Do Additional National Patent Laws Stimulate Domestic Innovation In A Global Patenting Environment?

A Cross-Country Analysis of Pharmaceutical Patent Protection: 1978-1999

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***** I would like to give my special thanks to Professors Richard Caves, Donald Rubin, Josh Lerner, Richard Cooper, and Dale Jorgenson for their constant advice and encouragement; to Professors Gary Chamberlain, Markus Mobius, Ariel Pakes, Mike Scherer, Dr. Basma Abdelgafar, Dr. Calestous Juma, Dr. Pierre Sauve, Dan Benjamin, Yu-chin Chen, Davin Chor, Gopal Garuda, Jennifer Hill, Jesse Shapiro and Kia Song for comments on various drafts; to Drs. Arvind Subramanian, Jayashree Watal, Gary Haufbauer, and Keith Maskus for their advice and references at early stages of my research; to Professors Andrei Shleifer, Paul Beamish, and Dr. Fritz Foley for providing data.

Section 1. Introduction[1]

The rationale for patent protection is that by granting exclusive marketing rights to innovators, they can reap the benefits and recoup the costs of their R&D investments, which should ensure their incentives to innovate. The actual effect of intellectual property rights on innovation, however, remains one of the most controversial questions in the economics of technology[2]. Although the World Trade Organization's (WTO) Trade-Related Aspects of Intellectual Property Rights[3] (TRIPs) negotiations were successfully concluded in late 1993, the question of whether national intellectual property rights protection are beneficial to developing countries still provokes heated debate. The question remains whether such legislation could stimulate enough innovation to justify the economic, political and social costs associated with its implementation and enforcement.

This paper studies the effects of new implementation of a nation's pharmaceutical patent policy on innovation, as indicated by United States patents awarded to that country of origin and R&D expenditures by its pharmaceutical industry. The analysis covers a sample of eighty-five countries from 1978 to 1999. An innovation is typically a new chemical entity that satisfies the regulatory agency's efficacy and efficiency requirements, or "a molecular manipulation of a known drug that yields significant benefits" (Taggart, p14, 1993). This study seeks to overcome data and methodological constraints that have confined previous research predominantly to single country analyses and led to inconclusive results. It makes several contributions to this literature. First, fixed-effects regressions on matched country pairs control more thoroughly for observed country characteristics. Second, non-parametric matching methods easily accommodate a large number of control covariates; this in turn enables the succeeding estimation to control for many observable country characteristics that are correlated with a country's innovative potential and patent implementation[4]. These two contributions are methodological improvements that may reduce biases in the patent effect estimate. The main findings of this study are that in the group of sampled

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[1] Benjamin (2000) and Kia Song's comments provide invaluable help for the organization of this Section.
[2] Please see Jaffe (2000) for a detailed review on the vast literature.
[3] Intellectual property rights are a category of law that generally include patents, copyrights, trademarks, geographical indications, industrial designs, utility models, plant breeder rights, integrated circuits rights and trade secrets.
[4] A country legally implements patent protection for a particular sector.

countries the implementation of patent laws by itself does not promptly stimulate domestic innovation. However, national patent laws in combination with high levels of development and economic freedom do have a positive effect on innovation. This study also provides some of the first empirical support for the theory that the relationship between innovation and the strength of intellectual property rights is "inverted U" shaped (Gallini, 1992; Cadot & Lippman, 1995; Horwitz & Lai, 1996). In particular, an optimal level of intellectual property rights strength appears to exist, above which additional strengthening measures actually tends to discourage innovation.

Since the 1980s, intellectual property protection has become much more extensive as countries at various stages of development began to implement or extend their national patent rights[5]. The US pressed developing countries' to implement patents not only through direct bilateral trade threats[6], but also through indirect multilateral pressure, particularly by bringing intellectual property rights to the agenda of the Uruguay Round negotiation of the WTO. The impact of patent protection on innovation is therefore an important policy question – one that is especially pertinent for developing countries.

Cross-country analyses of patent protection and domestic innovation are scarce. Very little research has been done for non-OECD (Organization for Economic Cooperation and Development) countries, mainly because of the difficulty in collecting data. Furthermore, some previous studies of intellectual property rights in developing countries tested their effects on innovation for the whole economy. This is problematic because patent protection may have different effects in different industries. For instance, surveying 650 US firms, Levin *et al.* (1986) found patenting important mainly in the pharmaceutical industry, where copying is easy.

A few empirical studies have tested the effect of patent protection on countries' pharmaceutical innovation, with inconclusive results. Pazderka (1999), the Patented Medicines Prices

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[5]At least forty developing countries lacked pharmaceutical product patent protection as of the late 1980s[5](Siebeck *et al.* 1990). By the end of 1999, however, only sixteen WTO member countries excluded pharmaceuticals from national patent protection (Scherer and Watal, 2000).

[6] The US congress enacted legislation in 1988 that required the US Trade Representative to annually identify such countries in the "Priority Watch List" of the "Super-301" trade report and take unilateral trade sanctions against those countries not assisting in the protection of US patent rights. These threats were credible. One example is the increasing US tariff on Brazil imports in 1989 in retaliation to Brazil's copying of patented drugs (Lanjouw and Cockburn, 2000). Similarly, the threat of US trade action, rather than internal factors, pushed forward South Korea's decision to strengthen its intellectual property rights (McFetridge, p3, 1997).

Review Board (PMPRB 1997), and McFetridge (1997) each found a statistically significant increase in pharmaceutical R&D expenditure after the tightening of Canadian pharmaceutical patent protection in 1987[7]. In contrast, Scherer and Weisburst (1995) showed that the Italian pharmaceutical patent legislation of 1978 did not increase R&D expenditures. Instead, it seemed to have worsened Italy's terms of trade[8]. Challu (1995) also demonstrated a decline in new chemical entities introduced in Italy post-patent protection. These inconsistent and inconclusive results provide little consensus on the general effects of augmenting national patent protection. Because we cannot observe counterfactual outcomes of patent protection, international comparisons provide valuable leverage for analysis (Lerner, 2000). The passage of national pharmaceutical patent laws in a group of countries in the 1980s and 1990s creates a natural experiment to test the economic impact of patent protection.

