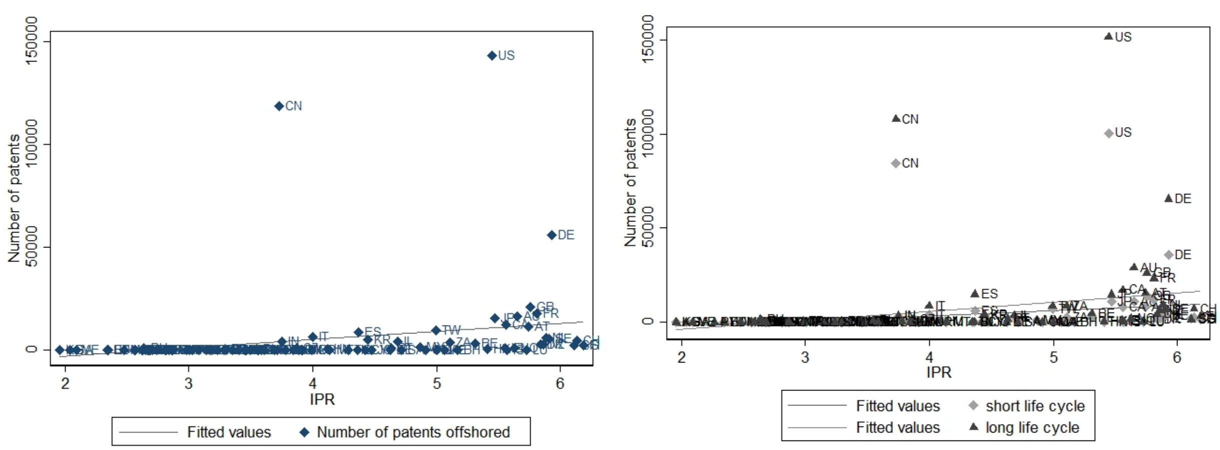


(a) Commercial Innovation

(b) External Innovation

Figure 3: Top 20 home-destination activities for innovation

R&D. IPR protection is much stronger in those countries where innovation is initiated along with production activities, rather than undertaken externally. This confirms the findings in Smarzynska Javorcik (2004), which stress that IPR protection matters more for commercialization purposes rather than innovation itself. We therefore expect to find stronger IPR in the destination countries of commercial R&D, instead of external R&D.



(a) All offshored innovation

(b) Innovation in short vs long life cycle length sectors

Figure 4: Number of patents and IPR in the destination country

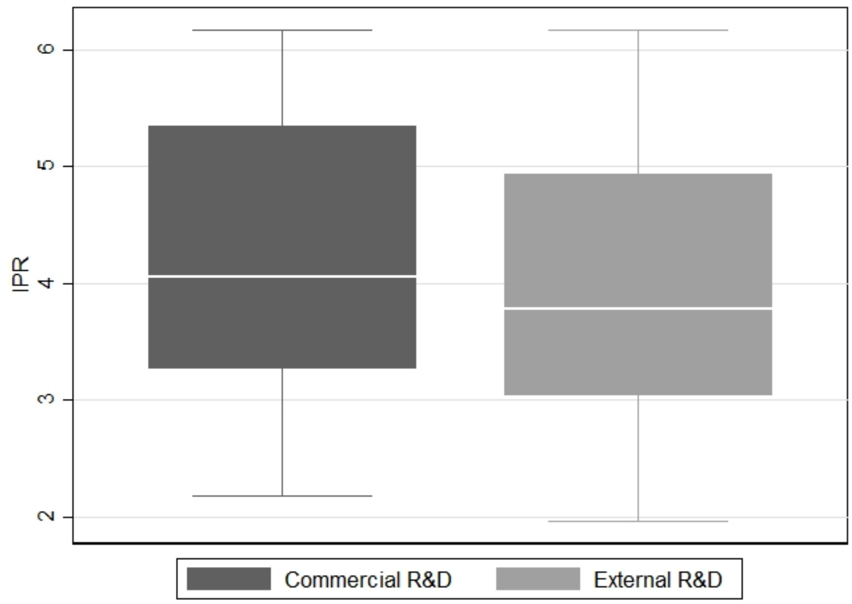


Figure 5: IPR intensity in the destination country for different types of innovation

