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Abstract

This paper analyses the causal impact of Intellectual Property Rights (IPR) on pharmaceutical innovation in a panel of 74 countries. The identification strategy exploits the different timing across countries of two sets of IPR reforms. Domestic innovation is measured as citation-weighted domestic patents filed at the European Patent Office (EPO): to account for their distribution, count data models are used. A Zero Inated Negative Binomial model is adopted to consider the choice not to patent at the EPO. Results show that, in the short-run, IPR stimulate innovation. The effect for developing countries is roughly half of that for developed countries.

JEL-Codes: O340, O310, I180, K110.

Keywords: intellectual property rights, developing countries, pharmaceutical sector, innovation, patents, TRIPS.

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1 Introduction

Over the last 30 years, an increasing number of countries at various stages of development have introduced or extended their national level of Intellectual Property Rights (IPR) protection. This trend saw the establishment of the Agreement on Trade-Related aspects of Intellectual Property rights (TRIPS) in 1995, when all WTO members were required, with different transitional periods depending on their level of development, to set down and implement minimum regulation standards for all industries. The agreement caused an intense debate, concerning whether IPR legislation, granting exclusive rights to inventors to enable them to recoup the costs of R&D investments, could stimulate enough innovation to justify the social welfare costs associated with monopoly pricing. The debate was particularly lively regarding the pharmaceutical sector. Developing countries were worried about higher drug prices associated with pharmaceutical patents, whereas developed countries pointed out the beneficial effects of such protection, claiming that the agreement would stimulate domestic innovation, research for tropical diseases, and technology transfer (Lanjouw, 1998).

This analysis focuses on an aspect of this debate, and in particular on whether pharmaceutical patent protection stimulates pharmaceutical domestic innovation in developed and developing countries. It is conducted on a panel of 74 countries, observed over the period 1977-1998. The different timing of reforms modifying patent protection across countries is exploited to identify the causal effect of protection, as in a Difference-in-Differences identification strategy.

Most empirical contributions study the impact of IPR by considering all industries together. As a consequence, their findings cannot be easily translated into policy recommendations since, as pointed out by Lo (2011), the effect of IPR may strongly vary across industries, depending on their peculiarities. For example, the pharmaceutical sector heavily relies on patents (in countries where these may be granted) to protect innovation, while the employment of trade secret protection or lead time advantages is limited (Nagaoka et al., 2010). The high R&D costs and the high uncertainty characterizing this sector may explain the strong recourse to patents. Indeed, as few as 1 or 2 out of 10,000 tested compounds end up as a marketable drug (Sloan and Hsieh, 2007; European Commission, 2009; Scherer,

2007), and the average cost for the discovery of a new molecule is estimated to be between 500 and 900 million US$ (DiMasi et al., 2003; Paul et al., 2010).[1]The R&D on sales ratio, equal to 18% (European Commission, 2009), is around seven times higher than in other manufacturing industries (Scherer, 2007).

Although the pharmaceutical sector is characterized by the aforementioned peculiarities, few contributions focus on it. Most of them analyse the reactions to specific changes in patent protection of a single country, raising doubts on the generalization of their findings (Branstetter et al., 2006). To the best of my knowledge, only two studies use panel data to estimate the effect of patent protection on pharmaceutical domestic innovation, and they yield contrasting results. In their working paper, Liu and La Croix (2014) find that patent protection has no effect, whereas Qian (2007) shows that patent protection alone does not stimulate domestic innovation, although the interaction of protection with the country's GDP per capita has a statistically significant impact. Differently from Qian (2007) contribution, this paper provides punctual estimates of the effect of patent protection for both developed and developing countries. In particular, my examination brings some evidence in favour of a positive effect of protection in both sets of countries although, for developing countries, this is roughly half in comparison with developed ones.

This contribution also provides novelties with respect to previous literature along three technical directions. First of all, instead of using a quinquennial index of IPR protection (as in Liu and La Croix, 2014), or to consider different policy interventions in this field (as in Qian, 2007), the effect of two homogeneous sets of IPR reforms are evaluated. The first set concerns reforms granting a level of patent protection comparable to the one set by the TRIPS Agreement, while the second one includes reforms granting a lower level of protection.

The second novelty concerns the use of applications filed at the European Patent Office (EPO)[2] to measure innovation. Patents of more than local relevance are assumed to be registered in the main markets of reference (Qian, 2007) but, al-

[1]These figures, reported by the Pharmaceutical Research and Manufacturers of America, are supposed by several organizations and various scholars, such as Light and Warburton (2005), to be inflated. For example Public Citizen (2001) estimated the cost to be between 71 and 150 million US$ per drug (including failures).

[2]See Appendix A for more details on the EPO.

though both the US and Europe represent the largest markets for pharmaceuticals, previous empirical literature has considered only patents filed at the United States Patent and Trademark Office (USPTO). This paper marks a departure, by considering patents filed at the EPO. These present a lower number of self-citations, since 95% of references to previous patents are added by the examiner instead of by the applicant (OECD, 2009): this makes EPO citations a more precise measure in retrieving patents' innovative value than USPTO citations.

The third novelty relates to the models used to perform the analysis. To account for the highly skewed distribution of patent applications, count data models are adopted. Besides an unconditional Negative Binomial (NB), an unconditional Zero Inflated Negative Binomial (ZINB) model is carried out. This model explains the high quantity of zeros characterizing the flow of yearly national applications by taking into account the two processes that can determine them: nature (the lack of innovative capabilities) and choice (the decision not to patent in Europe). Thus, differently from the NB model, it does not require the assumption that all innovations of more than local relevance are patented in the US and Europe.

Results show a high, positive and significant effect of TRIPS compliant protection on domestic innovation. However, this effect is not long-lasting, disappearing after 6 years. Also offering lower forms of patent protection has a positive effect, which is not statistically different from the one computed for TRIPS compliant protection: this suggests that domestic innovation is sensitive to IPR protection, but not to its degree. Importantly, my findings point out that developing countries profit significantly less than developed ones from all forms of protection. Results for the ZINB model also confirm previous literature assumption that all innovations of more than local relevance are patented in the main markets of reference, even when local protection is offered. Placebo estimations support the causal interpretation of the results.

2 Literature review

2.1 Theoretical literature

The role of patent protection and the optimal structure of patent system, in terms of patent length and breadth[3], have been extensively studied since the end of the '60s (Nordhaus, 1967; Scherer, 1972; Nordhaus, 1972). Subsequent literature has shown two different approaches. Some researchers, such as Gilbert and Shapiro (1990) and Klemperer (1990), assume that new innovations do not use previous ones as an input (inventions are considered as independent). In this case, the optimal patent structure has to address the trade-off between the dynamic benefits associated with more innovation, and the static costs caused by monopoly prices. Although studies suggest different combinations in terms of patent length and breadth, they unanimously demonstrate that a strengthening of protection promotes innovations (Arrow, 1962; Bessen and Maskin, 2009; Hall and Harhoff, 2012; Jaffe, 2000).

Other contributions instead consider that new discoveries are based on their predecessor or, in other words, *"stand on the shoulders of giants"* (Scotchmer, 1991). The optimal patent structure for cumulative innovations takes into account not only the incentive to innovate and the deadweight losses associated with monopoly power, but also (positive and negative) innovation externalities. While knowledge inbuilt in an early patent stimulates further inventions, subsequent activity may be affected by the concern with regard to infringing previous patents. Moreover, R&D incentives for basic research may be reduced because new inventions make previous ones obsolete. In this context, literature has found that optimal patent structure involves no protection (Scotchmer, 1996), or protection limited to larger innovations (O'Donoghue, 1998) for second generation products, or longer protection for early inventions (Green and Scotchmer, 1995; Chang, 1995. See Sena, 2004 for a more extensive review of this literature).[4]

[3]Patent breadth involves the extent of coverage (how many inventions can be included in the patent), the scope of patentable inventions (which inventions are patentable), protection from infringements and restrictions on patent rights.

[4]Slightly different conclusions are reached if the assumption of complementarity (innovators take different research lines) is considered (Bessen and Maskin, 2009).

2.2 Empirical literature[5]

Contributions studying the effect of IPR on domestic innovation have widely used patents, filed in a given Patent Office and assigned to the inventors' countries of residence, as a proxy for domestic innovation. When relying on patents filed in a given Patent Office, it is important to notice that changes in IPR in the inventors' country of residence may affect local inventors' propensity to innovate, while the propensity to patent is affected by changes in regulation in the country where the patent is filed. If the two countries coincide, as in Sakakibara and Branstetter (1999); Hall and Ziedonis (2001) and Yang (2008), it may be difficult to separate these two effects (Lo, 2011).

To test the effect of the 1982 US reform, which created a centralized appellate court, on both the propensity to patent and the propensity to innovate of US inventors, Kortum and Lerner (1999) develop an appealing model in which the number of patents filed in several countries (including the US) by foreign inventors is regressed on a set of dummies for destination and origin countries. While the dummy for the US being the destination country measures the propensity to patent and the possible *"friendly court effect"* arising from the reform, dummies for the origin countries measure their innovative potential. The authors conclude that the increase of patents filed in the US was not caused by an increased propensity to patent of US inventors but rather by a real innovation boost.

The positive effect of IPR on the propensity to innovate is corroborated by Lo (2011), who finds that the strength of patent owners' rights introduced in Taiwan in 1986 led to a long-lasting increase in the local propensity to innovate, measured both in terms of innovation input (R&D) and output (patents filed in the US).

