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Exploring the nexus between appropriability and productivity in highly innovative and globalised companies

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Exploring the nexus between appropriability and productivity in highly innovative and globalised companies*

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Abstract

This paper identifies the dichotomous role (bright and dark sides) of Intellectual Property Rights (IPR) protection on labor productivity among highly innovative globalised firms. The role of appropriability conditions—such as IPR protection—as "Schumpeterian" incentive to innovation has been largely explored in the empirical literature. In this paper, we contribute to this strand explore the role of appropriability conditions on firm labor productivity under different configurations of R&D activities in highly globalized companies. In line with the literature, we show that labor, capital and R&D investments lead to productivity gains, and that the strength of the patent system the firm is embedded into is positively linked to the firm's labor productivity too. We call this the 'bright side' of IPR. However, stronger intellectual property rights might have a detrimental effect on the R&D returns, which appear to be maximized around the median level of IPR protection. In other words, too much protection might actually reduce R&D returns, again in line with the "Schumpeterian prediction". Then, we call this the 'dark side' of IPR. To our knowledge, this is the first paper highlighting such dichotomy (bright and dark sides of IPR) on a purpose-built high-quality database of globalized firms, which tend to be the most innovative firms in the world.

Keywords: panel data, appropriability, productivity.

JEL Codes: C23, O34.

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1 Introduction

The nexus between appropriability conditions and innovation has been largely explored by the empirical literature, recognizing the role of property right protection in incentivizing innovation efforts (Cohen et al., 2000). Recent empirical work—particularly from the UK and US—has strengthened the understanding that formal appropriability mechanisms (e.g., patents) are correlated with higher productivity among innovators (e.g., Hall and Sena, 2017; Hall et al., 2014; Mezzanotti and Simcoe, 2023). Critically, studies of multinational enterprises have shown that stronger IPR regimes in host countries amplify productivity spillovers to globalized subsidiaries, highlighting the importance of IPR in international settings (Smeets and de Vaal, 2016). In this paper, we investigate companies highly involved in innovation activities, as for example big multinational enterprises with subsidiaries scattered around the globe. We look at how they choose their investment in R&D activities in order to account for the first two pillars of "invention" and "innovation" of the Schumpeterian trichotomy (Schumpeter, 1928, 1942). Hence, we look at how companies "choose" the right intellectual property right (IPR) protection to account for the third pillar of the Schumpeterian trichotomy, "diffusion". Finally, we investigate how these joint strategies foster their efficiency, measured as firm-level labour productivity.

We look at the economic relationship between productivity and R&D in a reduced form, considered by the literature as key input of the innovation process. We consider the IPR as a potential moderator variable between R&D and efficiency.[1] We aim to understand the role of R&D for productivity enhancements in countries with different degrees of national IPR protection strength.

The analysis is based on a dataset integrating information from the JRC-R&D Scoreboard and COR&DIP with company information from ORBIS (BvD). Firm-level information on granted patents from ORBIS measures the strength of firm-level protection of intellectual property rights. Data span the time period 2007–2016, in which we have complete information on about 1,300 globalised firms.[2]

Previous literature extensively analyzed appropriability's impact on innovation but rarely explored its nuanced effects on productivity specifically within globalized innovation-intensive firms. Our study addresses this critical gap by identifying the dichotomous role (bright and dark sides) of IPR protection on labor productivity among highly innovative

[1] We would rather not regard IPR as a "direct" input of a production function, but as a moderator variable working *via* R&D.

[2] The most innovative firms in the world tend also to be highly globalised. Hence we do not incur in a specific problem of selection by looking with our data set.

globalised firms. We find that labour, capital and R&D investments lead to productivity gains and that the strength of IPR systems is positively linked to the firm's labour productivity (bright side of IPR protection). However, very strong intellectual property rights have a detrimental effect on the R&D returns, which appear to be higher when firms operate at median levels of IPR. In other words, too much protection reduces R&D returns, again in line with the Schumpeterian prediction. We call this the dark side of IPR. To our knowledge, this is the first paper documenting such dichotomy on a purpose-built high-quality database of globalised firms, which tend to be the most innovative firms in the world.

The paper proceeds as follows. In section 2 we review the literature. Section 3 describes data and measurement, with a particular focus on IPR. Section 4 introduced the empirical model in its different specifications. Section 5 reviews in detail the results and finally section 6 concludes.

2 Literature

In this section, we first review Schumpeterian hypotheses on innovation, then explore the relationship between appropriability and innovation, and finally survey recent empirical literature linking these concepts to firm productivity

The classification of the three-stage innovation activity of a company has been first developed by Schumpeter (1928) and Schumpeter (1942) with a focus on the initial phase of the invention (characterized by basic research), followed by innovation (embodied in applied research, development, commercial production), and finally conducting to diffusion (regarded as an *unintended* consequence of the first two stages). The company has in fact limited interest in innovation in the first place if the process of diffusion of such innovation is immediate to potential competitors and other companies. Diffusion is a positive outcome for society as a whole, which can benefit in the medium run, but a single firm needs to reap the benefit of costly investment in R&D by "expecting" some form of (temporally limited) protection and market power. The innovative incentive spurs efficiency in turn (Cohen et al., 2000).