Figure 4 presents simple correlation between IPR and number of patents invented in every country. There is a positive trend, which indicates that countries with stronger IPR protection tend to attract more innovation. This happens with few exceptions like China, which, despite a lower IPR, still attracts a great number of invention (see Figure 4(a)). When the distinction between long and short life cycle sectors is introduced, in Figure 4(b), we seem to capture the fact that IPR stringency matters more for longer life cycle industries rather than shorter ones. This is coherent with the idea that long life cycle products rely more on patent protection as their obsolescence period is lower.

6. Empirical Model

Following our theoretical model prediction we can derive the main equation to be estimated:

$$ln(P_{j,k,t}) = \alpha + \beta_1 IPR_{k,t}T_j + \beta_2 IPR_{k,t}T_j^2 + + \gamma_1 lGDP_{k,t}T_j + \gamma_2 lGDP_{k,t}T_j^2 + \eta_j + \eta_k + \eta_t + \varepsilon_{j,k,t} \tag{6}$$

where $P_{j,k,t}$ represents the number of patents invented in sector j, country k at time t[13]; $IPR_{k,t}$ is the IPR protection ascertained in a certain country k in year t; and T_j is the life cycle length of sector j as measured in Bilir (2014) index. A set of fixed effects is included to make sure that we control for unobservables which may affect the innovation activity. In particular, we consider: 1) sectoral features (η_j), that are partly related to industry characteristics, which are practically difficult to capture[14]; 2) conditions which are specific to a country, but not to the others (η_k) such as national reforms, competition levels or law enforcements; 3) time-related factors (η_t) which affects all countries and all sectors in given years, such as the financial crisis. The error term $\varepsilon_{j,k,t}$ combines any omitted factors that affect the innovation activity pattern. β's are the coefficients attached to the interaction terms between IPR protection and T; they are of particular interest as they disentangle the IPR effect across sectors with different time lengths.

Equation 6 may be enriched with a set of other controls to improve the identification of the β-effects. We include different orders of interaction terms between T and GDP per capita to better capture the IPR effect.

6.1 Identification Strategy

Some concerns may arise about possible endogeneity problems in the estimation exercise. First of all intellectual property rights stringency is correlated with several economic and legal factors. Strengthening IPR typically comes together with other policies which improve the quality of the legal system[15]. This makes it very difficult to identify the real contribution of IPR in explaining innovation in a nation as it could capture effects of other policies, such as trade or tax reforms which also favour firms' activities in particular R&D. Introducing the interaction term between IPR and T, we are able to capture the real effect of IPR protection on innovation as T varies across sectors and stays independent of firms' sensitivity to overall institutions and development levels

[13] If we indicate with z a specific MNC in our sample, then $P_{j,k,t} = \sum_z P_{z,j,k,t}$.

[14] Cohen and Levin (1989) talk about the differences in opportunities for technical advance across sectors which are difficult to make "empirically operational".

[15] The decision to strengthen IPR system protection often is motivated by a compliance trigger such as joining a new transnational organization or agreement which requires the member states to undertake certain policies to reach target goals in terms of institutional quality.

of a country.

T index of life-cycle length comes from Bilir (2014) and is built using US patent citation data[16]. We believe that since it is a sector-specific measure, it doesn't vary across countries and therefore the data estimated from the US can be applied to our full sample. Nonetheless as a robustness check (see Section 7.1) we run the same analysis removing all North American innovation from the sample. We find no divergence from the original findings which convinces us that T is not related to a precise country but, conversely, is a sector-specific characteristic and can be used in a multi-country study like ours.