The above mentioned studies evaluate reactions to specific changes in the IPR regime of a single country. However, doubts can arise concerning the generalization of these results (Branstetter et al., 2006). Moreover, as pointed out by Jaffe (2000), the analysis based on a single country makes it extremely difficult to identify the causal effect of IPR strengthening because of its interaction with many other variables. Cross-country studies overcome these difficulties, although they face another obstacle: the comparison of IPR regimes across countries. Protec-

[5]Table 7 and 8 in Appendix B resume each contribution reviewed below.

tion offered to patent owners indeed differed for various aspects, such as patent length and strength, and the enforcement of protection. Given this heterogeneity, many papers resort to the use of patent rights indexes, such as the one created by Ginarte and Park (1997), which takes into account: extent of coverage, membership in international patent agreements, restrictions on patent rights, enforcement mechanisms, and duration of protection. The main drawback of these indexes is that they are not constructed on yearly basis, but usually they are calculated over a five years period. An alternative to the use of an IPR index is represented by the identification of homogeneous reforms. Branstetter et al. (2006), for example, analyse the impact of a set of interventions extending patent rights along at least four of the following five aspects: range of patentable goods, effective scope and length of protection, level of enforcement, administration of the patent system. Interestingly, as in the Ginarte-Park index, no dimension concerning the effectiveness of enforcement is taken into account, given the difficulties to measure it.

Independently from the measure of IPR protection adopted, cross-countries studies, such as the ones of Kanwar and Evenson (2003) and Branstetter et al. (2006), find a positive relationship between IPR and R&D spending. The latter also detects a null effect on the propensity to patent, but a positive effect on US technology transfers to reforming countries. Sweet and Maggio (2015) highlight a positive impact of IPR on innovation, as measured through export sophistication, only for countries with an above average level of development and complexity; for developing countries, the effect is at best non-significant, and most often negative. The conclusion that the effect of the reforms depends on the level of economic and industrial development of the country is confirmed by Moser (2003), who shows how, in the 19th century, the presence of any form of protection had a strong effect in changing the direction of innovative activity (in terms of industries), but no effect on its overall level.

All the above-mentioned studies assume the level of IPR to be exogenously determined. Many contributions base this assumption on the strong influence the US exercised on other countries through the Special 301 List[6](Lo, 2011; Yang, 2008; Sakakibara and Branstetter, 1999; Kanwar and Evenson, 2003). Only Branstet-

[6]This list, drawn up annually by the USPTO, identifies countries which do not provide adequate and effective protection of IPR.

ter et al. (2006) find that being included in the list does not have a statistically significant power to explain the timing of domestic patent reforms, putting forward other motivations to sustain the exogeneity of protection: at the time of the interventions, countries were at different levels of industrial development, and an increase in innovation was not observed before the reforms. Other authors, such as Moser (2003) and Lerner (2000), explain the introduction of patent protection in the last century focusing on political systems, cultural factors and legal tradition, making protection exogenous in relationship to the level of innovation.

Few papers treat patent protection as endogenous. A significant contribution is found in Chen and Puttitanun (2005), who study the effect of IPR on domestic innovation in developing countries using a two-stages least squares procedure. Instruments used for IPR are: GDP per capita, GDP per capita squared, education, trade, economic freedom and WTO membership. Results from the first stage show the presence of a U-shaped relationship between IPR and economic development, as already pointed out by Maskus (2000); the second stage indicates a positive impact of IPR on innovation, with a more relevant effect in developing countries with a relatively higher level of economic development. A dummy variable indicating whether the change in patent legislation took place in the Paris Convention or TRIPS aftermath is used as an instrument for reforms taking place over the last 150 years by Lerner (2009). Results confirm a positive and significant relationship between strengthening of IPR and innovative activity, although this relationship becomes negative for countries with strong a pre-reform protection.

2.2.1 Pharmaceutical industry

Results presented so far are not easily translated into policy recommendations since IPR have different effects in relationship to the industry (Lo, 2011). Concerning the pharmaceutical sector, contributions find contrasting results.

Single-country studies focusing on Italy and Korea show a negative effect of pharmaceutical patent protection. In particular, Challu (1995) shows that the 1977 Italian reform caused a decline in the number of new drugs developed in Italy, while it had a null effect on R&D spending, probably because of the strict price control imposed on the industry (Scherer and Weisburst, 1995). The number

of US patents granted to Italian firms rose, but this was caused by an increase in the propensity to patent, connected to the US patent reform, rather than in the propensity to innovate. Concerning Korea, La Croix and Kawaura (1996) find that the 1986 reform, urged by the US, did not increase the expected market value of domestic firms. At the opposite, Kawaura and La Croix (1995) discover an increase in the rate of return on domestic firms' equity in Japan in 1976, when the Japanese reform was introduced.[7] The authors conclude that the government only revised its patent law when domestic producers would profit from the reform. A positive and significant effect of IPR is also found by Pazderka (1999) and McFetridge (1997) while investigating the impact of the 1987 Canadian reform on domestic pharmaceutical R&D expenditures. However, several doubts may arise concerning these results, since the government and pharmaceutical firms previously agreed to increase R&D investments in case of tighter patent protection.

Cross-country studies only include few contributions. To obtain a uniform measure of protection, Liu and La Croix (2014) create the Pharmaceutical Innovation Patent Protection (PIPP) index, which aggregates information about: the range of protected pharmaceutical innovations; restrictions on pharmaceutical patent rights; the country's participation in international agreements dealing with pharmaceutical protection. Like the Ginarte-Park's, this index is computed every five years and takes into account law provisions- not necessarily actually enforced. Protection is modelled as an endogenous regressor, and the index is instrumented by the country presence in the US Special 301 List. Results from the first stage are supportive of the proposed instrument, showing a positive (negative) relevance of the List in explaining pharmaceutical patent protection for developing (developed) countries, while results from the second stage point out that protection does not affect domestic innovation.[8] Instead, the size of the population has a positive effect, while GDP per capita is significant only for developing countries and human capital and the degree of openness of the economy are never significant.

Qian (2007) studies the effect of amendments introducing patent protection for pharmaceutical products. She applies a matching method to control for ob-

[7]The rate of return increased one month before the bill was finally approved, suggesting an anticipation effect.

[8]Also the interactions of the PIPP Index with GDP per capita, or the degree of openness, are not significant, while the interaction with education is significant only for developed countries.

servables, while fixed-effect regressions on matched country pairs control for unobserved country characteristics. Results show that protection do not affect domestic innovation (measured as citation-weighted US pharmaceutical patent awards in the forward three to ten years), although it has a positive and significant effect conditional on the country's level of economic development. However, the effect of protection is negative when interacted with the level of patent strength, showing an inverted U-shaped relation between patent strength and innovation, as pointed out also by Lerner (2009). Applying the same methodology, Qian (2010) finds that pharmaceutical import increases after the amendments: foreign producers are indeed more willing to sell their products in countries where imitation is forbidden. Instead, differently from the predictions of the North-South product cycle model developed by Branstetter and Saggi (2011), FDIs seem to increase following a strengthening of protection only conditional on economic freedom, or educational attainment.

3 Definitions and measurement

3.1 Domestic innovation

Two proxies for domestic innovation have been used in previous literature: R&D expenditure and patenting activity. Empirical evidence demonstrates a high correlation between the two proxies, both at corporate (Pakes and Griliches, 1980; Trajtenberg, 1990) and at country level (De Rassenfosse and Van Pottelsberghe de la Potterie, 2009), and the assumption that patents reflect innovative activity has been validated in a number of studies (see Nagaoka et al., 2010 for an extensive review). Patent data present the advantages to be listed administratively and to be available for many countries, but also the disadvantages, pointed out by Pakes and Griliches (1980), that not all innovations are patented, and that patents differ in their economic impact.

Concerning the objections of Pakes and Griliches (1980), it is worth noting that the pharmaceutical sector is characterized by an extremely high propensity to patent (Nagaoka et al., 2010). The strategy followed by the pharmaceutical companies is to file patents from the very beginning of the discovery process. This

can lead to file also less useful patents, resulting in as much as 63% of drug patents not used in practice (Nagaoka et al., 2010). To better assess their real innovative value, patents can be weighted through different variables:[9] among these, citations are usually preferred because they precisely assess patent's technological importance (Harhoff et al., 2003; Trajtenberg, 1990; Gambardella et al., 2008). In this contribution, a concave weighting scheme is adopted (as in Qian, 2007)[10] and each patent i is weighted according to the formula: $weighted\ patent_i = (1 + cit_i)^{0.6}$. To obtain a homogeneous measure of patents' value (Hall et al., 2001), citations received in a span of six years are considered: in this period of time more than 50% of citations received in the patent's life usually occur.[11] Citations can also be received by patent applications: it is therefore possible to usefully increase the sample size by considering both grants and applications without damaging the accuracy of the innovation measurement.

While the presence of IPR protection may have an immediate effect on R&D, some time is needed for innovation input to transform in innovation output. Although patents are filed throughout the entire life cycle of a medicine, most applications are filed at the end of the basic research phase (during the lead identification/optimisation process): at the EPO, 84% of applications filed by the largest companies active in the EU market are filed at this time (European Commission, 2009). Thus, the time lag between the beginning of R&D and patents priority date (the first date of filing of an application, anywhere in the world) usually lasts at least the time of basic research, which is on average of three years (Schweitzer, 2006). Therefore $innovation_{c;t}$, domestic innovation taking place at time t in country c, can be measured as the number of citation-weighted patent applications filed at time $t+3$[12] by inventors whose country of residence is country c. Since the order in which inventors' names are listed does not give details concerning the effective

[9] Among these: opposition and litigation information, family size, renewal period, number of claims, number of IPC subclasses, number of citations received (Trajtenberg, 1990).