However, if such protection is prolonged and unlimited the opposite might occur, excessive market power via protection blocks diffusion altogether, and ultimately productivity will also suffer due to a lack of competitive pressure. Therefore, the economic debate has widely focused on contrasting the situation where scant research is conducted, if the patent system does not guarantee incentive in doing research in the first place (for example locations where IPR are extremely low), compared to the opposite situation where too much incentive in the form of excessive market power post-innovation is granted, stifling both diffusion of technology into the society and productivity of the "protected" firms. Furthermore, not only patent laws but also the institutional environment (e.g. informal practices) have an impact on the so-called "appropriability" environment (Schankerman, 1998). By pushing the argument to the extreme (Schankerman, 2013, pag. 471) notes that :

> "The proliferation of patents, and the fragmentation of ownership rights among firms ('patent thickets'), are believed to raise transaction costs and constraint the freedom of action to conduct R&D, particularly in complex technology sectors like information technology".

Hence Schankerman (1998) and Schankerman (2013) show the bright but possibly the dark side of the appropriability environment.

Greenhalgh and Longland (2005) highlighted how the productivity gains in United Kingdom firms that invest in R&D are possibly short-lived, the reason being that firms need to keep investing in high R&D to maintain an advantage over competitors. In other words, the pursuit of R&D investments is not only instrumental to keeping an edge on competitors but also to avoid falling behind, that is altogether another matter. Bronzini and Piselli (2016) show the usefulness of the incentives for smaller firms to increase patents, when generated by a R&D subsidy program implemented in Italy, but this comes at a high "funding" cost for the government.

Within the economics of innovation literature, the initial formulation of the Schumpeterian hypotheses in terms of the relationship between market power/structure (size) and innovation has seen a shift in more recent years. Other factors driving innovation such as technology opportunities, demand-pull, IPR (e.g. Levin et al., 1985; Nelson and Wolff, 1997; Breschi et al., 2000) have taken a more central stage. With the availability of data on IPR, the return on investment in R&D from both formal and informal IPR protection has been widely investigated (Hall and Sena, 2017; Hall, 2002; Hall et al., 2014, 2013a; Mohnen and Hall, 2013; Hall and Lerner, 2010; Hall et al., 2013b).

The literature has further delved into the exploration of the role of the IPR regime within MNEs' strategies (e.g. Globerman and Shapiro, 2002; Nandkumar and Srikanth, 2016; Santangelo et al., 2016; Zhao, 2006; Bruno et al., 2022) or have explicitly looked into the relationship between appropriability and firms performance and how the degree of appropriability might affect the return on R&D investment for firms that are more or less publicly supported (e.g. Ceccagnoli, 2009; Gelabert et al., 2009)

Hence, this paper contributes to the stream of research on the nexus between R&D and productivity spurred by the seminal contribution of, e.g., Griliches (1979), Cockburn and Griliches (1987) and it builds upon the the model specification adopted by Hall and Mairesse (1995) as we will discuss in Section 5.

3 A simplified Model

4 Data and measures

The empirical analysis relies on firm-level data. The dataset integrates information extracted from different sources. First, we considered the top 2,000 R&D spenders worldwide listed in the 2017 EU Industrial R&D Investment Scoreboard (SB) and COR&DIP. In addition to the value of R&D expenditures, information on the number of employees and sales values is obtained from this source. Time coverage has been extended using various editions of the SB database up to the year 2007.[3] To proxy firm-level productivity, we rely on value-added (VA) data extracted from the Moody's ORBIS database.[4] Unfortunately, the VA figure is missing for about 45% of the observed firm-year records, substantially reducing the number of firms available for estimation.[5] To mitigate this issue, we devise a strategy based on the imputation of VA value on the basis of the country / four-digit sector (NACE Rev. 2) / year ratio of VA to sales. We only imputed values to those firms where we deem the ratio is reliably identified.[6]

The value of tangible capital has also been extracted from ORBIS. The perpetual inventory method has been applied for the computation of R&D and capital stocks. For physical capital, we follow Gal (2013), whereas in the case of R&D we consider a 5% pre-sample growth rate and a rate of obsolescence of knowledge equal to 15%. Finally, firm-level values of R&D, capital and value-added are deflated using country-sectoral specific producer price indexes (PPI) of industrial production. In order to maximize country coverage we considered PPI from three different sources, namely the OECD-STAN database, Eurostat, and the Chinese Statistical Yearbook. Still, due to missing

[3] More than 75% of firms in the sample are continuously available over the observed time-span. In few cases, for those firms having discontinued information within the database, we used interpolation to impute missing values (39 values imputed in the case of R&D expenditures of 28 firms).