7. Results

Table 3 reports the results of the initial estimations on innovation realized by all firms in our sample. We run a fixed effects estimation of our baseline regression in Equation 6. Column 1 regresses the number of patents on both IPR and GDP per capita without including any interaction term. As highlighted before, this type of estimation can suffer from endogeneity problems therefore we do not focus on that. Nonetheless column 2 shows that, indeed, the innovative activity concentrates in countries with stronger law enforcement: the largest impact is registered for sectors with longer life-cycle duration. These industries are systematically more responsive to IPR protection in the destination country. Adding the second order interaction term in column 3, we confirm Bilir's prevision about the non-monotonicity of the relation between IPR and T which reaches its highest effect in mid-length life cycles sectors. Column 4 represents the main specification of the model, where both the first and second order interaction terms between GDP and T are included. Since countries with high GDP level per capita, typically also have a strong legal system and consequently better patent protection, we want to be sure to disentangle the impact of overall development from the more specific influence that IPR protection could have on innovation decisions.

After having confirmed that the existing literature's predictions about IPR protection attractive-

[16] The author calculates the length of time during which a given patent continues to be cited by subsequent patents.

Table 3: IPR Protection and Innovation - Fixed Effect Estimation

Variables	(1) Offshored Patents	(2) Offshored Patents	(3) Offshored Patents	(4) Offshored Patents
IPR	0.063***			
	(0.016)			
lGDP	0.187***			
	(0.032)			
IPR x T		0.012***	0.129***	0.081***
		(0.003)	(0.010)	(0.011)
IPR x T^2			-0.011***	-0.008***
			(0.001)	(0.001)
lGDP x T				0.165***
				(0.015)
lGDP x T^2				-0.013
				(0.001)
Observations	40,481	13,126	13,126	9,525
R-squared	0.743	0.796	0.799	0.825

Notes: Country, year and sector fixed effects are included in all estimations. Dependent variable is inserted in logarithmic form. Cluster-robust standard errors in parentheses. *,** and *** respectively denote significance at 10%, 5% and 1% levels. Coefficient of constant has not been reproduced.

ness extend to innovation, we want to enrich our analysis and see if the same results remain valid when we focus only on external innovation. Different reasons could, in fact, drive research done in countries where a subsidiary is present from the one done in places where the firm has no productive activity and relies only on collaborations. There is a higher probability that collaborative patents, with an international team of inventors, are observed when a firm is entering into a new foreign country for innovative work, especially in settings where IPR protection is weak (see Kerr and Kerr (2015)). Therefore, even though our definition of external innovation does not correspond to Kerr and Kerr's idea of collaborative research, we don't expect external R&D to be driven by patent protection. This hypothesis is confirmed in Table 4; in column 1, IPR is an insignificant driver of outsourced R&D. Also the interaction effect between IPR and life cycle's length is poorly significant, which corroborates the idea that IPR stringency doesn't matter much for external innovation, that may be driven by factors other than law enforcement.

Table 4: IPR Protection and Innovation - Fixed Effect Estimation: Commercial vs External R&D

Variables	(1) Commercial Patents	(2) External Patents	(3) Commercial Patents	(4) External Patents
IPR	0.062***	-0.022		
	(0.016)	(0.017)		
lGDP	0.183***	0.154***		
	(0.034)	(0.035)		
IPR x T			0.082***	0.019*
			(0.011)	(0.011)
IPR x T^2			-0.008***	-0.002*
			(0.001)	(0.001)
lGDP x T			0.163***	0.130***
			(0.016)	(0.016)
lGDP x T^2			-0.013***	-0.010***
			(0.001)	(0.001)
Observations	38,213	19,598	10,156	6,271
R-squared	0.742	0.544	0.823	0.625

Notes: Country, year and sector fixed effects are included in all estimations. Dependent variable is inserted in logarithmic form. Cluster-robust standard errors in parentheses. *,** and *** respectively denote significance at 10%, 5% and 1% levels. Coefficient of constant has not been reproduced.