In traditional economic analyses, the effect of patent protection on innovation is estimated simply by comparing the level of innovation in countries with and without patent law, controlling for appropriate country specific characteristics. Three factors make this standard strategy unfeasible for this study. The first difficulty arises from deficient data. Data on innovation levels and on the various country characteristics that may affect them are deficient, particularly for non-OECD countries. This study constructs a new database for eighty-five countries, including a set of country covariates in annual panel form from years 1978 to 1999. Unfortunately, there are many missing values in this data set I collected at first, especially for the pharmaceutical industry variables, and it is necessary to use appropriate statistical and econometric methods to address the complexities of missing data.

A second difficulty lies in controlling for countries' latent innovative potential when we infer the effects of patent protection on innovation. Although countries with patent protection, many of them developed countries, tend to have higher innovation levels, patent protection need not be the causal factor. Countries with strong patent protection may simply have a greater capacity for

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[7] Nonetheless, all these studies point out that the dramatic increase in the R&D spending growth rate is also attributable to the commitment of expanding R&D by PMAC member companies to facilitate the passage of Canadian patent legislation. This commitment to raise their R&D-to-sales ratio to 10% by 1996 was satisfied in 1993, and the rate of growth in R&D spending in these companies slowed substantially in the period from 1994 to 1997 (McFetridge 1996).
[8] The authors note, however, that the price control policy could be a confounding factor.

innovation. The factors that determine a country's innovative potential can be correlated with the national patent policy; failing to control for this correlation would yield biased estimates of patent policy's effects. Previous research has indeed found correlations between national patent legislation and market openness, lagged R&D expenditure, GDP per capita (Park 1997), economic growth (Evenson 1990), and the legal origin of a country's commercial laws (Lerner 2000a). Industry level characteristics should also affect a nation's decision to implement patent laws and its innovative potential (Kaufer 1989). This study assumes that national patent law implementation is conditionally random (Rubin 1973), given a set of country- and industry-level covariates important for both the innovation outcome and patent implementation. This study controls for a rich set of covariates that may be correlated with innovation and the implementation of patent rights. The controls substantially mitigate the potential for omitted variable bias. Lagged values of these variables are used to avoid simultaneous interaction between them and patent implementation.

The last difficulty lies in the procedure for appropriately controlling for these observed country and industry level variables. Because patent and no-patent countries differ substantially in certain characteristics (Tables 1a,b), standard linear regression, which assumes a linear relationship between each control variable and the outcome variable for all observations, may not adequately control for these covariates and may produce biased estimates. This study controls covariates through a two-step process: the first step identifies pairs of countries with similar characteristics, and the second step performs pair-wise econometric analyses on the matched pairs. Various matching or clustering techniques are commonly used in statistics and in the medical sciences, but have only recently gained popularity in economic literature (Heckman *et al.*, 1996). The Mahalanobis matching method is used to establish comparable counterparts for the countries that implemented new patent legislation, and fixed effects regression models are then applied to these matched pairs.

Section 2 introduces a graphical approach to illustrate the theories and policy issues. Section 3 describes the study design and briefly motivates the choice of data and methodology employed. The constructions of the data set and further details on the methodologies are in Sections 4 (supplemented with the Data Appendix) and 5 respectively. Section 6 presents the main empirical results. Discussions and policy implications are addressed in Section 7. Finally, Section 8 summarizes the main approach and results and makes recommendations for future studies.

Section 2. Theories

The faith in patent systems is related to Schumpeter's (1942) revolutionary idea that large-scale firms with monopoly power can be a superior market structure than perfect competition. The practical effects of patent protection on innovation, however, have been controversial. It has been argued that patent systems are irrelevant for appropriating returns on investment in an era where product life cycles are shorter than patent processing times. Patents may even be counterproductive, incurring additional application costs and promoting litigation, defensive behavior, and wasteful invention around patents[9]. Patent laws could also block spillover effects in sequential innovations, where each innovation is built upon its predecessors, by fostering high licensing fees and races for licensing (Scotchmer & Green, 1990). While the negative correlation between tightening IPR and innovation is found empirically in Bessen & Maskin (1999) and Sakakibara & Branstetter (1999), it is not supported in Kortum & Lerner (1998). The hypothesis of whether patent protection stimulates innovation deserves continuing attention.

Although a series of surveys conducted in the US (Taylor & Silberston, 1973; Mansfield *et al.* 1981; Levin *et al.* 1987) and Switzerland (Harabi, 1997) uniformly establish the importance of patents for pharmaceutical innovations relative to other industries, it is not clear how much patent protection is optimal. One could argue that sufficient incentives to innovate are already ensured through well-established patent systems in the major markets, such as the US and European markets, and that additional developing countries' patent laws might not stimulate much more innovation given their limited capacity to innovate domestically. Counter-arguments have that additional patent laws provide favorable local environment for domestic inventors with first-hand knowledge of the country-specific diseases. Prior to national patent implementation, domestic consumers alone purchase the drug at the domestic competitive price of its generic equivalent drug; which is lower than its world price. Static impacts immediately follow the national patent legislation,

[9] "Inventing around a patent" occurs when imitators attempt to avoid patent protection and licensing rules by making small modifications on the original innovation. The disclosure of technical details required in granting a patent helps this activity.

including the shrinking consumer surplus and creation of deadweight loss due to higher monopoly price[10]. Some time after the patent legislation, possible dynamic innovation stimuli are felt, where a major innovation will lead to a larger consumer surplus gain than a small innovation. When the particular patent has expired, the drug invented is widely produced and marketed at a lower price. If the new innovation is originated from a national, then producer surplus is added to the total welfare of the country. Otherwise, monopoly rents go to the foreign inventor and are not captured by the country.

Whether or not a country benefits from adopting national patent legislation depends critically on the dynamic impact of the patent privilege. If the patent legislation stimulates innovation, consumers can realize more surplus in Phase Four. The welfare of the country may even rise as early as in Phase Three depending on the degree of the innovation (how low the new supply curve lies) and the innovation's origin. Multi-country theoretical models predict that more national patent protection in developing countries may not add much to R&D investment incentives, given the existing world intellectual property regime (Chin and Grossman 1990; Deardorff 1992; and Helpman 1993). The importance of domestic patent protection in developing countries is least controversial in special cases where the diseases are only found in home country. The lack of demand elsewhere makes foreign patent laws irrelevant. Without a national patent system to block imitations, inventors are not likely to invest in developing it unless through altruism or through government funded projects[11]. It is not always the case that one country's national patent could provide enough market incentive for the innovators to devote research resources for the country's specific disease. This implies that a group of countries with similar therapeutic needs should implement patent laws together, which is exactly the position the Pharmaceutical Research and Manufacturing Association of America (PMA) held during the TRIPs negotiations, and is formalized mathematically by Diwan and Rodrik (1991). Yet, there is no evidence so far that the research investments or innovations in tropical disease drugs have increased significantly after a group of developing countries have implemented their national patent laws (Lanjouw & Cockburn, 2000).