[4] At this stage, 2.11% observations have to be excluded from the analysis, because we were not able to link them with information from ORBIS.

[5] R&D values are not statistically significant in the two groups of observations defined on the basis of the observability of the VA figure.

[6] In particular, we did not consider ratios estimated on less than 5 observations, and with a coefficient of variation larger than 2. All in all, we imputed the VA figure to 557 firm-year observations.

information on PPI for countries outside these regions, the sample size is reduced.

In order to assess the impact of missing information on the analysis, we report estimates on the original data, imputed data, and deflated values.

Our interest is in the role of appropriability conditions as a moderator for the returns to R&D. To measure appropriability conditions at the firm level, we consider different proxies, as detailed in the following. The patent data necessary for the construction of this measure are drawn from ORBIS Intellectual Property.

Since the seminal work of Ginarte and Park (1997), various measures of the strength of IPR protection have been developed at the country level over time. Unfortunately, the Ginarte-Park index cannot be exploited in our application because it is only available up to the year 2005 (Park, 2008).

Rather, we rely on two alternative indicators, characterized by a different coverage, both over time and across countries.

First, we consider the index of IPR protection by Papageorgiadis and Sofka (2020). The Papageorgiadis and Sofka's (2020) indicator is now well known in the literature and is available in 51 countries (mostly developed countries) over a long time span (1988–2017). It ranges from 0 (no enforcement) to 10 (perfect enforcement).

We also consider the measure of intellectual property protection from the Economic Freedom Survey of the World Economic Forum, EFW (https://www.weforum.org/; scaled 1 to 7). The index is available for a wider set of countries (151, also covering developing countries) over a shorter time span (2007-2017).

Both indexes are available at the country level, and the correlation between the two measures is very high (0.95). In order to build a firm-level measure of IPR protection we follow Bruno et al. (2022) and measure appropriability as a weighted sum of the patent enforcement measures (PEI_{ct} and WEF_{ct}) in each country c at time t multiplied by the proportion of patents filed by the firm in that country, namely:[7]

$$Appr_{it} = \sum_c \frac{\#P_{ict}}{\#P_{it}} App_{ct} = \sum_c s_{ict} App_{ct} \tag{1}$$

where App_{ct} is the country measure of appropriability, respectively EFW and PEI, in country c at time t, $\#Pt_{ict}$ is the number of patents of firm i at time t granted in country c, and $\#Pt_{it}$ is the total number of patent of firm i at time t.

[7] The proposed measure of appropriability can only be computed for firms with patents. When a firm has no granted patent, we apply the index of protection of the country in which the headquarter of the firm is located.

As a result, $Appr_{it}$ is the weighted average of the IPR strength in the countries in which firm i chooses to protect its rights at time t. This may raise endogeneity concerns that will be addressed developing an exogenous measure of appropriability. In particular, the observed share in (1) are replaced by predicted ones from a (negative binomial) regression whose dependent variable is the number of patents by firm i at time t in patenting office c, as a function of firm's R&D, GDP in patenting country and the distance between firm i location and patenting office p:

$$Pt_{ipt} = f(\ln(RD_{it}), \ln(\bar{R}D)_i, \ln(GDP_{pt}), Dist_{ip}) \tag{2}$$

The regression also includes fixed effects for the country in which the firm is located, the country of the patent office, and time effects. Appropriability is therefore computed on the basis of the (exogenous) predicted rather than observed shares in (1):

$$\hat{A}_{it} = \sum_c \frac{\#\hat{P}t_{ict}}{\#\hat{P}t_{it}} App_{ct}$$

5 Empirical methods

Our focus is IPR as a potential moderator variable of the relationship between R&D and productivity. The baseline regression model builds on Hall and Mairesse (1995) that links firm-level productivity to capital and R&D investments (control variables omitted for simplicity):

$$\ln\left(\frac{VA_{it}}{L_{it}}\right) = \beta_1 \ln\left(\frac{K_{it}}{L_{it}}\right) + \beta_2 \ln\left(\frac{RD_{it}}{L_{it}}\right) + \beta_3 \ln(L_{it}) + \beta_4 Appr_i + \beta_5 \ln\left(\frac{RD_{it}}{L_{it}}\right) \times Appr_{it} + e_{it} \tag{3}$$

where the dependent variables is firm's i labour productivity at time t, defined as (log) value added (VA_{it}) over employment L_{it}; K_{it} is the physical capital stock, RD_{it} is the stock of R&D expenditure (both included in the equation in log and over employees, L_{it}). We are interested in understanding the role of R&D for productivity enhancements in countries with different degrees of IPR 'institutional' strength (i.e., different levels of appropriability of returns). The original specification is augmented including a proxy of appropriability at the firm level on the right-hand side, $Appr_{it}$, as well as its interaction with R&D in order to tease out the hypothesized moderation role (if any).