7.1 Robustness

Such results are robust to different specifications of the fixed effects[17]: we decided to include three distinct kinds - sector, country and time - which, in our opinion, is able to better capture most of the variation along different dimensions of the dataset.

In order to avoid endogeneity issues with the use of T, we remove all innovation undertaken in the US from our sample. This ensures the removal of the bias associated with the possibility of life-cycle length being country specific. In this specification our previous findings still hold confirming the validity of our intuition.

We are aware of the fact that the granting process could take up to some years, and we expect our sample of patents to be downward-biased towards the end of the period; also, this may differ depending on the application authority, making it faster in certain countries to have a granted patent than in others. In order to avoid this type of distortion, and check the robustness of our specification to change in time of analysis, we run the same estimation on the shorter interval of time (2004-2010) excluding more recent years, when this problem has greater probability to arise. Results do not change as we can see from Table A.1: coefficients are rather stronger in such a specification.

8. Conclusions

This paper analyses innovation responsiveness of innovation to intellectual property rights protection. We find that multinationals tend to innovate in countries with stronger patent enforcement: this connection seems to matter particularly for R&D in long life-cycle industries which, ceteris paribus, rely more and for a longer period on patented inventions, rather than their short cycle counterparts. Nevertheless innovation attraction towards better IPR protected countries does not seem to hold any more when we consider external R&D in isolation; in that case there should be other decisive factors, beside IPR stringency, which drag a corporation in a country where it

[17]For example we run the same regressions using sector-country specific fixed effects and a time trend, finding exactly the same results.

doesn't hold any production activity. With external innovation, MNCs may want to acquire a specific knowledge with the only purpose of bringing it back home, as the technology-sourcing stream of literature would hypothesise, or they may desire to create a local network to, later on, start a production activity there, in both cases IPR protection doesn't seem to matter in their choices.

The contribution of this study is two-fold: first of all, it confirms that the literature findings about the relation between firms' production activity and IPR protection apply also to innovation; secondly it deepens the analysis distinguishing among production and non-production driven R&D and rejecting the hypothesis that the same effect, as for production driven R&D, of IPR on innovation attraction is observed for external R&D. Understanding firm's operational mechanisms seems a crucial step in order to be able to seize and eventually redirect firms' activities across the globe. The current debate concerns a switch from dirty to green and more sustainable production. We believe that this paper's insights could help the policy makers undertaking more oriented and effective policies in that respect.

Future work needs to be done along two lines: first of all understanding which factors are determinant in attracting external innovation; secondly focusing specifically on environmentally sound technologies whose attraction and support is of primary interest in the current economic scene. External innovation could be the key to drag firms' technologies, especially green ones, towards less developed countries, since it doesn't necessarily redirect towards states with better legal systems as much of the richer and more developed nations are.

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Appendices

A. Robustness Checks

Table A.1: Robustness Checks - (2004-2010) Period

Variables	(1) Offshored Patents	(2) Commercial Patents	(3) External Patents	(4) Offshored Patents	(5) Commercial Patents	(6) External Patents
IPR	0.066***	0.070***	-0.010			
	(0.017)	(0.018)	(0.018)			
lGDP	0.183***	0.187***	0.187***			
	(0.038)	(0.039)	(0.039)			
IPR x T				0.083***	0.083***	0.022*
				(0.011)	(0.012)	(0.012)
IPR x T^2				-0.008***	-0.008***	-0.002**
				(0.001)	(0.001)	(0.001)
lGDP x T				0.180***	0.177***	0.152***
				(0.017)	(0.018)	(0.017)
lGDP x T^2				-0.014***	-0.013***	-0.011***
				(0.001)	(0.001)	(0.001)
Observations	35,518	33,456	17,864	9,525	8,839	5,677
R-squared	0.752	0.750	0.557	0.835	0.833	0.642

Notes: Country, year and sector fixed effects are included in all estimations. Dependent variable is inserted in logarithmic form. Cluster-robust standard errors in parentheses. *,** and *** respectively denote significance at 10%, 5% and 1% levels. Coefficient of constant has not been reproduced. This estimation has been run only on innovation patented between 2004 and 2010.