[10] Some argue that quality adjusted drug price may be lower than that in no-patent situation and can be beneficial.

On the one hand, the costs of patent implementation for developing countries are identified in the literature, ranging from the capture of national patent monopoly rights mainly by foreigners (Lanjouw, 1998; Maskus, 2000), to the legal administration and litigation costs of a national patent system (UNCTAD, 1996; Love, 2001). On the other hand, previous research fails to reach consistent conclusions on the innovation gain derived from the implementation of new national patent systems [Challu (1995), Scherer & Weisburst (1995), and Lanjouw & Cockburn (2000) contrast with Pazderka (1999), the PMPRB (1997) and McFetridge (1996)]. The present study controls for the country pre-patent (Phase One) characteristics that are relevant for patent implementation and innovative potential, and tests whether domestic patent laws have stimulated domestic pharmaceutical innovations in Phase Three.

Section 3. Study Design

Had national patent systems been implemented as exogenous shocks, the effects of patent protection on innovation could be tested simply by comparison of mean innovation levels between the patent and no-patent countries. This is computationally equivalent to regressing the innovation outcome variable on the binary variable of patent protection, where controlling for all other country covariates is unnecessary for obtaining unbiased estimate because of the randomization. Controlling for country characteristics that are relevant for innovation outcomes only assists in obtaining greater precision of the experimental estimates. The estimate, $E_X[E(Y_{i1} - Y_{i0} | X_i=x_i)]$[12] being the "average treatment effect" (Rosenbaum & Rubin, 1983), is the patent effect on innovation outcome Y of a country i with characteristics $X_i=x_i$, integrated with respect to the population distribution of country characteristics.

This ideal randomization faces severe practical limitations. In fact, individual countries make the decisions whether to have national patent laws. Although these decisions can be regarded as exogenous shocks to the extent that many of them are made under persistent bilateral and

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[11] Trouiller and Olliaro (1999) provides some figures, "of the 1223 new molecular entities sold worldwide during 1975-96, less than 1% were destined for tropical diseases". Most of these drugs are generated either from "incidental discoveries in veterinary medicine or from molecules discovered by governmental or academic institutions" (p1).

[12] Y_{i1} is the innovation outcome of country i if it implements patent protection, and Y_{i0} if not. X is the set of controls.

multilateral pressures, some voluntary decision-making still exists in different countries' patent implementations, as demonstrated by the differences in the legislation years and scopes[13] among different countries. The country characteristics may affect both the innovation outcome and the decision of national patent implementation. Due to the endogeneity concern, the conventional method of regressing the outcome variable on the patent implementation indicator and country covariates would very likely produce biased results on the patent effect estimate. There is no sound instrumental variable to address this endogeneity concern. Instead, this study applies statistical matching method to form country pairs where patent treatment can be considered randomly assigned within each pair. This study defines treatment as the implementation of new national pharmaceutical patent law, and control as no change of patent law. A dummy variable "PAT" is constructed to indicate the patent treatment. Two control groups ("PAT"=0) are defined in order to make the most use of the sample size available, and to check the robustness of results. One control group consists of countries that never had patent protection for pharmaceuticals up until the reference period, and the other control group consists of countries that had patent protection even before the reference period. The treated group ("PAT"=1) consists of the countries that implemented new pharmaceutical patent laws during the reference period.

An additive regression equation applied to the entire sample essentially attempts to control covariates by forcing the same linear relationship on countries from the control and treated groups. Because there are significant differences among the patent, new-patent, and no-patent countries[14], assuming the same linear relationship for countries in the control and treated groups implies large extrapolation across groups and therefore makes the resultant OLS results extremely sensitive to the regression specification. This problem with OLS has been known for decades in the statistical literature (Cochran and Chambers 1965)[15]. Matching methods have been shown to reduce these

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[13] For instance, China first implemented national patent laws in 1983, but excluded the pharmaceutical sector until 1992.

[14] Countries that long had patent protection have statistically significantly higher average levels of incomes, GDP per capita PPP, pharmaceutical outputs and exports in the previous reference period than those in the new-patent countries (Table 2); the variable values of the new-patent countries are again higher than those of the no-patent countries (Table 1).

[15] If there is only one control variable, then this problem can possibly be overcome by adding a set of higher order terms of the control variable and interaction terms of the control and the patent indicator variables until the linear assumption is satisfied. However, this does not work if there is limited overlap in the covariate distributions. Moreover, when there are a large set of variables to be controlled, as is the case here, adding terms for each control variable takes away already

confounding variable biases (Rosenbaum and Rubin 1984; Heckman *et al.* 1996), by balancing the relevant pre-treatment country characteristics of the control and the treated groups. In this study, each new-patent country is paired with one country from the never-patent group and another country from the always-patent group. Fixed effects regression analyses are then carried out on these two groups of matched pairs separately. The two-way comparison based on two control groups can help to reduce or at least detect the potential bias arising from the country-specific factors in the matched pairs. This methodology of statistical matched sampling in combination with fixed-effects regression model is detailed in Section 5.

Exhibit 2 lists the specific years the sampled countries started to implement new pharmaceutical patent protection. Five periods are defined accordingly: 1978-82, 1983-85, 1986-90, 1991-95, and 1996-99, for several reasons. First, for some of these countries, Thailand and Indonesia for instance, the exact years of new pharmaceutical patent legislation are not clearly identified, because the different sources give different dates, and their national patent offices did not respond to my query. Second, in some cases, countries anguish over their decisions before the patent legislation year. The values of the control variables in the previous several years could be as important as those in the one year before the new domestic patent law in affecting their decisions. Third, some control variables, such as the average years of schooling and economic freedom indices are only available at a five-year interval. I therefore use the averaged values over the previous two to five years for the control variables. This could also help to smooth out any outlier values in a particular year[16].