[10] An example of a convex weighting scheme can be found in Trajtenberg (1990). For a positive number of citation, the convex weighting scheme attributes a higher relevance to forward citations than the concave weighting scheme.

[11] For the same reason, a span of five years has been considered by Nagaoka et al. (2010). Moreover, as pointed out by Lanjouw and Schankerman (1998), this time period is sufficient to construct meaningful measures of a patent's value based on forward citations.

[12] Another contribution using a forward dependent variable is Qian (2007).

contribution of each of them, in this paper patents are attributed to all inventors, following a fractional counting (as suggested in OECD, 2009).

The choice of the jurisdictions where to file an application[13] is determined by commercial strategies, and usually applications are first filed in all the countries that are well-developed and highly profitable export markets, *"regardless of the innovator's domestic patent legislation conditions"* (Qian, 2007). Since North America and Europe represent the majority of world's pharmaceutical sales, applications filed at the USPTO or at the EPO should be taken into account. Forward citations are usually computed within the patent office considered (Harhoff and Reitzig, 2004). At the EPO, about 95% of citations are added by the examiner (OECD, 2009): the use of EPO data grants therefore a higher degree of precision with respect to the USPTO data when patents are weighted by forward citations.

To identify pharmaceutical patents, the International Patent Classification (IPC) codes have been used. In particular, patents classified by the examiner as A61K or A61P have been considered,[14] in accordance with the 2013 WIPO Technology Concordance Table, also adopted by the OECD.

3.2 IPR protection

Before the standardization imposed by the TRIPS Agreement, the level of protection for pharmaceuticals was highly heterogeneous. For sake of homogeneity, in this analysis protection is divided in two categories: protection respecting at least TRIPS requirements, and other forms of lower protection. The main features of TRIPS standards, presented in detail in Appendix C, relate to the subject matter to be protected, the rights to be conferred, permissible exceptions to those rights, and the minimum duration of protection (Jaffe, 2000). For the pharmaceutical sector this translates in: product and process protection; the exclusive right to make, use, offer for sale, sell, and import for these purposes the product, independently from its place of production (with the exceptions due to compulsory licenses, parallel imports and the "Bolar" provision); a patent duration of 20 years. Importantly,

[13]With the exception of the first year following the priority date, in which it is protected worldwide, a patent is valid and enforceable only in countries where it has been granted.

[14]The two classes includes "preparations for medical, dental, or toilet purposes" and "therapeutic activity of chemical compounds or medicinal preparations" respectively.

some countries respected these standards even before the TRIPS Agreement.

4 Data

The sample is composed of 74 countries (see list in Appendix D), of which 25 are developed ones (according to the IMF classification).

Patent data are drawn from the Bocconi University Center for Research on Innovation, Organization and Strategy (CRIOS) database. This covers the period 1977-2008 but, because of the delay of data recording in patent databases, 2001 is the latest year for which information is nearly fully available, including citations received in the following six years. Weighted patents present a high level of overdispersion and a highly skewed distribution (see Table 1). Indeed, only 64 countries included in the sample exhibited some propensity to patent in Europe, as shown by a non-zero sum of EPO applications filed over the period, and 51% of country-year observations (43% if we consider only the above mentioned 64 countries) are zero.

GDP, constant 2000 US$, the rate of school enrolment in tertiary education and country's population data come from the World Bank Indicators.[15] The economic freedom index is developed by the Fraser Institute by taking into account a number of government policies and openness factors. It ranges from 0 to 10, with a higher index indicating a higher level of economic freedom.[16] The last variable presented in Table 1 refers to the value, in thousand US$, of domestic export of medicinal and pharmaceutical products towards Europe (EU27) in 1995, the first year for which UNCTADSTAT data are available.[17]

The dataset regarding domestic reforms introducing or modifying IPR protection in the period under analysis has been self-constructed, by cross-referencing several sources, such as previous contributions and intellectual property laws, mainly drawn from the WIPO Lex database. For each country, information re-

[15] In these Indicators, Taiwan is not listed as a separate country: data for China are therefore used. Missing values for GDP and education have been interpolated using data from 1977 to 2007, while those at the beginning of the period have been replaced by the first available value.

[16] Since the index is calculated over a five years period, values for the last year of the quinquennial have been carried back for previous years.

[17] In 7 countries the 1995 value is missing, and it has been replaced by the first available value.

Table 1: Summary statistics (74 countries; 22 years).

Variable	Mean	Std. Dev.	Min.	Max.	Obs.
annual weighted patents[a]	170.6	827.1	0	11,218.5	1,628
rate of school enrolment in tertiary educ.[b]	18.8	16.4	0.2	97.1	1,628
population[b,c]	68.2	200.1	0.6	1,241.9	1,628
GDP, constant US$[b,c]	279,620.5	901,736.1	308.4	9,061,073	1,628
economic freedom index[d]	5.9	1.3	2	8.7	1,628
pharmaceutical export, US$ (in 1995)[e,f]	411,036.0	1,071,735.3	0.9	5,182,633	74

Sources: [a]CRIOS database; [b]World Bank Indicators; [d]Fraser Institute; [e] UNCTADSTAT.
Units of measurement: [c] Millions.[f] Thousands.
Period: 1977-1998; 1980-2001 for patents (which measure innovation taking place in the period 1977-1998).

Table 2: Years of introduction of TRIPS compliant patent protection.

'77 or before	'78-'79	'80-'89	'90-'94		'94-'98
Germany	France	Austria	Australia	Lithuania	Brazil
Kenya[a]	Italy	Denmark	Bolivia	Mexico	Finland
Uganda[a]	Sweden		Bulgaria	Norway	Mongolia
UK	Switzerland		Canada	Peru	Panama
			Colombia	Poland	Philippines
			Czech Republic	Portugal	South Africa
			Ecuador	Slovakia	
			Estonia	Slovenia	
			Greece	Spain	
			Hungary	Taiwan	
			Ireland	US	
			Japan	Venezuela	
			Latvia		

[a]Kenya and Uganda abolished the protection in 1990 and 1991 respectively, and never introduced it again in the period under analysis.

garding the years of introduction of TRIPS compliant (or higher) protection and other forms of lower protection (such as process, or product protection not fulfilling TRIPS standards) has been extracted. Out of the 74 countries included in the sample, 37 introduced TRIPS compliant protection during the period under analysis (see Table 2); 4 countries, instead, already offered this protection in 1977, although two of them, Kenya and Uganda, abolished it later on.

5 Empirical model

To account for the highly skewed, non-negative distribution of patents, and for the high number of zero observations, count data models are adopted.[18] In particular, a Negative Binomial (NB) model is used, given the overdispersion of patents data.[19]

I hypothesize that domestic innovation is an exponential function of patent protection and other country time dependent characteristics ($x_{c,t}$), as well as of country (γ_c) and year (λ_t) fixed effects:

$$E[y_{c,t}|x_{c,t}, \gamma_c, \lambda_t] = \mu_{c,t} = exp(\beta x_{c,t} + \gamma_c + \lambda_t) \tag{1}$$

and that the variance of y is increasing with the conditional mean μ:

$$Var(y_{c,t}|\mu_{c,t}, \alpha) = \mu_{c,t}(1 + \alpha\mu_{c,t}),^{20} \tag{2}$$

where α is a constant over-dispersion parameter.

The identification strategy exploits the different timing of the two sets of IPR reforms across countries to estimate the causal effect of patent protection, controlling for unobservable characteristics. This closely resembles the logic behind a Difference-in-Differences strategy, although the model is non-linear. To estimate the model, an unconditional likelihood method (Allison and Waterman, 2002) is adopted.[21]

Country time dependent characteristics ($x_{c,t}$) included in the model are:

- $TRIPS\,protection_{c;t}$, a dummy variable defined to be unity for countries and

[18] To account for the positive distribution of patents, several contributions resort to log-linear models. Here, a small positive number has to be added to the patent count when this is null. This number is arbitrary and small differences can seriously affect the result (Flowerdew and Aitkin, 1982). The transformation also makes the coefficients interpretation non obvious, since $E(y|x)$ has to be recovered from a linear model for $E[log(1+y)|x]$ (Wooldridge, 2002, page 645).

[19] Also a quasi-maximum likelihood Poisson (QMLP) model could be applied. However, given the higher efficiency of the NB model (Verbeek, 2004, page 217), the latter is applied, while results for the QMLP are presented in Appendix G.

[20] A NB2 is preferred to a NB1 model (characterized by a linear relationship between the mean and the variance) since it is robust to distributional misspecification (Verbeek, 2004, page 217).

[21] This is preferred to the conditional method (Hausman et al., 1984) since the latter, based on a decomposition of the overdispersion parameter (rather than the decomposition of the mean, as in conditional fixed effects linear models) does not control for all time-invariant covariates.

time periods subject to a level of protection that is at least TRIPS compliant;

- $lower\,protection_{c;t}$, a dummy variable defined to be unity for countries and time periods subject to a lower form of protection. This variable is mutually exclusive with TRIPS protection;
- $GDP\,(log)_{c;t}$, to proxy economic development;
- $economic\,freedom_{c;t}$, to proxy the ease of business development;
- $school\,enrolment_{c;t}$, to proxy the stock of human capital[22];
- $population\,(log)_{c;t}$, to control for scale effects;
- $nepolaws_t$, the number of European Patent Organisation members where the application can be filed, providing TRIPS compliant protection. It is reasonable to assume that this number positively affects the number of applications filed at the EPO, influencing the propensity to patent;
- $epo_{c;t}$, a dummy variable for the membership in the European Patent Organisation. It is reasonable to assume that members have a higher propensity to patent at the EPO.