We explore the possibility of a non-linear relationship by specifying a quadratic equation, as well as by considering thresholds in terms of appropriability as defined by variables' quartiles. Namely, we estimate the following equations:

$$\begin{aligned}\ln\left(\frac{VA_{it}}{L_{it}}\right) &= \beta_1 + \beta_2 \ln\left(\frac{K_{it}}{L_{it}}\right) + \beta_3 \ln\left(\frac{RD_{it}}{L_{it}}\right) + \beta_4 \ln(L_{it}) \\ &+ \beta_5 App_{it} + \beta_6 App_{it} \times \ln\left(\frac{RD_{it}}{L_{it}}\right) \\ &+ \beta_7 App_{it}^2 + \beta_8 App_{it}^2 \times \ln\left(\frac{RD_{it}}{L_{it}}\right) + e_{it}\end{aligned} \tag{4}$$

measuring $Appr_{it}$ using both PEI and EFW, and

$$\begin{aligned}\ln\left(\frac{VA_{it}}{L_{it}}\right) &= \beta_1 \ln\left(\frac{K_{it}}{L_{it}}\right) + \beta_2 \ln\left(\frac{RD_{it}}{L_{it}}\right) + \beta_3 \ln(L_{it}) \\ &+ \beta_4 A_{(Q2.Q3),it} + \beta_5 A_{(Q2.Q3),it} \times \ln\left(\frac{RD_{it}}{L_{it}}\right) \\ &+ \beta_6 A_{(Q3+),it} + \beta_7 A_{(Q3+),it} \times \ln\left(\frac{RD_{it}}{L_{it}}\right) + \varepsilon_{it}\end{aligned} \tag{5}$$

in which classes are defined according to the main percentiles, namely the median $Q2$ and the third quartile $Q3$ ($A_{(Q2.Q3)}$ being those firms with a level of appropriability between the median and the third quartile, and $A_{(Q3+)}$ having a value of the index higher than the third quartile).

A fixed-effects model was selected due to concerns about unobserved heterogeneity potentially biasing the productivity estimates. Besides firms fixed effects α_i, all estimated equation includes time fixed effects, τ_t. The robustness of results is explored by including sector and regional time effects (sector dummies and region dummies interacted with τ_t), as well as by using country-sectoral specific producer price indexes (PPI) of industrial production to produce deflated values.

6 Estimation results

Before reporting the results of the regression analysis, Table 1 reports descriptive statistics of the variables over all available observations.

Results of the baseline estimation of (3) are reported in Table 2. The equation is estimated considering both the index of appropriability built on the basis of PEI and EFW. For each index, we report the results of the estimation on the original dataset (for short "orig."), on the extended dataset obtained by imputing some missing information on value added ("imputed"), and on deflated data ("imp. & defl."). The coefficient of

Table 1: Descriptive statistics

Variable	Mean	Std. Dev	Obs.
$\ln(VA_{it}/L_{it})$ (original)	10.64	1.921	8,021
$\ln(VA_{it}/L_{it})$ (imputed)	10.64	1.877	8,474
$\ln(VA_{it}/L_{it})$ (defl. & imputed)	6.200	1.664	6,606
$\ln(K_{it}/L_{it})$	10.72	2.450	14,545
$\ln(K_{it}/L_{it})$, deflated	6.269	2.325	12,323
$\ln(R\&D_{it}/L_{it})$	10.99	1.542	16,360
$\ln(R\&D_{it}/L_{it})$, imputed	6.544	1.516	14,074
$\ln(L_{it})$	8.847	1.879	16,827
$Appr_{it}$, PEI	6.515	1.236	15,817
$\hat{A}_{it}$, PEI	6.690	1.207	17,453
$\bar{A}_{it}^{00.06}$, PEI	7.076	1.446	19,958
$Appr_{it}$, EFW	4.926	0.6203	15,768
$\hat{A}_{it}$, EFW	5.003	0.5687	17,486

$\ln(L)$ is not statistically significant, supporting a constant return to scale hypothesis, and it is omitted in the latest specifications.[8]

The results in Table 2 show that the key variable measuring the input of innovation (R&D) and the scope of protection of the generated knowledge are positively related to labour productivity. However, the interaction term between R&D stock and appropriability is negative; it is also statistically significant when appropriability is measured according to EFW. Its interpretation from a globalization of innovation and knowledge perspective is particularly important. At the bottom of Table 2, we report the p-value for assessing the validity of the null hypothesis that appropriability has no effect on productivity (No app.).