Most of the new-patent countries had some degree of protection for pharmaceutical processes before they formally introduce national patents for pharmaceutical products in the corresponding periods. The only exceptions are Brazil, China, Chile, Korea, Indonesia, Mexico, Peru, Romania, Taiwan, Thailand, and Turkey[17]. An indicator variable "PATMOD" is constructed to

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limited degrees of freedom and becomes unfeasible. Even with a large sample, it would be difficult to model response surfaces in high dimensions, because it is especially difficult to assess linearity in a high dimensional covariate space.

[16] I owe this point to Professor Richard Cooper. The lagged one year values are also used in one round of regression analysis to test the robustness of results, as described in Section 6.

[17] This information is obtained by cross-referencing Lerner (2000) Table 1, his listed source documents, and the WIPO (1992) document. Because the US patent data and the OECD R&D expenditure data as alternative specifications of the

distinguish countries started implementing pharmaceutical patent law anew (PATMOD=0) from those that modified their patent laws to protect pharmaceutical products as well as processes (PATMOD=1).

Section 4. Data

The study design in Section 3 called for an extensive effort to gather and construct a suitable database. This section motivates the selection and construction of variables, and full descriptions of the data sources and properties are collected in the Data Appendix.

4.1. Selection of the Outcome Variables

Innovation is not easy to quantify. Pharmaceutical research and development expenditure may be relevant as a direct measure of innovation input, even though it does not capture the innovation output. Unfortunately, expenditures are available only for twenty-three OECD countries. An extensive search for this variable for other countries was fruitless, so I impute R&D values using a regression model as described in Data Appendix c. Although the adjusted R^2 of the imputation model approaches 1, the imputed values cannot be expected to equate with the actual R&D expenditures. I therefore apply regression models to the OECD countries and the others separately when testing the relationship between patent implementation and R&D expenditures (Section 5.2). Data on research and development personnel for the OECD countries are also used as an alternative innovation estimate. However, imputation for the non-OECD countries is not possible due to the small number of personnel observations.

Patent data are used as an alternative estimate for innovation. A series of papers by Evenson, Griliches, Pakes, and others (collected in Griliches, 1984) suggests that patent counts and R&D expenditure are highly correlated in cross-section, and statistically significant but less strongly

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outcome variable are only available up until 1999, the countries that switched patent law in 1999 will not be examined.

correlated for within-firm variations over time. The studies also show concordances in the shifts of R&D expenditure and patenting level, which is confirmed in other studies (Kaufer, 1989). Thus, "to a first approximation, one can use patent data as an indicator of technological activity in parallel with or in lieu of R&D data" (Griliches, p14, 1984). Evenson (1984), in particular, suggests that patented inventions are a reasonable proxy for inventions in general, and this proxy relationship has a reasonable degree of international comparability. Following previous cross-country researches on inventive activities (Daniele Archibugi, 1992; Scherer & Weisburst, 1995), this study uses the US pharmaceutical patent awards as the main indicator of innovation. This patent data are listed by country of residence of the first listed innovator. This information provides a uniform base for comparison because US patent law has treated applications from different countries in a non-discriminatory manner since the 1880's, with the only exception being interference cases (when multiple patent applications make similar or identical claims). In addition, US pharmaceutical patent law has not changed much in the period I am examining, except two modifications after the WTO Uruguay Round in 1995[18]. The US extended the duration of pharmaceutical patents from seventeen years to twenty years and modified the interference rules. Before 1995, the law ruled that only innovative activity in the US territory is valid evidence for establishing the first invention date in cases of interference. After 1995, innovative activities in foreign countries also count. Although the probability of having interference cases is very low[19], the threat of litigation can still have important implications for innovators' incentive to patent in the US[20]. This may partly explain the generally increasing trend of foreign patenting in the US. Fortunately, this change does not influence the international comparative analyses this study carries out, because it affects innovations from all foreign countries equally.

The impacts of patent protection on these countries are not likely to show up immediately in the data of 1999.

[18] Mr. Paul Harrison at the USPTO kindly searched their internal documents and provided this information upon my request.

[19] Scherer recorded that only five interference cases were declared per thousand invention patent applications in 1970's, and the incidence of interference fell to three per one thousand applications on average in 1980's (Griliches, p123, 1984). According to the USPTO, there are thirteen interference cases declared out of 2000 applications in 1999.

[20] I owe this point to Professor Josh Lerner.

One major concern of using the US patent data is how fully this variable can capture innovative activities. There are two aspects to this problem. First, not all patentable[21] innovations are patented. Although accurate time-series data on the percentage of patented innovations over the total number of patentable innovations do not exist, Mansfield (1986) finds in his 1981-83 survey of 100 US firms that around 82% of the patentable inventions in the pharmaceuticals were patented. Arundel and Kabla (1998) finds that 79.2% of pharmaceutical innovations are patented, based on a 1993 survey on innovative activities of Europe's largest industrial firms.

Second, not all foreign innovations are patented in the US. The innovators' decision to apply for a patent in the US depends on many factors, including geographical distance from the US, market potential of their invention in the States, *et cetera*. Because these factors are also related to trade between an innovator's residential country and the US, their bias might be corrected by controlling for the pharmaceutical exports to the US. Given that the US market is the world's largest, innovations of more than local significance tend to be patented in the US if they are patented at all (Scherer and Weisbust, 1995). Putnam (1996) shows that around 63.9% of international patents in 1975 (those patents filed in at least two countries) are patented in the US. Based on the data collected in this study, the number of US patent awards is about three times of that of the EPO patent applications on average for a particular country and year[22]. Since the cost and standard of patent filing is high, the US patent data are expected to capture only the main innovations[23]. Using the US patent data serves as a natural selection of only the important innovations, which is what this research is most interested in testing. This also helps to make the levels of innovation comparable across years, because for any country, the important innovations would be patented in the US both before and after the implementation of domestic patents[24]. The country-specific propensity to patent in the US is controlled for by the construction of "innovative potential" variable, which is based on

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[21] The three statutory requirements for an innovation to be patentable are: novelty, utility and nonobviousness of the subject over the prior art. "Novelty" in the US means being the first to invent, and in Japan means being the first to file patent application. In addition, there are other legal requirements for patentability.

[22] The ratio of number of patents awarded in the US to that in the domestic country is calculated to be in the range of .83 and 11, using the USPTO and WIPO data for a particular country in the same year. The US patent counts are bigger than the domestic patent counts in some cases, possibly because it takes longer to process patent applications in these countries than in the US. The US patent application counts are not available.