NB models require the count for an individual to be non-zero in at least one period. Moreover, they assume that zero and positive values come from the same data-generating process. Thus, a null flow of yearly national applications towards Europe is seen as a consequence of low innovative capabilities, relying on the assumption, common in empirical literature (Qian, 2007), that all innovations of more than local significance are patented in the main markers of reference. Zero Inflated Negative Binomial (ZINB) models overcome these limits, modelling the two possible processes determining a zero outcome (Lambert, 1992): choice (the decision not to patent in Europe) and nature (the lack of innovative capabilities) (Winkelmann, 2008). Domestic innovation (y) is therefore modelled as:

[22]To proxy human capital, the rate of enrolment in tertiary education has to be preferred to the primary school enrolment rate or to the literacy rate (Kanwar and Evenson, 2003).

$$y = \begin{cases} 0, & \text{if } d = 1 \\ y*, & \text{if } d = 0 \end{cases} \tag{3}$$

where:

- d is a binary variable representing the decision not to patent in Europe. If $d = 1$, the outcome is a "certain zero";
- $y*$ is an overdispersed count variable, representing the number of citation-weighted applications filed at the EPO. When $y* = 0$, zeros in the outcome are due to nature.

If we define $f_1(.)$ as the density of the binary process and $f_2(.)$ as the count density, the model taking into account both choice and nature processes has a density:

$$f(y) = \begin{cases} f_1(d=0) + [1 - f_1(d=0)]f_2(y) & \text{if } y{=}0 \\ [1 - f_1(d=0)]f_2(y) & \text{if } y \geq 1. \end{cases} \tag{4}$$

Zero Inflated models have two parts, which are estimated simultaneously: a probit or logit model, to estimate the probability to be in the "certain zero" case, and a count NB or Poisson model, explaining the determinants of domestic innovation for countries not included in the "certain zero" group. The expected level of domestic innovation is expressed as a combination of the two processes.

Results for unconditional NB and ZINB models are presented in the next section. Since the Wooldridge test for autocorrelation in panel data indicates the presence of serial correlation, cluster standard errors at the country level are used (Stock and Watson, 2008).[23] The use of robust (or cluster) errors also represents an effective way to solve the downward bias in standard error due to the adoption of an unconditional model (Allison and Waterman, 2002).

[23]Cluster standard errors are used by Branstetter et al. (2006) and Qian (2007), while Chen and Puttitanun (2005) use robust errors since performed tests do not indicate any correlation.

6 Results

Table 3 presents the main results, estimated through an unconditional NB[24] and a ZINB model (Column 1 and 2, respectively). As shown in Column (1), both forms of protection have a positive effect on domestic innovation. A test on the coefficients for "$TRIPS\,protection$" and "$lower\,protection$" also points out that these are not statistically different, suggesting that innovation is sensitive to patent protection but not to its degree, at least in the range of protection taken into account. TRIPS compliant protection is responsible, in developed countries, for an increase in weighted patent applications of $exp(0.487) - 1 \approx 1.63 - 1 = 63\%$, ceteris paribus.[25] For poor countries, the effect reduces by 46% ($= exp(-0.617) - 1 \approx 0.54 - 1 = -46\%$), being therefore equal to 0.63+(-0.46*0.63)=34%.[26] This difference confirms Chen and Puttitanun (2005) and Qian (2007) conclusion that the effect of protection increases with the level of development of the country.

The positive impact of domestic IPR protection on innovation can be explained by the defensive role played by patents in the pharmaceutical sector. In this sector, patents are filed at the early stage of the research process, and the propensity to patent is very high, causing patenting costs to be a remarkable expenditure for the inventors. Thanks to the knowledge of the language, of domestic institutions and of the patenting system, the possibility to file the applications in the home country allows to reduce patenting costs, as well as the time needed to file the application (giving origin to what is defined by Dernis et al., 2001 as the *"home advantage"*). The reduction in costs provided by domestic protection increases the opportunities for local inventors to protect their inventions (starting from the priority date, the patent is protected worldwide for one year), stimulating domestic innovation.

At the time IPR protection was introduced, many developing countries were characterized by a lack of innovative potential that limited the benefit they get from protection. Many of them were also characterized by a strong propensity towards imitation:through imitation, they were able to innovate (Bessen and Maskin, 2009).

[24]The NB model may be estimated only over the 64 countries having a positive number of applications over at least one year.

[25]More details on coefficients interpretation in non-liner models are provided in Appendix E.

[26]Just to give an idea, if Argentina would have implemented TRIPS compliant protection in 1997, it would have reached the level of innovativeness of Brazil of that year, ceteris paribus. Similarly, in 1990, Spain would have reached the level of innovativeness of Australia.

Preventing this opportunity, the introduction of IPR may have reduced the growth in the domestic level of innovativeness. Concerning bureaucratic factors, the low level of enforcement (Levitsky and Murillo, 2009) and the underdevelopment of information and communication technologies, that makes more difficult for foreign offices to conduct searches on previous patents registered in (some) developing countries, reduce the effectiveness of protection, making it less able to stimulate domestic innovation.

Other variables affect domestic innovation. In particular, a 1% rise in GDP is associated with a 1.5% increase in weighted patents, while a 1 unit rise in the economic freedom index provokes an increment of 20%, confirming the importance of development and economic freedom in stimulating innovation. The presence of scale effects is instead demonstrated by the increase of 2.6% in weighted patents due to a 1% rise in the population. The rate of school enrolment in tertiary education on the other hand has no effect on domestic innovation, possibly because of the time lag with which this affects available human capital.

To control for changes in the propensity to patent, the variables *nepolaws* and *epo* have been included in the model. Results show that European Patent Organisation members have a higher propensity to patent in Europe: ceteris paribus, the membership to the Organisation is associated with an increase of 43% in the number of weighted patents filed at the EPO. Moreover, if the number of countries where the patent can be granted after EPO examination procedures increases by one unit, the propensity to patent at the EPO increases by 7%.

In the ZINB model (Column 2), the decision not to patent in Europe is modelled, through a logit, by the distance between the country capital and Munich, chosen as point of reference for its central position in Europe (CEPII data), by the value of pharmaceutical export towards Europe in 1995, by the presence in the country of origin of patent protection, and by the number of European Patent Organisation members where the application can be filed.[27] Results show that countries with a higher level of export towards Europe have more interest to patent in this region, having a lower probability to be found in the "certain zero" group (as pointed out by the negative coefficient for *pharmaceutical export*). This find-

[27]Both distance and export are supposed to influence also the number of patents filed at the EPO but, being time invariant, cannot be included in the NB part of the model with fixed effects.

Table 3: Results.

	(1) NB *innovation*	(2) ZINB *innovation*
TRIPS protection	0.487***	0.430***
	(0.157)	(0.150)
lower protection	0.564***	0.504***
	(0.177)	(0.167)
TRIPS protection poor countries	-0.617**	-0.645***
	(0.290)	(0.217)
lower protection poor countries	-0.749**	-0.844***
	(0.313)	(0.281)
GDP (log)	1.488***	1.646***
	(0.411)	(0.393)
economic freedom	0.183**	0.197***
	(0.080)	(0.076)
school enrolment	0.005	0.005
	(0.005)	(0.005)
population (log)	2.587**	2.550**
	(1.300)	(1.239)
epo	0.356**	0.363***
	(0.144)	(0.141)
nepolaws	0.064	-0.0784
	(0.028)	(0.0772)
constant	-82.95***	-83.50***
	(19.40)	(15.69)
FIRST STAGE: LOGIT		
pharmaceutical export (log)		-1.321***
		(0.299)
nepolaws		-0.123
		(0.100)
TRIPS protection		-2.014***
		(0.470)
lower protection		-25.08***
		(2.327)
distance (log)		-2.585***
		(0.717)
constant		31.61***
		(8.331)
alpha	0.067***	0.061***
	(0.025)	(0.021)
Observations	1,408	1,628

Clustered SE in parenthesis. Countries and Time (unconditional) fixed effects included. In the ZINB model the likelihood function is maximized using the Broyden-Fletcher-Goldfarb-Shanno (BFGS) algorithm.

ing confirms previous literature assumption that inventions are patented in the main markets of reference. Given the same level of export, a more distant country shows a higher commercial interest towards Europe than a closer country, for which Europe may represent a "natural" export market because of proximity. This consideration explains the lower probability that more distant countries have to be in the "certain zero" group once controlled for the level of export. Controlling for patent protection in the home country allows the verification of whether inventors change their patenting strategies when they have the opportunity to patent at home. The results show that the presence of domestic protection does not negatively affect the decision to patent in Europe, but rather increases the probability to file an application at the EPO. Indeed, thanks to domestic protection, countries develop their innovative capabilities (as shown by the results of the second stage) and therefore have greater opportunities to develop relevant innovations. The number of European Patent Organisation members instead does not affect the decision to file an application at the EPO.