Results when *Appr* is computed on the basis of EFW show that the positive relationship between R&D investment and productivity is negatively offset by the strength of firms' cross-border IP protection system. In other words, when firms offshore their research activities in countries with weaker IPR protection, their R&D expenditure has a stronger positive effect on productivity. When *Appr* is computed on the basis of PEI, estimated coefficients are coherent but appropriability lacks statistical significance. Given that the enterprises included in our data set are world top R&D investors, they could benefit from performing R&D activities in countries where their IP is less protected (e.g. Brazil or Indonesia; Papageorgiadis and Sofka, 2020) because they have access to smarter ways to protect their inventions, they have more sophisticated patents strategies

[8] For an explanation of such specification look at Hall and Mairesse (1995)

Table 2: Baseline model - regression results.

	PEI				*EFW*			
Variable	orig.	imputed	imp. & defl	imp. & defl	orig.	imputed	imp. & defl	imp. & defl
$\ln(K/L)$	$.533^{***}$	$.529^{***}$	$.551^{***}$	$.551^{***}$	$.531^{***}$	$.528^{***}$	$.552^{***}$	$.552^{***}$
	(.033)	*(.033)*	*(.035)*	*(.035)*	*(.033)*	*(.033)*	*(.035)*	*(.035)*
$\ln(RD/L)$	$.554^{***}$	$.505^{***}$	$.432^{*}$	$.452^{**}$	$.747^{***}$	$.701^{***}$	$.824^{***}$	$.852^{***}$
	(.201)	*(.195)*	*(.237)*	*(.214)*	*(.246)*	*(.236)*	*(.271)*	*(.250)*
$\ln(L)$	.110	.086	-.027		.095	.070	-.041	
	(.131)	*(.126)*	*(.120)*		*(.130)*	*(.126)*	*(.122)*	
App	.083	.047	.196	.195	.601	.550	$.814^{**}$	$.811^{**}$
	(.279)	*(.270)*	*(.215)*	*(.215)*	*(.492)*	*(.475)*	*(.339)*	*(.340)*
$\ln(RD/L) \times App$	-.007	-.003	-.029	-.028	-.049	-.045	$-.115^{**}$	$-.115^{**}$
	(.025)	*(.024)*	*(.031)*	*(.031)*	*(.044)*	*(.042)*	*(.049)*	*(.049)*
N	5781	6133	4954	5762	6133	7431	4953	4953
N. firms	1091	1129	924	924	1089	1127	925	925
No app.	.949	.949	.088	.654	.405	.448	.057	.059
Firm FE	yes	yes	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes	yes	yes
Sector × time FE	yes	yes	no	no	yes	yes	no	no
Region × time FE	yes	yes	no	no	yes	yes	no	no

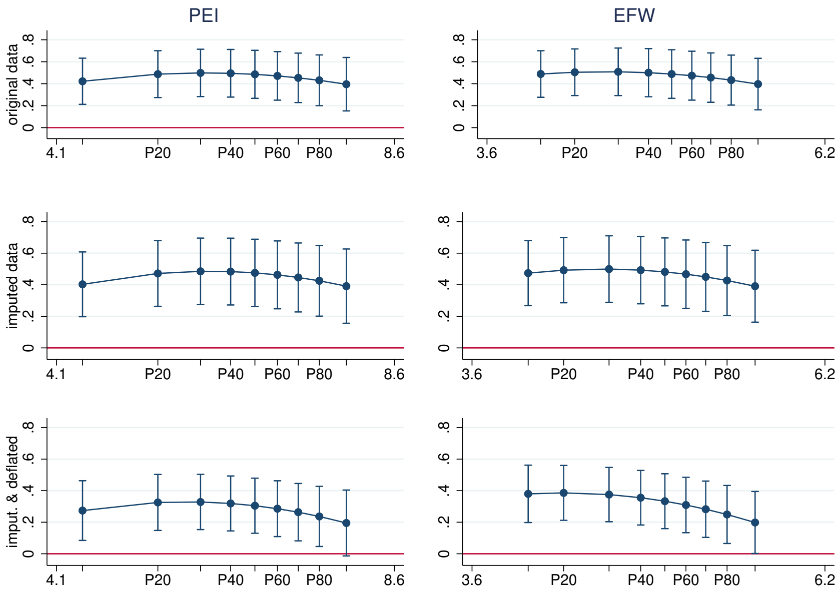

Figure 1: Average partial effect of R&D on productivity, as a function of the level of appropriability (PEI–left column; EFW–right column).

that cannot be replicated, and they are better positioned to hire the best local inventors (see Bruno et al., 2022).

Furthermore, the large investment in R&D can potentially substitute for locating their "knowledge generation" labs in relatively weaker cross-border institutional environments as far as intellectual property rights protection is concerned. Hence, they can still benefit in terms of productivity if the higher R&D "effort" counterbalances weaker IPR protection.

We further explore the nexus between appropriability and productivity by estimating the non-linear relationship (5). Estimated coefficients are omitted here to save space (see Appendix A). Rather, we show the results of this estimation in Figure 1, which shows the average partial effect of R&D on productivity for different levels of appropriability (represented on the x-axis; effects evaluated at the deciles of the distribution of each appropriability index: PEI–left column; EFW–right column).