[23] The flip side is that this estimate loses information on new innovations that might be locally successful.

the total number of US patents awarded to a country in all other industries except the pharmaceuticals, as detailed in Section 4.2.1. In addition, this study tests the change of US patents due to national patent laws, instead of absolute numbers of patents, in order to capture the change of national innovative activities.

Other advantages of the US patent data are discussed in the Data Appendix, which also includes a detailed discussion on selection of the US patent awards data over the WIPO domestic patents and EPO patents data.

4.2 Controls for Latent Innovative Potential

In order to gain unbiased estimated coefficients of the key independent variables ("PAT" and "PATMOD" as specified in Section 3), one would hope to control for countries' different innovative potentials. Economists have speculated widely on the country characteristics that might relate to latent innovative potential and the decision to implement domestic patent law (Section 1). While this study leaves the details of the obvious control covariates to Data Appendix b and refers to the statistically significant coefficients on some of them in Section 6.3, this section highlights the importance of controlling for some pharmaceutical industry variables. These characteristics differ across countries and could also affect both innovation outcome and the decision to implement domestic patent legislation, as reflected by the fact that some countries decide to exclude the pharmaceutical industry from their national patent laws[25].

The sector's employment level is used to normalize industry size across different countries. The innovators' propensity to patent in US depends on the cost of US patent applications. Industry output values in US dollars controls for the application costs as a share of industry output (a measure of affordability). This is because the US patent application fees are the same for all countries. In addition, the industry employment level and value of output could both affect a country's decision whether or not to implement national patent protection. If a country's

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[24] Eyeballing the US patenting trend data seems to support this assumption, as US patents were awarded to innovators of different countries even before their domestic patent protections were in place.

[25] For instance, China first implemented national patent laws in April 1985, but it denied patentability for chemical substances and processes. At the same time, the Chinese government announced its willingness to extend patent law to

pharmaceutical industry mainly engages in imitative activities, as many developing countries do, then the immediate impact of domestic patent law would be the loss of imitative production and unemployment in the sector. The dynamic impact is of course not certain, and is examined in this study. From a political economy point of view, both dynamic and static impacts are important factors in a country's decision on legal change. It appears that interaction terms between a country's inventiveness with industry employment (as a share of total employment) and with output should be included as controls. Again, inventiveness is not directly observed and was estimated using a categorical variable indicating at what level the country has been awarded US patents in all industries except pharmaceuticals[26].

Considering the fact that transfer of technology from abroad could have an impact on domestic innovation and countries' decisions of patent implementation, estimates of technology transfer through direct investments (FDI) are also included. The most relevant data would be the total FDI received in a country's pharmaceutical industry, which is not collected in practice. US and Japanese FDI to each host country is instead used. By including both the US and Japanese FDI, geographic proximity in FDI locations could be controlled for to some extent[27](Data Appendix b).

It is worth emphasizing that this study uses the lagged (pre-patent period) values for all the control covariates, because many of them are likely to be affected by the national patent implementation. Some of these variables are correlated with each other and will not be included together in the regression models, but they are important to include in the matching procedure.

4.3 Testing the Conditional Importance of Patent Implementation

Countries at different developmental levels differ in some other latent factors that could be important for their R&D or US patent-filing responses to domestic patent protection. One such notable factor is the technology infrastructure. Maskus (2000) suggests that developed countries and many high-income developing countries have already built extensive systems of promoting national

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these excluded sectors once it had established viable chemical and pharmaceutical industries (Kaufer, 1989). Similarly, Japan did not have pharmaceutical patenting until 1976 and Holland not until 1978 (Lanjouw, 2000).

[26] The pharmaceutical patents are excluded to avoid interference with the outcome variable, which is the pharmaceutical patent counts.

[27] I tried to search for European FDI, but was not successful.

technological change (p202)[28]. I therefore generate a dummy variable indicating the developed or high-income nations according to the World Bank classification (WDI, cover page, 2000). I interact this new variable with "PAT" to form a new control variable. In addition, I interact the GDP per capita PPP variable with "PAT" to test the effects of patent implementation conditional on a country's level of development. The correlation between these two interaction variables is 0.64. I use these two variables separately in the different regression specifications. Interaction variables between education and "PAT", between "innovative potential" variable and "PAT", and between economic freedom and "PAT", respectively, are also generated to test the notion that human capital and open markets are complementary factors to patent protection as stimuli to innovation (Maskus, 2000). The interaction term of the price control policy and "PAT" is generated to examine the linkages between patent protection and other industry policy. To test the validity of theories that there is an optimal level of intellectual property rights strength, I construct several variables: the squared term of the IPR composite score (Ginarte and Park, 1997), the interaction term of this composite score with "PAT", and the quintile dummies of the IPR score.

Section 5. Methodology

5.1. Matched Sampling[29]

Grouping countries with similar characteristics according to a single country variable, as done by Ginarte and Park (1997), only balances the countries on this particular variable, and does not help to eliminate biases due to disparities in other variables. The challenge is to find a composite score that encompasses all the country characteristics that are deemed to be important both for the probability of implementing domestic patent protection and for innovative activity in the country.

[28] These supporting programs include public assistance for basic R&D in universities and research institutes, extension services in agricultural science, promotion of commercialization of the public research breakthroughs, and encouragement for collaboration among private and public enterprises, *et cetera* (Maskus, p202, 2000).
[29] Matched sampling is a method for selecting units from a large pool of potential controls to form a reduced control group that has similar distributions of observed covariates to a treated group (Rosenbaum and Rubin 1985).

Each new-patent country can then be matched to a no-patent (or always-patent) country by ordering the values of this composite score among all the no-patent (or always-patent) countries and finding the country whose score is the closest to that of the new-patent country to be matched. The propensity score method[30] and the Mahalanobis matching method are two ways to calculate this composite score. Such non-parametric matching method is used instead of the Heckman procedure mainly because the decision of patent implementation is too complicated and idiosyncratic to model. An important diagnostic check for the effectiveness of a matching method is the covariate balance—the degree of similarity in country characteristics between the no-patent (or always-patent) and new-patent countries—within matched pairs (Rosenbaum and Rubin, 1984). Both the propensity scores and Mahalanobis distances can be thought of as instruments for covariate balance. As long as the country characteristics are similar after matching, it does not matter which method is adopted to achieve such balance. It is also important to recognize that the matching procedures do not involve the outcome variable at all, so that there is no chance of biasing results in favor of one patent condition versus the other during matching.