For developed countries not in the "certain zero" group, the presence of TRIPS compliant protection emerges responsible for an increase in weighted patents of 54%. For poor countries the impact reduces by 48%, being therefore equal to 28%.[28] As in the NB model, the effect of the two forms of protection is not statistically different, neither for developed nor for developing countries.

The ZINB is preferable to the NB model, as pointed out by its smaller residuals (see Appendix F). However, the ZINB model presents some computational challenges that make it difficult to be implemented when the specification includes several covariates. Thus, since the hypothesis that major innovations are patented in the main markets of reference is confirmed, and results for the two models go in the same direction, pointing out a positive effect of both forms of IPR protection on domestic innovation for both developed and developing countries,[29] in next sections the less demanding NB model is adopted.

[28] If we exclude from the analysis the 10 countries having a null number of applications all over the period, the results for the logit part slightly change, while those for the count do not.

[29] For each form of protection, the NB and ZINB estimates are statistically different for developed countries, while the null hypothesis of equality cannot be rejected for developing ones.

6.1 Dynamic model

Model specifications presented so far impose the assumption of a constant response to the reforms. In this section, a dynamic model[30] is presented to verify if the effect of TRIPS compliant protection changes over time. This specification embeds dummy variables for the year of introduction of the protection, for the first year after the introduction, for the second year after the introduction, and so on until the seventh year. To model the entire response function, tracing out the full adjustment path of domestic innovation to the reforms, a variable for all the years after the seventh has also been incorporated.[31]

The results, presented in Table 4, suggest that protection stimulates domestic innovation not only in the very short, but also in the medium run, with the effect being positive for both developed and developing countries over the first 6 years. After this period, it is difficult to detect any effect. Results are not sensitive to the specific modelling of the dynamic effect.

6.2 Stock of knowledge

Malerba and Orsenigo (2002) and Galasso and Schankerman (2013) point out that the pharmaceutical sector is characterized mainly by independent innovations, justifying model specifications adopted up to this point. If innovations are instead assumed to be cumulative, internal and external stocks of knowledge should be included in the model. Following the perpetual inventory method (Hall and Mairesse, 1995; Mancusi, 2008; Verdolini and Galeotti, 2011), the internal stock of knowledge is computed as the sum of new pharmaceutical innovations developed by country c in year t plus the country's stock in the previous year, discounted by a factor δ:

$$stock\_int_{c,t} = innovation_{c,t} + (1-\delta) stock\_int_{c,t-1}. \tag{5}$$

The initial value of the stock ($stock\_int_{c,t_0}$) is calculated as follows:

$$stock\_int_{c,t_0} = \frac{innovation_{c,t_0}}{g+\delta} \tag{6}$$

[30] The model is defined as dynamic following the approach of Halla (2013).

[31] Only five developing countries had been offering the protection for more than 7 years.

Table 4: Dynamic model.

	NB *innovation*
TRIPS protection (year of introduction)	0.453**
	(0.184)
TRIPS protection (first year after introduction)	0.434***
	(0.156)
TRIPS protection (second year after introduction)	0.377**
	(0.184)
TRIPS protection (third year after introduction)	0.481**
	(0.190)
TRIPS protection (fourth year after introduction)	0.441**
	(0.185)
TRIPS protection (fifth year after introduction)	0.438**
	(0.218)
TRIPS protection (sixth year after introduction)	0.394*
	(0.229)
TRIPS protection (seventh year after introduction)	0.352
	(0.260)
TRIPS protection (more than 7 years after introduction)	0.265
	(0.297)
TRIPS protection (year of introduction) poor	-0.600*
	(0.339)
TRIPS protection (first year after introduction) poor	-1.112**
	(0.468)
TRIPS protection (second year after introduction) poor	-0.557**
	(0.241)
TRIPS protection (third year after introduction) poor	-0.702***
	(0.217)
TRIPS protection (fourth year after introduction) poor	-0.197
	(0.545)
TRIPS protection (fifth year after introduction) poor	-0.618
	(0.497)
TRIPS protection (sixth year after introduction) poor	-1.205***
	(0.329)
TRIPS protection (seventh year after introduction) poor	-1.034***
	(0.372)
TRIPS protection (more than 7 years after introduction) poor	-21.058**
	(0.852)
lower protection	0.551***
	(0.183)
lower protection poor	-0.855***
	(0.315)
constant	-78.502***
	(22.950)
alpha	0.064***
	(0.024)
Observations	1,408

Clustered SE in parenthesis. Countries and Time (unconditional) fixed effects included. Control variables as in Table 3 included.

where δ is the depreciation rate, set at the value of 0.1, in line with the literature on innovation (Keller, 2002), and g is the rate of growth of patenting for the period 1977-1980 computed over the countries included in the sample.

The external stock, available to country c at time t, is measured as the sum of knowledge produced abroad at time t, that has crossed country c's borders:

$$stock\_ext_{c,t} = \sum_{j \neq c} \phi_{c,j} stock\_int_{j,t}. \tag{7}$$

Perfect diffusion of knowledge ($\phi_{c,j} = 1$) is here assumed:[32] the amount of external knowledge available to country c at time t equals the sum of the internal stocks of knowledge of other countries. The external stock is therefore equal for all countries.

The results, presented in Table 5, show that neither the internal nor the external stock of knowledge influences domestic innovation, confirming the hypothesis that the pharmaceutical sector is characterized mainly by independent innovations. Other results remain remain the same as in Table 3.

6.3 Placebo and robustness

A placebo test is run to estimate the effect of a fake protection introduced one, two or three years (Column 1, 2 and 3 of Table 6, respectively) prior to the real one. To avoid the fake protection to include also the effect of the real, subsequent one, the variable for the fake protection is set equal to zero after the implementation of TRIPS complaint protection. Results show no significant effect for fake protections.

Similarly, when the yearly effect is taken into account and dummy variables for the year *before* the introduction of the protection, for the second year *before* the introduction and for the third year *before* the introduction are included in the dynamic model presented in Section 6.1, these dummies prove not to be significant[33], supporting the causal interpretation of the main findings. These results also point out the absence of anticipation effects.

[32] $\phi_{c,j}$ may be computed using citations data. This, however, goes far beyond the scope of this paper.

[33] These regression results are available from the author upon request.

Table 5: Internal and external stock of knowledge.

	NB
	innovation
TRIPS protection	0.492***
	(0.155)
lower protection	0.565***
	(0.173)
TRIPS protection poor	-0.630**
	(0.286)
lower protection poor	-0.747**
	(0.309)
stock_ext	-0.012
	(0.008)
stock_int	-0.008
	(0.010)
constant	-83.124***
	(19.510)
alpha	0.066***
	(0.025)
Observations	1,408

Clustered SE in parenthesis. Countries and Time (unconditional) fixed effects included. Control variables as in Table 3 included.

Table 6: Placebo.

	(1) NB *innovation*	(2) NB *innovation*	(3) NB *innovation*
TRIPS protection	0.495***	0.521***	0.545***
	(0.156)	(0.168)	(0.176)
lower protection	0.546***	0.543***	0.535***
	(0.186)	(0.186)	(0.190)
TRIPS protection poor	-0.625**	-0.651**	-0.672**
	(0.296)	(0.308)	(0.318)
lower protection poor	-0.730**	-0.722**	-0.713**
	(0.336)	(0.323)	(0.333)
GDP (log)	1.482***	1.476***	1.469***
	(0.413)	(0.416)	(0.414)
economic freedom	0.185**	0.191**	0.197***
	(0.0782)	(0.0779)	(0.0762)
school enrolment	0.00396	0.00325	0.00275
	(0.00543)	(0.00555)	(0.00561)
population (log)	2.567**	2.548**	2.515**
	(1.262)	(1.258)	(1.246)
nepolaws	0.0651**	0.0657**	0.0653**
	(0.0283)	(0.0279)	(0.0276)
epo	0.357**	0.356**	0.353***
	(0.143)	(0.139)	(0.136)
law fake (1 year prior to real one)	0.0887		
	(0.0960)		
law fake poor (1 year prior to real one)	-0.0893		
	(0.328)		
law fake (2 years prior to real one)		0.125	
		(0.101)	
law fake poor (2 years prior to real one)		-0.132	
		(0.220)	
law fake (3 years prior to real one)			0.153
			(0.0954)
law fake poor (3 years prior to real one)			-0.146
			(0.216)
constant	-82.49***	-82.04***	-81.31***
	(19.15)	(18.87)	(18.71)
alpha	0.067***	0.066***	0.066***
	(0.025)	(0.024)	(0.024)
Observations	1,408	1,408	1,408

Clustered SE in parenthesis. Countries and Time (unconditional) fixed effects included.

The main findings are also robust to the model (OLS and QMLP) and the dependent variable (innovation measured through unweighted patents) adopted, and to the sample taken into account (see Appendix G).

7 Conclusions

This paper sheds some light on the role that patent protection has in stimulating pharmaceutical domestic innovation, measured as the yearly number of citation-weighted applications filed at the EPO by domestic inventors. In particular, it provides punctual estimates of the impact of two homogeneous sets of IPR reforms for both developed and developing countries, filling a gap in the existing literature.

Results show that the flow of domestic innovations rises dramatically following the introduction of IPR protection, with an increase in weighted applications exceeding 54% when TRIPS compliant protection is offered in developed countries. The presence of other forms of lower protection, such as process or product protection not respecting TRIPS requirements, has a similar effect, suggesting that innovation is sensitive to IPR protection but not to its degree.