Table A.2: Robustness Checks - Without US innovation

Variables	(1) Offshored Patents	(2) Commercial Patents	(3) External Patents	(4) Offshored Patents	(5) Commercial Patents	(6) External Patents
IPR	0.061***	0.056***	-0.016			
	(0.016)	(0.017)	(0.019)			
lGDP	0.185***	0.180***	0.152***			
	(0.032)	(0.033)	(0.035)			
IPR x T				0.080***	0.080***	0.019*
				(0.011)	(0.011)	(0.012)
IPR x T^2				-0.007***	-0.008***	-0.002**
				(0.001)	(0.001)	(0.001)
lGDP x T				0.154***	0.149***	0.123***
				(0.015)	(0.016)	(0.016)
lGDP x T^2				-0.012***	-0.011***	-0.009***
				(0.001)	(0.001)	(0.001)
Observations	39,263	36,998	18,638	10,644	9,897	6,022
R-squared	0.721	0.719	0.533	0.806	0.803	0.613

Notes: Country, year and sector fixed effects are included in all estimations. Dependent variable is inserted in logarithmic form. Cluster-robust standard errors in parentheses. *,** and *** respectively denote significance at 10%, 5% and 1% levels. Coefficient of constant has not been reproduced. This estimation has been run removing all innovation located in the US.

B. Theoretical Model

In this section we examine in more details the resolution of the model in Section 3, deriving the main formula of the paper. Firm i wants to maximize, with respect to the obsolescence time t, its expected profits:

$$\underset{t_s}{\text{Max}} \quad E\left(\Pi_{i,s,c}\right), \tag{B.1}$$

just taking the expectation of (1):

$$E\left(\Pi_{i,s,c}\right) = \left(\pi_{i,s,c} + k_{i,s}\right) E\left(MIN\left[t_s, m_c\right]\right) + \Sigma_{z \neq i} k_{z,s}\left(T_{max} - E\left(MIN\left[t_s, m_c\right]\right)\right) + E\left(\varepsilon_{i,s,c}\right), \tag{B.2}$$

where ε is a white noise process and m has a uniform distribution accordingly to Assumption 1. It follows that the probability density function and the cumulative distribution function for m are respectively:

$$f\left(m_c\right) = \frac{1}{\overline{m}_c}, \tag{B.3}$$

$$F\left(m_c\right) = P\left(m_c \leq x\right) = \frac{x}{\overline{m}_c}. \tag{B.4}$$

To ease the calculation we assume just one competitor firm in the market: company j.
Notice that the expectation in equation (B.2) can be rewritten as:

$$E\left(MIN\left[t_s, m_c\right]\right) = t_s \cdot P\left(t_s < m_c\right) + E\left(m_c \cdot P\left(t_s \geq m_c\right)\right), \tag{B.5}$$

with

$$P\left(t_s < m_c\right) = 1 - P\left(t_s \geq m_c\right) = 1 - \frac{t_s}{\overline{m}_c}, \tag{B.6}$$

and

$$E\left(m_c \cdot P\left(t_s \geq m_c\right)\right)\right) = \int_0^{t_s} m_c f(m_c)\, dm_c = \frac{t_s^2}{2\overline{m}_c}. \tag{B.7}$$

We can therefore simplify equation B.2 into:

$$E\left(\Pi_{i,s,c}\right) = \left(\pi_{i,s,c} + k_{i,s,c}\right) t_s - \frac{t_s^2}{2\overline{m}_c}\left(\pi_{i,s,c} + k_{i,s,c}\right) + k_{j,c,s} T_{max} - k_{j,c,s} t_s + \frac{k_{j,c,s} t_s^2}{2\overline{m}_c}. \tag{B.8}$$

A comparison between expect profits in North and in South leads to equation (2). Finally, extracting the FOC for equation (B.2), we arrive at the expression in (3).
For the external innovation case we just followed all precedent steps considering $\pi_{i,s,c} = 0$.