Table 3 reports the p-values of the test comparing the effect of R&D at its median value ($P50$) with the percentiles considered to draw Figure 1. All in all, significant differences in the effects emerge for high values of R&D expenditure.

The result further confirms the existence of a moderator role of appropriability in

Table 3: Test for the difference in the effect of R&D at its median value ($P50$) as compared with the percentiles reported in Figure 1: p-value.

	PEI			EFW		
Null hp.	orig.	imputed	imp & defl.	orig.	imputed	imp & defl.
$P50 = P10$	0.187	0.111	0.544	0.998	0.865	0.414
$P50 = P20$	0.954	0.887	0.532	0.632	0.732	0.154
$P50 = P30$	0.490	0.587	0.243	0.260	0.294	0.030
$P50 = P40$	0.303	0.360	0.150	0.132	0.141	0.011
$P50 = P60$	0.158	0.182	0.086	0.062	0.060	0.005
$P50 = P70$	0.124	0.140	0.071	0.049	0.046	0.005
$P50 = P80$	0.099	0.110	0.061	0.041	0.037	0.004
$P50 = P90$	0.078	0.084	0.052	0.035	0.030	0.005
All equal	0.018	0.011	0.074	0.095	0.075	0.017

terms of the effect of R&D on productivity: higher levels of appropriability at the firm level are associated with a lower effect of R&D on productivity. Also, results are very similar when comparing the effect of PEI and EFW.

Interestingly, when deflated data are considered the overall effect of R&D expenditure turns out to be not statistically different from zero for a high level of appropriability.

As a further robustness check, in Table 4 we define appropriability using classes on the basis of main percentiles, namely the median $Q2$ and the third quartile $Q3$ as in equation (6). The results confirm the larger effect of R&D stock on productivity for firms operating within a relatively lower level of appropriability.

6.1 Endogeneity

The previous results could suffer from one potential limitation, as the patent enforcement index could be correlated with the error term in the estimated equations, as it implicitly includes information on the yearly location choices of each and every firm; in other words, location choices that are correlated with productivity levels.

In order to tackle this issue, we consider the strategy described in Section 5, and we replace the observed patent shares with predicted share estimated on the basis of exogenous variations.

Table 5 reports the results when firm-level appropriability is computed on the basis of predicted shares based on the results of the negative binomial regression 2, whose results are reported in Appendix B.

The mediating role of appropriability conditions on the R&D-productivity relation-

Table 4: Exploring non-linearities in the relationship between R&D, appropriability and productivity.

	PEI				EFW			
Variable	orig.	imputed	imp. & defl	imp. & defl	orig.	imputed	imp. & defl	imp. & defl
$\ln(K/L)$	.533***	.529***	.551***	.551***	.530***	.527***	.551***	.550***
	(.033)	*(.032)*	*(.035)*	*(.035)*	*(.033)*	*(.033)*	*(.035)*	*(.035)*
$\ln(RD/L)$	.540***	.512***	.299**	.326***	.538***	.510***	.317***	.335***
	(.153)	*(.149)*	*(.121)*	*(.087)*	*(.154)*	*(.150)*	*(.122)*	*(.088)*
$\ln(L)$	.100	.074	-.037		.098	.071	-.025	
	(.129)	*(.124)*	*(.118)*		*(.129)*	*(.125)*	*(.120)*	
$A_{(Q2.Q3)}$	.554	.556	.509	.508	.128	.063	.406	.406
	(.583)	*(.559)*	*(.358)*	*(.358)*	*(.538)*	*(.517)*	*(.288)*	*(.288)*
$A_{(Q3+)}$	1.17	1.10	.982**	.978**	1.14*	1.10*	1.06**	1.06**
	(.776)	*(.739)*	*(.458)*	*(.459)*	*(.631)*	*(.606)*	*(.416)*	*(.416)*
$A_{(Q2.Q3)} \times \ln(RD/L)$	-.042	-.043	-.062	-.062	-.003	.003	-.147**	-.147**
	(.052)	*(.050)*	*(.052)*	*(.052)*	*(.047)*	*(.045)*	*(.060)*	*(.060)*
$A_{(Q3+)} \times \ln(RD/L)$	-.102	-.094	-.139**	-.139**	-.095*	-.091*	-.147**	-.147**
	(.068)	*(.065)*	*(.067)*	*(.067)*	*(.055)*	*(.053)*	*(.060)*	*(.060)*
N	5781	6133	4954	4954	5762	6113	4953	4953
N. firms	1091	1129	924	924	1089	1127	953	953
H_0: No app.	.337	.350	.114	.116	.124	.101	.050	0.050
Firm FE	yes	yes	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes	yes	yes
Sector × time FE	yes	yes	no	no	yes	yes	no	no
Region × time FE	yes	yes	no	no	yes	yes	no	no

Table 5: Exogenous measure of appropriability, from the regression of patents granted to firm i in patent office p at time t.