The positive effect of IPR protection can be explained by the strong recourse to patents with respect to secret protection or lead time advantages to protect innovation (Nagaoka et al., 2010). The pharmaceutical sector is indeed characterized by a high number of applications and by the early stage of the research process at which applications are filed. In particular, inventors also wish to protect innovations at their preliminary stage to avoid competitors doing so. Due to the higher costs of patenting abroad (mainly indirect costs), the optimal situation for inventors is to patent these intermediate innovations at home. Therefore, when domestic patent protection is offered, innovation in the country is fostered.

Developing countries benefit significantly less from IPR: for them, the effect of TRIPS compliant protection is roughly half of that for developed countries, being therefore equal to 34%. This can be explained by two factors. First, developing countries did not have enough innovative potential at the time protection was introduced to fully profit from it; moreover, forbidding imitation, patent protection limits their ability to innovate through imitation. Second, protection offered by these countries is less effective in defending innovations. Indeed, the underdevel-

opment of information and communication technologies makes it more difficult for foreign offices to conduct searches on previous patents registered in these countries; furthermore, the level of enforcement in some cases may be too low to make protection effective.

Many countries present, at least in one year, a null number of applications filed at the EPO. Zero applications can be due to two different processes: choice (the decision not to patent in Europe), and nature (the lack of innovative capabilities). Results for the ZINB model show that the choice to patent at the EPO is affected by the level of pharmaceutical export towards European countries, confirming the hypothesis found in previous literature that patents are filed in the main markets of reference. The presence of domestic protection does not negatively affect the decision to patent in Europe, but rather increase the probability to file applications at the EPO. This last result may be driven by the opportunities to develop relevant innovations in countries offering domestic protection.

The positive effect that patent protection has on domestic innovation is not long-lasting, persisting for six years. This limited duration has important policy implications. Indeed, after this period, countries may be induced to introduce more restrictive protection to stimulate further domestic innovation. Although my results suggest that this strategy works, an important point must be emphasized: the negative effect that IPR have on innovation increases with the level of protection. Indeed, when more protection is offered, problems such as royalty stacking or patent hold-up become more severe: further research is then obstructed by the high royalties claimed by the owners of existing patents to allow the use of their inventions, or by the risk to infringe previous patents, when the infringer, who made sunk investments for the production of its invention, can be asked to pay conspicuous royalties in order not to face a court injunction (Lemley and Shapiro, 2006). Thus, the impact that patent protection has on innovation may present an inverted U-shaped relationship, with an optimal level of patent protection beyond which its effect is no longer beneficial (Aghion et al., 2005; Qian, 2007). Since pharmaceutical innovation is sensitive to IPR protection but not to its degree, it would be preferable to implement gradual reforms that slightly increase the level of protection rather than rare reforms that greatly alter it. Reaching the optimal level of protection in a gradual way is fundamental in developing countries: for

them, it would be preferable to increase the level of protection when they are able to fully profit from its effect. These considerations suggest that a "one size fits all" approach can be inappropriate, while the recent extension of the transitional period for the implementation of the TRIPS Agreement in the least developed countries can be beneficial, if it is exploited to introduce gradual reforms.

These policy implications are drawn by considering the effect of IPR protection on domestic innovation. However, protection may also affect other outcomes, such as the access to new drugs, in terms of delay of launches, number of drugs marketed in a country and drugs prices (see, among others, Duggan and Goyal, 2012; Goldberg, 2010; Lanjouw, 2005; Cockburn et al., 2014). Further analysis on the effect of protection on access to new drugs or on some more comprehensive outcomes, such as life expectancy, are needed to evaluate both costs and benefits of IPR protection.

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Appendix A The European Patent Office

The major regional office is the European Patent Office (EPO), born in 1977. Patent applications can be filed at national patent offices or at the EPO. In this case, the EPO performs the examination procedure on behalf of countries that are members of the European Patent Organisation.[34] Even though the examination procedure is centralized, the grant is not automatically effective in all member states. After the patent is granted by the EPO, the owner has 6 months (during which the invention is protected) to file an application in the member states, or to file a Patent Cooperation Treaty application. In the former case, the conditions under which the patent takes effect are regulated by domestic laws.

The first advantage provided by the EPO centralized procedure is that, during the 6 months preceding domestic applications, further research can be completed on the molecule or process. Further discoveries can influence the owner's strategic decision concerning countries where to file the application. Secondly, the validation in several member countries of a patent already examined by the EPO is less expensive than filing separate applications, since the centralized examination procedure reduces costs. Finally, the result of the examination carried out by the EPO can be different from the one carried out by national offices, providing an increased chance for the patent to be granted. For these reasons, firms interested in protecting their innovations in Europe tend to file applications at the EPO instead of directly to the national offices, as pointed out for the pharmaceutical sector by the European Commission (2009). Each patent filed at the EPO is validated, on average, in 15 member countries.

Appendix B Literature review tables

[34]Despite the name of the Organization, in addition to the 27 EU countries several non EU nations are member.

Table 7: Empirical literature: the effect of IPR protection.

AUTHORS	COUNTRIES UNDER ANALYSIS	DATA	METHODOLOGY	VARIABLES	ESTIMATED EFFECTS
Yang (2008)	Taiwan	-firm-level (209 high technology firms) -1990-1999	Count data model (Poisson model)	Y: patents filed in Taiwan by local residents X: 1994 reform extending patent duration C: firm's level of R&D; time dummies; firm's characteristic	-positive and significant -anticipation effect
Hall and Ziedonis (2001)	US	-firm-level (95 semiconductor firms) -1979-1995	Count data model (Poisson model)	Y: patents granted in the US to US firms X: 1982 reform improving enforcement C: R&D spending; firm's characteristics; time dummies	-positive and significant -time lag
Sakakibara and Branstetter (1999)	Japan	-firm-level (307 firms) -1980-1994	-OLS fixed-effect and random-effect -Count data model (Poisson and negative binomial model)	Y: log R&D spending of Japanese firms*; log Japanese patent applications filed by local residents*; log US patent granted to local residents (weighted for number of IPC subclass codes, number of claims or number of forwards citations)* X: 1988 reform extending patent breadth; reform*firm patent intensity C: industry dummies; time dummies; firm's level of R&D	-non robust on Japanese patents -positive and significant on R&D and US patents
Kortum and Lerner (1998)	US	-country-level -1955-1993	Pooled OLS	Y: log patent applications filed in Germany, France, UK, Japan, the US by inventors from each of these countries X: year*destination country; year*source country C: destination country dummies; origin countries dummies; time dummies	-positive and significant effect of year*source country -not significant effect of year*destination country
Lo (2011)	Taiwan	-industry-level -1984-1991	Pooled OLS	Y: patents granted in the US to country's residents/ industrial production; R&D of Taiwanese firms/ industrial production X: 1986 reform improving enforcement C: log industry export intensity; industry dummies	-long-lasting, positive and significant on R&D intensity -positive and significant on patents for industries highly reliant on patent protection or R&D intensive
Moser (2003)	several countries	-country-level -1851-1876	Count data model (negative binomial model)	Y: innovations presented at World Fairs X: existence of a patent system; patent length C: log population; education; GDP per capita	-not significant -significant on the direction of innovation

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Branstetter, Fisman and Foley (2005)	16	-firm-level -1982-1999	OLS with time and country FE	Y: US multinational transfer to affiliates; log patent applications filed by domestic or foreign inventors in the country*; log affiliate R&D expenditures in the country* X: domestic reforms C: income per capita; indexes of trade**** and FDIs openness; country controls; time dummies; country time trend; time-invariant fixed effects for the parent-affiliate pair; time-varying parent, host country and affiliate characteristics	-Positive and significant on transfer and R&D concentrated in affiliates of patent-intensive parents -positive and significant on non-resident patent filings -not significant on residents patent filings
Kanwar and Evenson (2001)	29	-country-level -at 5 year periods -1981-1990	Random effects GLS estimates	Y: R&D spending/GNP X: Ginarte-Park index C: log (gross domestic savings/GDP) in t-1; log (per capita GDP/per capita GDP in t-1); log education**; political instability dummy***; real lending rate of interest; black market premium dummy	positive and significant
Chen and Puttinam (2002)	64 developing countries	-country-level -at 5 year periods -1975-2000	-OLS on first-differenced data -2SLS. IV: GDP per capita, economic freedom, education, population (all in log)	Y: patent applications of country's residents in the US X: Ginarte-Park index C: log GDP per capita; log education; log trade; economic log freedom; WTO	-positive and significant -stronger for countries with patent protection and higher level of economic development
Lerner (2009)	60 developed countries	-country-level -1850-1999	-Weighted least squares estimator -2SLS. IV: reform took place in Paris Convention or TRIPS aftermath	Y: patent applications of country's residents in UK (from 2 years before to 2 years after the reform) X: changes in domestic patent laws changes in domestic law*strength of protection pre-reform C: inception of conflicts; change in territory; applications 2 years before event; population	-positive and significant -negative and significant for countries with strong pre-reform protection
				*One is added to the outcome variable before taking the log to avoid the dismissal of observations having zero patents (and therefore an undefined log value) **Average years of schooling (Barro-Lee 2000) ***Center for International Development and Conflict Management ****Heston, Summers and Aten (2002)	

Table 8: Empirical literature: the effect of IPR protection in the pharmaceutical sector.