C. Database Creation

Orbis database, compiled by Bureau Van Dijk, is a commercial dataset containing financial and administrative data on over 150 million firms across the planet. While coverage of firms is not exhaustive, it has been proved that it offers a fair representation of economic activity in each state, arriving to cover almost 75-80%

of firms in developed countries such as European ones (Kalemli-Ozcan et al., 2015). National censuses are, by far, more complete including a large number of small companies, but they typically lack of annual representation of the firms as surveys are not conducted every year. For the purposes of our study, given the focus on multinational activity and innovation, we are not concerned about the exclusion of smaller firms, which are rarely conducting R&D activities, and we prefer more systematic data on bigger companies offered by Orbis.

The Bureau Van Dijk's platform presents two sections: ”Companies” which contains financial data on each firm present in the database, and ”Patents” which include all information on patents hold by represented firms and accessed through PATSTAT database. Orbis advantage is to connect these two parts through a unique BvD ID number which exclusively identify each enterprise.

We start our analysis downloading all granted patents owned by a firm with a publication date between 1 January 2004 and 1 July 2015 (initial date of our research). Orbis does not allow you to select patents based on their priority date therefore, even if our analysis is limited to the interval of time 2004-2013 (years in which we have data for IPR at country level), we extended the time of selection in order not to lose any observation, knowing that typically patents are published after 18 months from the priority date except for certain patents at the USPTO which are published only if/when granted. For each patent we download: IPC codes, BvD ID of the firm which is currently owning it, priority date, application number, inventors' names and countries of residence.

Once obtained all the innovating firms we need to build, for each of them, the corporate group in order to understand if they are the head of a corporation or just subsidiaries held by other companies. Additionally, since our paper focuses on multinationals, we want to rule out national enterprises which only have subsidiaries within their national territory. Building precisely the ownership structure of the MNCs is crucial to attribute the correct patents to each multinational. In the Companies section we download the Global Ultimate Owners (GUO) associated to the previously extracted BvD ID; for all firms which lack this information we assume that they are themselves GUOs. Subsequently we download all their subsidiaries owned at more than 25% by all the GUOs in our sample: the participation level threshold, fixed at 25%, is intended to include only effectively controlled subsidiaries. Also we make sure to unfold up to the 10th, and last, subsidiary level. Subsidiaries can be controlled at different levels. As figure 1 shows if firm A holds 100% of firm B, and firm B holds 100% of firm C, then indirectly firm A holds 100% of firm C: firm C is a second level subsidiary, while firm B is a first level subsidiary for A.

Here a limitation of the platform arises: Orbis, according to his settings, only gives a maximum of 1.000 subsidiaries at a time. Since some MNCs have many more we isolate them in a group of ”big” GUOs, and we download manually all their subsidiaries from their reports one by one. This task is very time consuming but it is necessary since the bigger multinationals in our sample are more likely the more active ones in term of R&D, and excluding them would inevitably bias our findings. Also there is a limit of 40.000 subsidiaries that can be downloaded in excel from Orbis but none of our GUO exceeds this threshold.

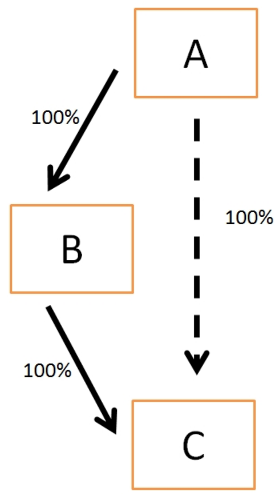

Figure 1: Different levels of ownership