	PEI				*EFW*			
Variable	orig.	imputed	imp. & defl	imp. & defl	orig.	imputed	imp. & defl	imp. & defl
$\ln(K/L)$	.515***	.514***	.572***	.572***	.515***	.514***	.572***	.573***
	(.031)	*(.031)*	*(.032)*	*(.032)*	*(.031)*	*(.031)*	*(.032)*	*(.032)*
$\ln(RD/L)$	.380***	.349***	.146*	.220***	.390***	.360***	.163*	.236***
	(.116)	*(.113)*	*(.087)*	*(.070)*	*(.116)*	*(.112)*	*(.088)*	*(.071)*
$\ln(L)$	-.045	-.080	-.117		-.057	-.088	-.114	
	(.104)	*(.100)*	*(.096)*		*(.104)*	*(.100)*	*(.096)*	
$\hat{A}_{Q2.Q3}$	-.290	-.258	.084	.069	.555	.491	.183	.175
	(.462)	*(.441)*	*(.263)*	*(.262)*	*(.462)*	*(.438)*	*(.258)*	*(.258)*
$\hat{A}_{Q3+}$	1.12	1.05	.916**	.908**	.988	.954	.857**	.880**
	(.787)	*(.763)*	*(.446)*	*(.446)*	*(.617)*	*(.592)*	*(.389)*	*(.389)*
$\hat{A}_{Q2.Q3} \times \ln(RD/L)$	.025	.023	-.007	.005	-.045	-.039	-.021	-.020
	(.041)	*(.039)*	*(.038)*	*(.038)*	*(.040)*	*(.038)*	*(.037)*	*(.037)*
$\hat{A}_{Q3+} \times \ln(RD/L)$	-.098	-.091	-.134**	-.132**	-.085	-.081	-.126**	-.125**
	(.068)	*(.066)*	*(.064)*	*(.064)*	*(.054)*	*(.051)*	*(.055)*	*(.055)*
N	6766	7149	5834	5834	6778	7161	5836	5836
N. firms	1150	1197	1020	1020	1151	1198	1020	1020
H_0: no appr.	.113	.135	.085	.085	.213	.22	.071	.074
Firm FE	yes	yes	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes	yes	yes
Sector × time FE	yes	yes	no	no	yes	yes	no	no
Region × time FE	yes	yes	no	no	yes	yes	no	no

ship is confirmed.

7 Discussion

In this paper, we have identified a complex empirical relationship between R&D and productivity, explicitly examining the role of appropriability conditions. Our results indicate that patent protection is beneficial for productivity when combined with R&D expenditures, supporting the dual (direct and indirect) role of R&D at the firm level (Cohen and Levinthal, 1989). However, we find significant non-linearities: excessive patent protection diminishes the productivity benefits of R&D.

We propose two potential channels to explain these findings. The first relates to spillover effects: stronger appropriability conditions reduce knowledge spillovers, potentially hindering productivity by limiting the firm's ability to benefit from competitors' research. Such productivity-enhancing spillovers have previously been documented at the national level (Peri, 2005) and within industry-specific contexts, such as pharmaceuticals (Henderson and Cockburn, 1996).

A second channel we consider is the differential effect of appropriability conditions on research versus development activities. According to Barge-Gil and López (2014), appropriability tends to incentivize development activities more strongly than fundamental research. Given that radical innovations, closely tied to basic research, can significantly boost productivity, overly strong appropriability may indirectly reduce productivity by disproportionately encouraging incremental development rather than pioneering research.

Our current dataset limits the ability to conclusively determine which of these channels dominates. Hence, future research employing more detailed measures of spillovers and distinguishing between research and development activities explicitly would offer valuable insights. Moreover, future studies could benefit from exploring how firm-specific capabilities, such as technological leadership, absorptive capacity, and managerial practices, might moderate these effects. Additionally, exploring the heterogeneous impact of appropriability across different industries or technological domains could yield further nuance to the productivity-IPR relationship identified here.

This study also has limitations that provide opportunities for future research. Our sample comprises top global R&D spenders, a selection driven by data availability constraints. Extending this analysis to include smaller, less globalized firms could test the external validity of our findings and potentially reveal contrasting patterns or additional nuances. Furthermore, the reliance on patent data, while advantageous for clearly identifying appropriability conditions, may inherently overlook non-patented innovations or innovations protected through informal mechanisms. While this concern is mitigated in our large-firm context, future research could integrate alternative appropriability metrics or qualitative assessments of intellectual property strategies to address these gaps comprehensively.

Finally, our results suggest pertinent policy implications. Policymakers aiming to stimulate productivity growth should balance IPR protection carefully, ensuring sufficient incentives for innovation without stifling knowledge diffusion and fundamental research activities. This nuanced approach to appropriability regulation could optimize the productivity outcomes of R&D investments in increasingly globalized innovation environments.