AUTHORS	COUNTRIES UNDER ANALYSIS	DATA	METHODOLOGY	VARIABLES	ESTIMATED EFFECTS
Challu (1995)	Italy	-country-level -1966-1990	OLS	Y: new drug invented in Italy X: 1977 reform introducing pharmaceutical product patent protection C: time dummies	negative and significant
Pazderka (1999)	Canada	-firm-level -1984-1997	-Maximum likelihood -OLS	Y: pharma R&D spending of Canadian industries as a share of: R&D spending in other Canadian industries R&D spending in pharma by OECD countries X: Canadian 1987 reform limiting the use of compulsory licenses and introducing product patent protection for drugs invented and developed in Canada C: /	positive and significant
McFetridge (1997)	Canada	-firm-level -1986-1995	OLS	Y: pharma R&D spending of Canadian industries as a share of: total R&D in Canada pharma R&D abroad pharma R&D in the US X: Canadian 1987 reform limiting the use of compulsory licenses and introducing product patent protection for drugs invented and developed in Canada C: time dummies	positive and significant
Kawaura La Croix (1995)	Japan	-firm-level (16 firms) -monthly -1966-1979	pooled OLS OLS disaggregated model (one regression for each firm)	Y: value of Japanese pharma firms listed in the Tokyo Stock Exchange; trading volume of the same firms X: Japanese reform introducing pharma products protection C: months dummies; rate of return on market portfolio	positive and significant
La Croix Kawaura (1996)	Korea	-firm-level -monthly -1985-1986	pooled OLS	Y: value of Korean pharma firms listed in Korean Stock Exchange X: Korean 1986 reform introducing pharma products protection (15 years patent length) C: months dummies; rate of return on market portfolio	strongly negative and significant (stronger in the months in which important information is revealed to the market)

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Liu and La Croix (2014)	66 (25 developed; 41 developing)	-country-level -at 5 year periods -1970-2004	-IV: US pressure exercised through the 301 Special List (USTR) -Dynamic probit and Poisson model	Y: presence or number of pharma patents awarded to country's residents and corporations by the USPTO (first listed applicant) in the 5 years period X: Pharmaceutical Innovation Patent Protection index C: log GDP per capita*; log population*; population with secondary education**; degree of openess***	-(relevance of USTR in explaining pharma patent protection) -not significant
Qian (2007)	26	-country-level -1978-2002	matching technique (new patent country matched with no-patent country and always-patent country) with fixed-effect model	Y: citation-weighted US pharma patent awards to country residents (three to ten years forward); domestic pharma R&D (for OECD countries); pharma export X: binary variable for pharma products protection C: pharma processes protection; log export towards the US; log GDP; log GDP per capita PPP; log GDP growth rate; log education****; log economic freedom***; country's legal system origin; log pharma sector employment; log FDIs received; time dummies	positive and significant effect of patent law only in combination with high levels of development
Qian (2010)	26	-country-level -1978-2002	matching technique (new patent country matched with no-patent country and always-patent country) with fixed-effect model	Y: US and Japanese FDIs (two to six years forward) pharma imports X: binary variable for pharma products protection C: pharma processes protection; log GDP; log GDP per capita PPP; log education****; log economic freedom***; log IPR score; log IPR score squared; log pharmaceutical sector employment; log pharmaceutical export to the US; price control; time dummies	-positive and significant effect of patent law only in combination with high levels of development -positive effect on imports
				*World Development Indicator ** Lutz et al. (2007) *** Computed as total trade volume divided by GDP ****Average years of schooling (Barro-Lee 2000)	

Appendix C TRIPS standards

The TRIPS Agreement regulates the use of patents in all fields of technology. The main features of TRIPS standards relate to the subject matter to be protected, the rights to be conferred and permissible exceptions to those rights, and the minimum duration of protection (Jaffe, 2000).

Regarding the subject matter to be protected, Article 27.1 states that *"...patents shall be available for any inventions, whether products or processes, in all fields of technology, provided that they are new, involve an inventive step and are capable of industrial application."* Three exceptions to the basic rule of patentability are admitted: members can exclude from patentability inventions that are contrary to public order or morality (Article 27.2); diagnostic, therapeutic and surgical methods for the treatment of humans or animals (Article 27.3 (a)); and plants and animals other than micro-organisms (Article 27.3 (b)). According to these provisions, pharmaceutical processes and products can not be excluded from patentability, although no clear requirement can be found concerning essential drugs.

Rights to be conferred include the exclusive right to make, use, offer for sale, sell (and import for these purposes) the product. Patents concerning processes instead *"prevent third parties, not having the owner's consent, from the act of using the process, and from the acts of: using, offering for sale, selling, or importing for these purposes at least the product obtained directly by that process."* (Article 28.1). Patent owners also have the right to assign the patent, to transfer it by succession, and to conclude licensing contracts (Article 28.2). Article 27.1 specifies that these rights shall be *"enjoyable without discrimination as to the place of invention, the field of technology and whether products are imported or locally produced".* This article makes the "local exploitation" clause included in many developing countries intellectual property laws not TRIPS compliant.

Some exceptions to rights conferred can be introduced by member States, *"provided that such exceptions do not unreasonably conflict with a normal exploitation of the patent and do not unreasonably prejudice the legitimate interests of the patent owner"* (Article 31). The TRIPS Agreement explicitly recognizes the exception represented by compulsory licenses. These consist in the exploitation of a patent, by a third party or by the government, without the authorization of the right holder. The following provisions must be satisfied in order to issue compulsory licences: national emergency, extreme urgency or public non-commercial use, for a limited scope and duration and for the supply of the domestic market[35]; the obligation to try to acquire

[35]In 2003, WTO members agreed to allow any member country producing generics under compulsory licenses to export them in countries unable to produce them locally. This gave exporter countries the opportunity to increase their economies of scale.

a voluntary license on reasonable terms and conditions within a reasonable period of time before resorting to compulsory licenses; the non-exclusive use of the patent; the obligation to pay an adequate remuneration to the patent holder and the requirement to submit the relevant decisions to independent reviews by a distinct higher authority (Article 31). Article 6 instead provides that *"nothing in this Agreement shall be used to address the issue of the exhaustion of intellectual property rights"*. This principle states that, once a patented product has been sold by the patent holder, or by any party authorized by him, the patent owner cannot prohibit the subsequent resale of the product. His or her rights in this respect have been exhausted by the act of selling the product. This article allows parallel imports, that are goods produced genuinely under protection of a patent, placed into circulation in one market, and then imported into a second market without the authorization of the local owner of the intellectual property right. The above mentioned article can be considered in contrast with Article 28, by eliminating the exclusive rights of the patent owner to prevent others from importing the patented invention. Only in 2001 this confusion was resolved by the Doha Declaration, which clarified the interpretation of TRIPS exceptions to rights conferred by the member States. According to Article 5 of the Declaration, each country has the right to grant compulsory licenses and the freedom to determine the grounds upon which such licenses are granted; the right to determine what constitutes a national emergency and circumstances of extreme urgency; the freedom to establish the regime of exhaustion of IPR, deciding whether or not to allow parallel imports. In 2000, the use of the "regulatory exception", or "Bolar" provision, was clarified. According to this provision, countries can allow generic manufacturers to use a patented invention to obtain marketing approval before the patent protection expires even without the patent owner's permission. Generic producers can then market their versions as soon as the patent expires.

Concerning the minimum duration of protection, Article 33 of the TRIPS Agreement fixes the term of protection to at least 20 years countered from the filing date.

Finally, Articles 65 and 66 contain the transitional periods. Developed countries had to apply the provisions within the year, while other countries could benefit from a longer transitional period: 5 years for developing countries that were already offering some form of pharmaceutical product protection at the time the TRIPS Agreement entered into force, and 10 years for the other developing countries. The least developed countries were allowed a 11 years transitional period, that has been extended twice.

Appendix D Further details on the data

Table 9 shows the list of countries included in the sample, specifying which of them present a null number of weighted applications over the period 1980-2001.

Table 9: List of countries included in the sample.

Albania[a]	Denmark	Jordan	Senegal
Argentina	Ecuador	Kenya	Slovakia
Australia	El Salvador[a]	Latvia	Slovenia
Austria	Egypt	Lesotho[a]	South Africa
Bangladesh	Estonia	Lithuania	Spain
Benin[a]	Finland	Mali	Sweden
Bolivia	France	Mauritania	Switzerland
Brazil	Gabon	Mexico	Taiwan
Bulgaria	Germany	Mongolia	Tanzania
Burkina Faso[a]	Ghana[a]	Nicaragua	Thailand
Burundi[a]	Greece	Nigeria	Tunisia
Cameroon	Guatemala[a]	Norway	Turkey
Canada	Honduras	Panama	US
Central African Rep.[a]	Hungary	Paraguay[a]	Uganda
Chad	India	Peru	United King.
China	Indonesia	Philippines	Uruguay
Colombia	Ireland	Poland	Venezuela
Costa Rica	Italy	Portugal	
Czech Republic	Japan	Republic of Korea	

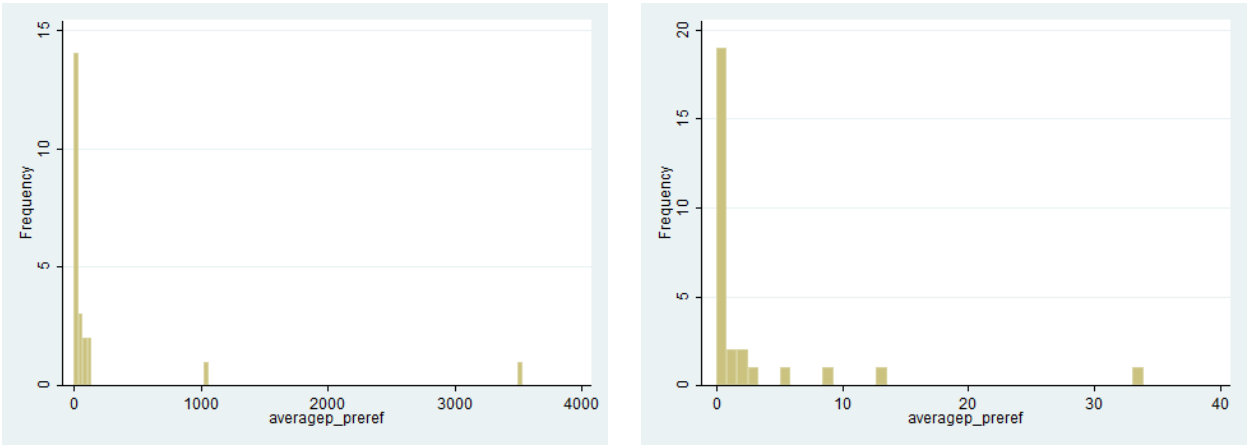
[a]Countries presenting a zero count of EPO applications over the period 1980-2001.