Mahalanobis matching is widely used in multivariate analyses (Gnanadesikan, 1997). The main advantage of using this method is its greater flexibility and accuracy in individual country matching, which results in country pairs that are most suitable for pair-wise statistical analyses. This method matches the points in a multi-dimensional space according to the distances between two points (Rosenbaum and Rubin 1985). In this study, the coordinates of the multi-dimensional space are the matching variables and the points to be matched are the sampled countries. The distance between any two countries is calculated as a function of the differences in the matching variables (Appendix V). The Mahalanobis method collapses the set of country covariates into a scalar distance score. Because this study conducts a two-way comparison, two control groups are defined (Section 3) to test robustness of the results. Each match is done by finding the country in a control group

[30] Propensity score methods have recently been introduced into the economics literature to balance treatment and control groups in non-randomized experiments [Dehejia and Wahba (1999); Garuda (2000); Benjamin (2000)]. This study attempted to adopt D'Agostino and Rubin (2000)'s method of calculating propensity scores—the probability of patent law implementation based on the countries' characteristics—with partially missing data. Unfortunately, the serious missing data problem in the initial data set, the industry variables from UNIDO in particular, requires estimating a large number of parameters, which are not supported by the sample size in this study.

that has the minimum Mahalanobis distance to the new-patent country. Please refer to Exhibit for the list of matched countries.

The balance of the covariates before and after matching is displayed in Tables 1 & 2. Comparing the t-statistics, we clearly see that the covariates are much more balanced after matching[31]. The matching balances the covariates between the new-patent and always-patent group better because always-patent countries are more numerous than no-patent countries.

5.2. Regression Models

5.2.1. Regressions on the entire matched sample.

Although this study attempts to match on and control for an extensive list of variables that are correlated with a country's innovative potential, biases may still exist due to incomplete controls. This is addressed by using a panel data regression method (Rubin & Thomas, 2000). The formal regression model is estimated on these two groups of matched pairs (Set 1: no-patent & new-patent pairs and Set 2: always-patent & new-patent pairs) separately:

$$RESPONSE_{i,j,t+n} = \beta_0 + \beta_1 * PAT_{i,j} + \beta_2 * PATMOD_{i,j} + \beta_3 * INTERACT_{i,j} + \beta_4 * COVARIATES_{i,j} + \beta_5 * D_t + \beta_6 * RESPONSE_{i,j,t} + \varepsilon_i \quad (1)$$[32]

Where "β_0" consists of the pair specific-effects. That is, $\beta_0 = \alpha_1 * D_1 + \alpha_2 * D_2 + \ldots + \alpha_m * D_m = \Sigma_{j=1}^{m} \alpha_j * D_j$. D_j is the indicator variable for pair j, which takes on value 1 if the observation belongs to pair j, and 0 otherwise. "$PAT_{i,j}$" is the dummy indicator of whether the country j in pair i changed product patent laws or not[33]. All the countries in the control group (that has not experienced law change during the period under examination) had process patents. "$RESPONSE_{i,j,t+n}$" is the

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[31] There are five variables that carry statistically significant differences between the new-patent and no-patent groups and two variables between the new-patent and always-patent groups at the 5% significance level, as opposed to ten and nine before matching (eleven of these nineteen variables are significant even at the 1% level before matching). Finding pairs in the no-patent group is extremely difficult, especially in the later periods, because only sixteen WTO member countries remain without pharmaceutical product patent laws by the year 1999. The variables that remain statistically significantly different across groups may not succumb to the linear assumption that regression model assumes for all observation units. I therefore generate quadratic and appropriate interaction terms for these variables to attempt to overcome the limitation of linear regressions.

[32] This is a panel regression model, where a group structure is defined – pair in this case. Please see Ashenfelter and Krueger (1994) for a classical application of this econometric method. Model 1 is computationally equivalent to the residual regression model that is widely applied in economics literature (Mundlak, 1961), which specifies a pair-wise regression where each observation is the difference in the various variables between the two countries in a pair.

[33] Pharmaceutical patent laws are quite separate from other patent laws. Empirically, the probability that a country has a change in drug patents and other areas at the same time is less than 5%.

outcome variable of each country j of pair i in the reduced sample in period (or year) t+n (n years after patent implementation). A similar definition applies to "$RESPONSE_{i,j,t}$" for period (or year) t. For the first specification, the outcome variable is the increase in the US patent awards after the new patent implementation[34]. In the second set of specifications, I use the R&D expenditure in pharmaceuticals as the outcome variable.

"D_t" stands for the five dummy variables for each of the periods. (eg. D_t takes on value 1 if pair i is matched when examining the period 1978-83, and the other four period dummies for pair i have value 0.) "PAT" and "PATMOD" are as defined in Section 3 (Also see the Data Appendix). "INTERACT" is the vector of interaction variables specified in Section 4.3. "COVARIATES" refers to a vector of control variables. The regression residual is denoted by ε_i.

Limited by the sample size and by the fact that some countries with similar characteristics tend to implement national patent laws in the same period, some countries are matched to more than one other country and therefore appear more than once in the observations. The observations in model 1 are then not entirely independent of each other, which biases the t-statistics upward. An alternative model is used to test robustness[35].

Since regression models using the different years of US patent awards as outcome variables differ in the degree of freedom available and in turn the number of independent variables included, seemingly unrelated regressions are adopted to obtain GLS estimators.

5.2.2. Regressions on the sample of OECD countries.

In testing the impacts of national patent protection on the R&D incentives, I first use the sample of twenty-three countries whose actual pharmaceutical R&D expenditures are observed. I

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[34] Preliminary regression using the difference in US patent award counts of consecutive years yields a very low adjusted R^2. Therefore the regression model is refined such that the left hand side response variable is simply the number of US patents after national patent legislation, and the US patent counts of the previous year (or period) are moved to the right hand side. This in effect is taking the difference of the two US patent awards variables.