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A Quadratic regression: estimation results

In this Appendix, Table 6 reports the results of the estimation of model (5).

B Negative binomial regression: estimation results

The Appendix shows the results of the analysis employed to isolate the exogenous variability of the patent share in (1).

First we estimate the following gravity equation for P_{ict}, the number of patents granted to firm i in country c at time t:

$$\begin{aligned} Pt_{ict} &= f(\ln(RD)_{it}, \ln(\bar{R}D)_i, \ln(GDP)_{ct}, \ln(GDP)_{it}, \\ &\quad dist_{ic}, \alpha_c, D(cty_i), \tau_t) \end{aligned}$$

in which we include the GDP of country c where the patent is granted, and the GDP of country i where the company's headquarter is located (respectively $\ln(GDP)_{ct}$ and $\ln(GDP)_{it}$), as well as the distance between these two countries, $dist_{ic}$. The equation also includes the logarithm of the R&D investments of firm i, both time-varying, $\ln(RD)_{it}$, and the company-specific average, $\ln(\bar{R}D)_i$. Fixed effects for country c, country i, and time t are also included.

In order to take into account the overdispersion that caracterize patent data, the negative binomial model is considered for estimation. Results are reported in Table 7.

Coherently with what is expected in a gravity framework, the GDP of country c where protection is sought is positive and statistically different from zero, whereas the distance between country c and the location of company's headquarter has a negative effect on the number of patents. The coefficient of country i is positive, but not statistically different from zero. As expected, also the relationship between R&D expenditure and the number of patents is positive and statistically significant.

On the basis of the estimated model, the number of predicted patent $\#\hat{P}t_{ict}$ is obtained, and appropriability is computed on the basis of the (exogenous) predicted rather than observed shares:

$$\hat{A}_{it} = \sum_{c} \frac{\#\hat{P}t_{ict}}{\#\hat{P}t_{it}} App_{ct}$$

Table 6: Estimation results of quadratic model specification (5).

	PEI			EFW		
	orig.	imputed	imp & defl.	orig.	imputed	imp & defl.
$\ln(K/L)$	.5321***	.5282***	.5518***	.5298***	.5268***	.5509***
	(.0332)	*(.0327)*	*(.0355)*	*(.03321)*	*(.0328)*	*(.0354)*
$\ln(RD/L)$	-.561	-.595*	-.693	-1.163	-1.294	-1.398
	(.3597)	*(.3487)*	*(.4602)*	*(.968)*	*(.9345)*	*(1.117)*
App	-3.869***	-3.905***	-2.5**	-8.222*	-8.698**	-6.194**
	(1.366)	*(1.333)*	*(1.041)*	*(4.478)*	*(4.346)*	*(3.063)*
App^2	.3198***	.3192***	.2142**	.918*	.9607**	.7195**
	(.1198)	*(.1166)*	*(.08969)*	*(.4689)*	*(.4554)*	*(.3217)*
$\ln(RD/L) \times App$	.3484***	.351***	.3506**	.7396*	.7856**	.8317*
	(.1254)	*(.1215)*	*(.155)*	*(.4091)*	*(.3953)*	*(.4668)*
$\ln(RD/L) \times App^2$	-.02868***	-.02854***	-.03002**	-.08187*	-.08607**	-.09684**
	(.01086)	*(.0105)*	*(.01317)*	*(.04253)*	*(.04113)*	*(.04859)*
Constant	11.49***	11.86***	8.195***	18.05*	19.4*6 13.72*	
	(3.897)	*(3.806)*	*(3.032)*	*(10.52)*	*(10.2)*	*(7.242)*
N	5,776	6,128	4,941	5,757	6,108	4,940
N. firms	1,091	1,129	924	1,089	1,127	925
p-value for H_0						
$H_0 : \ln(RD/L) \times App = \ln(RD/L) \times App^2 = 0$:	.018	.011	.075	.095	.075	.018
H_0 : no App.	.066	.047	.174	.257	.227	.050
Firm FE	yes	yes	yes	yes	yes	yes
Time FE	yes	yes	yes	yes	yes	yes
Sector × time FE	yes	yes	no	yes	yes	no
Region × time FE	yes	yes	no	yes	yes	no

Table 7: Results of the negative binomial regression; dependent variable P_{ict}, number of patents granted to firm i in country c at time t.

Variable	Coeff.	Std. err.	p-value
$\log(RD)_{it}$	0.2309	0.0080	<0.001
$\overline{\log(RD)}_{i}$	0.6701	0.0083	<0.001
$\log(GDP)_{it}$	0.9797	0.0965	<0.001
$\log(GDP)_{ct}$	-0.1159	0.0766	0.130
Dist. (Km/1000)	-0.1648	0.0012	<0.001

FE for firm i country, patenting country c, and time included.