As shown in Figure 1, at the time TRIPS compliant protection was introduced, most countries showed a low innovative level, measured as the annual average number of weighted patents filed between 1977 and the year of introduction of the protection. The only exceptions were the US and Japan, with an annual average number of weighted patents respectively of 3,533 and 1,033. As pointed out by Branstetter et al. (2006), this suggests that the introduction of pharmaceutical patent protection was not driven by the boost of the pharmaceutical sector.

Appendix E Coefficients interpretations in non-linear models

In non-linear models results can be presented on an additive scale, through marginal effects, or on a multiplicative scale. To interpret coefficients on a multiplicative scale, more suitable for these models being their "native form of effect" (Buis, 2010), it is necessary to exponentiate them (see Verbeek, 2004, page 214 and following).

Figure 1: Innovative level at the time TRIPS compliant protection was introduced.



(a) Developed countries. (b) Developing countries.

averagep_preref is measured as the annual average number of weighted patents filed between 1977 and the year of introduction of the TRIPS compliant protection.

Indeed, when coefficients are not exponentiated, they are interpreted as the difference among the logs of expected counts:

$$\beta = log(\mu_{x0+1}) - log(\mu_{x0})$$

where β is the regression coefficient and μ is the expected count for $x0$ and $x0 + 1$ (where "+1" implies one unit change in the predictor variable x).

Since the difference of two logs is equal to the log of their quotient, we have

$$\beta = log(\mu_{x0+1}) - log(\mu_{x0}) = log(\mu_{x0+1}/\mu_{x0})$$

from which:

$$exp(\beta) = \mu_{x0+1}/\mu_{x0}$$

and

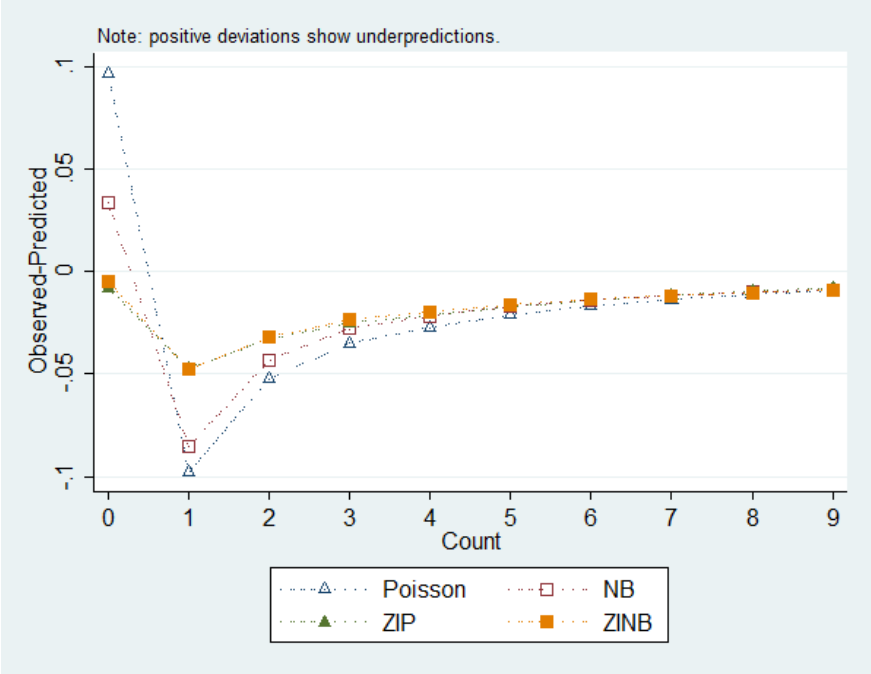
$$100[exp(\beta) - 1] = [\frac{\mu_{x0+1} - \mu_{x0}}{\mu_{x0}}]100.$$

When independent variables are in log form, their coefficient already represents the elasticity. In this case in fact $\mu = exp(\beta_1 log(x))$, from which: $log\mu = \beta_1 log(x)$.

Appendix F Comparison between models

Residuals for a Poisson, NB, Zero Inflated Poisson (ZIP) and ZINB model are plotted in Graph 2. Zero Inflated models perform better than their non zero inflated counterpart, having smaller residuals for all counts of the dependent variable. Moreover, NB models perform better than Poisson ones.

Figure 2: Residuals for a Poisson, a Negative Binomial, a Zero Inflated Poisson and a Zero Inflated Negative Binomial model.



Appendix G Robustness

Column (1) of Table 10 presents the results obtained using an OLS, where, to interpret results on a multiplicative scale, the model has been log-linearised. Being the log of zero undefined, a value of one has been added to the null number of weighted patents before computing its log.[36] Column (2) instead shows the results obtained using a quasi-maximum likelihood Poisson. Although the magnitude of the coefficients differ between the two models, both confirm a positive impact of all forms of patent protection for both developed and developing countries, with a smaller impact for the latter. Importantly, the results presented in Column (2) are similar to those obtained through the use of an unconditional NB model, suggesting that the NB model does not suffer from an incidental parameter problem.

In Column (3) of Table 10 innovation is measured as the number of unweighted patent applications. The results, estimated using an unconditional NB model, confirm the robustness of previous findings, pointing out that these were not driven by the weighting scheme adopted.

Results are not even sensitive to modifications of the sample, as shown in Column (1) and (2) of Table 11. Here, the analysis is run excluding countries that never offered TRIPS compliant protection over the period 1977-1998 and countries that offered it during all the period respectively.

[36]To have comparable results, the 10 countries having zero patents all along the period have been excluded from the sample also for the OLS model.

Table 10: Robustness tests: different estimation techniques and different dependent variable.

	(1) OLS *innovation* (*measured by the log of weighted patents*)	(2) Quasi-Maximum Likelihood Poisson *innovation*	(3) NB *innovation* (*measured by unweighted patents*)
TRIPS protection	0.422***	0.481***	0.422**
	(0.152)	(0.180)	(0.165)
lower protection	0.320*	0.579***	0.456***
	(0.172)	(0.183)	(0.176)
TRIPS protection poor	-0.588**	-0.762***	-0.790***
	(0.262)	(0.265)	(0.225)
lower protection poor	-0.632***	-0.646*	-0.683**
	(0.231)	(0.387)	(0.306)
GDP (log)	1.297***	0.455	1.365***
	(0.348)	(0.611)	(0.390)
economic freedom	0.088	0.205***	0.214***
	(0.061)	(0.0688)	(0.0765)
school enrolment	0.011	0.0105**	0.00436
	(0.010)	(0.00505)	(0.00401)
population (log)	-2.3826***	3.726***	3.660***
	(0.521)	(0.690)	(1.138)
nepolaws	0.089***	0.0777**	0.0707***
	(0.029)	(0.0316)	(0.0203)
epo	0.431**	0.313***	0.356***
	(0.165)	(0.108)	(0.116)
constant	7.954	-76.41***	-98.37***
	(9.620)	(14.02)	(15.08)
alpha			0.023***
			(0.009)
Observations	1,408	1,408	1,408

Clustered SE in parenthesis. Countries and Time (unconditional) fixed effects included.

Table 11: Robustness tests: different samples.

	(1) NB Excluding countries without TRIPS compliant protection over all the period *innovation*	(2) NB Excluding countries with TRIPS compliant protection over all the period *innovation*
TRIPS protection	0.461***	0.460***
	(0.151)	(0.162)
lower protection	0.402**	0.563***
	(0.171)	(0.179)
TRIPS protection poor	-0.771***	-0.593*
	(0.256)	(0.312)
lower protection poor	-0.780**	-0.762**
	(0.325)	(0.319)
GDP (log)	0.496	1.485***
	(0.427)	(0.412)
economic freedom	0.170	0.177*
	(0.104)	(0.0906)
school enrolment	0.00230	0.00495
	(0.00377)	(0.00569)
population (log)	2.847*	2.270
	(1.672)	(1.399)
nepolaws	0.0974***	0.0731**
	(0.0239)	(0.0332)
epo	0.403***	0.344**
	(0.146)	(0.147)
constant	-62.20**	-77.58***
	(24.57)	(21.27)
alpha	0.050***	0.086***
	(0.020)	(0.030)
Observations	858	1,364
Number of countries	39	62

Clustered SE in parenthesis. Countries and Time (unconditional) fixed effects included.