[35] $RESPONSE_{i,j,t+n} = \beta_0 + \beta_1 * PAT_{i,j} + \beta_2 * PATMOD_{i,j} + \beta_3 * INTERACT_{i,j} + \beta_4 * COVARIATES_{i,j} + \beta_5 * D_t + \beta_6 * RESPONSE_{i,j,t} + \varepsilon_i$ (2)

Model 2 resembles model 1, except that β_0 is simply the constant term instead of the linear combination of pair dummies in model 1. It is employed so that each country appears in the regression only once. However, the limitation of model 2 is that it assumes a common linear relationship between the outcome variable and the control variables for the entire covariate space, which may not actually apply for the covariates across different pairs. This model is only useful for robustness tests.

analyze the other countries using the imputed R&D data separately. Due to the small sample size of the OECD countries, I made two modifications to the analyses in 5.2.1 when using the US patent awards as the outcome variable or the imputed R&D. I define only one control group – countries that did not change their national pharmaceutical patent laws during a particular period t – to form a base of comparison for the new-patent countries. I also do not define pairs here. In order to check the covariate balances, I tabulated the summary statistics for the relevant covariates and their significance level of differences between the control and new-patent countries. Again, the new-patent countries are shown to be significantly different from the no-patent or always-patent countries in GDP, per capita PPP, pharmaceutical output and employment (Table 6a). Plots of some of these significantly different variables clearly show that there are a few outlier countries whose income, pharmaceutical output and employment levels are much higher than the majority of other sampling countries: UK, FRANCE, Germany, Italy, Japan, and US. With all the observations included, regression will tend to estimate centered on higher covariate means resulting from these countries with extremely large covariate values. These outlier observations are therefore removed from the sample, and the covariate balances are significantly improved (Table 6b)[36].

One would ideally like to run separate regressions for each period. However, this is not possible given that only a few OECD countries changed domestic patent laws in each period[37]. I therefore stack the observations of the four periods together to form a panel, and the panel method is again applied, but taking the period-specific effects as the fixed effects[38].

$$R\&D_{i,j,t+n} = \beta_0 + \beta_1 * PAT_{i,j} + \beta_2 * PATMOD_{i,j} + \beta_3 * INTERACT_{i,j} + \beta_4 * COVARIATES_{i,j} + \beta_5 * D_{period}^{t} + \beta_6 * R\&D_{i,j,t} + \varepsilon_i \qquad (4)$$

Where β_0 is the constant term. "$INTERACT_{i,j}$", and "$COVARIATES_{i,j}$" are similar to those in model 3, except that now the i subscript refers to period i instead of pair i. "$R\&D_{i,j}$" is the post-patent R&D expenditures of each country j of period i in the sample.

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[36] This finding naturally casts doubt on the results obtained in previous literature where the OECD countries as a group are used as control to test against any changes in the R&D or patenting behavior in the new-patent countries.

[37] The period with the largest number of new-patent countries is period three (years 1986-90). The cross-sectional regression applied to this period only yields the regression coefficients without corresponding standard errors.

[38] This fixed-effect model is the same as the cross-sectional model for each of the four periods, except it adds an additional constraint on the coefficients to be the same across the four periods.

5.2.3. Robustness Regressions.

In order to obtain robust results, regressions based on three different likelihood functions are employed: the normal regression, the least absolute value (LAV) regression, and the Huber regression. LAV regression, also known as the minimum L1-norm regression, assumes a Laplace distribution for the data, and obtains the MLE through minimizing the absolute value of the deviation of data points from the mean. Minimizing Bayes (average) risk is, however, only one of the two main approaches in classical decision theory (Chamberlain, Note 3a, p 16, 2000). The other is the *minimax* approach, which minimizes maximum risk. Huber regression does exactly this by assuming a least-favorable distribution for the data within a class of distributions, and obtains the MLE from this distribution, which is known as the Huber distribution[39]. The latter two regression specifications are particularly good at avoiding influences due to outliers in the outcome variable. If the distribution is exactly normal, then least-square is the maximum likelihood and the standard normal regression provides better estimates than the LAV[40] or Huber regressions. All three regressions are therefore performed in order to obtain robust results. All the above three types of regression assume linearity between the outcome variable and each control variable. This assumption is tested with scatter plots between the transformed outcome variable and each of the transformed country covariates.

Section 6. Results

6.0 Preliminary Estimation

[39] The Huber distribution is a type of contaminated normal distribution, where a random variable (the outcome variable, for instance) is drawn from a standard normal distribution with probability (1-φ) and from an alternative distribution (such as Cauchy or Laplace) with probability φ. In the regression analyses of this study, this parameter is determined through several iterations to find the value that is most suitable to describe the data distribution.

[40] Monte Carlo research suggests that standard errors calculated with the LAV regressions sometimes underestimate the true sample-to-sample variation, particularly with small samples (Stata5 Manual). Therefore, the standard errors in the LAV regressions are obtained through empirical bootstrapping (data resampling).

To provide some preliminary test of the question of interest, this study regresses the forwarded[41] pharmaceutical US patent awards on an indicator variable that takes on value 1 if a country has pharmaceutical patent law in year t and 0 otherwise, the US patent awards for all products except the pharmaceuticals, and the country dummies. The resulting coefficient on the patent implementation indicator is statistically insignificant (with mean 7.34 and standard error 10.91). While the total number of US patent awards except pharmaceuticals acts as a control for confounding shocks to innovations, it has limitations. In particular, when countries decisions to implement patent protection in pharmaceuticals coincides with that in other industries, the patent effect on pharmaceutical innovation may be washed away by its similar effect on other innovations, as measured by the control variable here. The matched sampling combined with pair-wise regression methodology effectively improves on this preliminary regression model.

6.1. Regression Results on the Main Independent Variables

6.1.1 Response variable specification one—US patent awards

After establishing the matched pairs through the Mahalanobis matching algorithm discussed in Section 5.1, I carry out regression analyses on the two sets of pairs following Model 1 specified in Section 5.2. Tables 4-6 have results for all countries and Tables 8-9 contain related results for OECD countries only. I first test the effects of national patent law on the change of US pharmaceutical patents awarded to domestic innovators after the national legislation. I use the US patent awards for a particular year after the establishment of the national laws[42] as the response variable. Specifically, three years (abbreviated as three-year forward), four-year forward, five-year forward, and the average of three- to five-years forward, are the markers used as alternative years for the outcome variables in a series of regressions. The average of three- to five-year forward US patent awards is used because the US patent awards may be subject to year-to-year fluctuations, while the individual year data specifications are also important because averaged data can erode important

[41] The number of patents awarded a few years after the domestic patent protection.

[42] In cases where the exact year of legal implementation is not confirmed, (for instance, Thailand either implemented national patent law in 1992 or 1993), the later year (for instance,1993) is used. When I use a longer-lagged structure for the outcome variable (for instance, in the case of four and five years forward awards), the sample size is too small to support the full model. As a result, I am compelled to use a reduced set of control variables.

trends. In all these regression specifications, no coefficient on patent implementation or modification indicators ("PAT" and "PATMOD") is found statistically significant at the 5% level[43]. In fact, after controlling for the interaction between patent implementation and per capita PPP, the coefficients on "PAT" are negative in some regressions. Neither a country's national pharmaceutical patent law nor its initial allowance of pharmaceutical process patents prior to the introduction of complete national patent laws has a statistically significant impact on the patent outcome.

Although patent implementation alone does not significantly impact the number of patents received from the USPTO, it nonetheless demonstrates some conditional importance with respect to a country's domestic development levels and its economic freedom. The detailed results of these interaction terms are discussed in Section 6.2.

6.1.2. Response variable specifications two & three – logged R&D expenditures and personnel

The US patent awards can be considered an estimate of innovation outputs, while R&D expenditures provide an estimate of innovation inputs. It is likely that the stimulus from patent protection could impact R&D much sooner than US patent grants. On average, it takes two years in the patent granting process (USPTO, 2000), not counting the time needed for drug development. The R&D for one year, two years, and one period after national patenting (one-year, two-year, and one-period forward[44]) are therefore specified as alternative outcomes. These regression specifications are carried out on the sampled OECD countries with their observed R&D data (Table 7). In addition, regressions with R&D one period forward are carried out separately on the pairs of the non-OECD countries (Bottom row in Table 3). Because their R&D outlays are imputed by period[45], it is not possible to test year-specific changes.

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[43] The results are robust in model 1 and 2 specifications.

[44] R&D expenditure is available from 1978-97 for most sampled OECD countries, with 1998 data available only for five countries. Therefore, R&D observations of three-year forward are too sparse to obtain accurate estimates on the main patent implementation variable.

[45] Annual industry level data is not extensive enough to provide meaningful imputations.

Most regressions yield no statistically significant results on either "PAT" or "PATMOD"[46]. The only statistically significant coefficient on the patent implementation indicator appears in the Huber regression of R&D two-year forward for the OECD countries, with a positive coefficient significant at the 5% level. A residual plot explains the disparity of results in applying normal or Laplace versus Huber regressions. There is an outlier in the data: Turkey experienced a drop in R&D expenditure from $10.09 million in 1992 to $.74 in 1994. While the standard normal and LAV regressions were likely skewed by this "influential" outlier, Huber regression successfully fits the optimal line for the remaining data points that tend to have similar R&D trends. This finding provides some evidence that the patent laws in certain OECD countries had a positive effect on domestic R&D activities two years after the legislation.

A series of robustness tests are carried out for the R&D outcome specification (Appendix II.a). The main results are the same: there is insufficient statistical evidence to reject the null hypothesis that patent implementations have not generally stimulated R&D incentives.

6.2. Results from the Interaction Terms

In the regressions using US patents as outcome variables, the high-income country indicator and "PAT" interaction variable bears positive signs, and some coefficients are statistically significant at the 5% or 1% level (Table 6, Columns 3 and 5). Similarly, the GDP per capita PPP and "PAT" interaction variable bears positive signs, statistically significant at 5% level in the OECD regressions with R&D as outcome variables (Table 8, Column 2). This suggests that the pharmaceutical patents are important conditional on the country's developmental level. A more developed country with pharmaceutical patents is likely to have more R&D incentive compared to a similarly developed country without patents, or a less developed country with patents.

The statistically significant negative coefficients on the interaction variable of the IPR composite score with "PAT" in the OECD regressions (Table 8, Columns 4&7) support the theory pioneered by Gallini (1992) that the relationship between patent strength and innovation adopts an

[46] In regressions, the "PATMOD" variable is disregarded because all the OECD countries, except Turkey, had process

"inverted U" shape. This result is further confirmed by the positive coefficients on the first quintile IPR score dummy and negative coefficients on the last quintile IPR score dummy (Table 7, Columns 6 to 8, although coefficients are not always statistically significant). Most OECD countries had pharmaceutical process patents before they introduced product patents; it is likely that a country's process innovations were effectively protected if its initial national IPR protection is strong. Additional product patents then may not stimulate innovation, as Scherer (1977) and Kumar (1996) also seem to suggest[47]. In fact, the strengthening of patent protection may block domestic initiatives to engage in "imitative" innovations, while "ingenious" innovation may not come easily and quickly. This leads to an overall decline in domestic R&D activities in the short run. An alternative explanation is that countries with a higher IPR index are more likely to effectively enforce a variety of laws that protect intellectual property, such as trade secret laws. Domestic innovators may have alternative ways to appropriate profits from their innovations.

No firm conclusions can be established on the conditional importance of patent protection given a country's education attainment or economic freedom, due to the mostly insignificant coefficients across various regressions. It is interesting to note, however, that the coefficients on the interaction variable of "PAT" and economic freedom index are positive and statistically significant at the 5% (or 1%) level in all the regressions with the OECD R&D as outcome variable (Table 9). This result hints at the possibility that in a highly integrated market as that formed by the OECD countries, the national patent law could complement a member country's open market access and favorable domestic investment policies to attract FDI and other forms of foreign technology transfers. It could also help domestic companies assimilating these inward technology transfers through patent disclosures. Economic freedom can also help countries with new patent systems to leverage their emerging national intellectual property advantages by facilitating exports.

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patents prior to their national product patent legislation.

[47] Scherer (1977) finds no clear relationship between the strength of intellectual property protection and the number of new drugs introduced per dollar of GDP (p39). Among his evidences is the fact that Switzerland and Denmark had the highest new drug to GDP ratio during 1940-75, when they protected only pharmaceutical processes**.** The US and Belgium, where both processes and products are protected, ranked third and fourth. Italy ranked thirteenth, although it had no pharmaceutical protection then. Canada only protected processes and had compulsory licensing during 1969-75 and ranked fifteenth (p38). Scherer's result is corroborated in Kumar (1996) for the food and chemicals industries. Kumar finds that the R&D intensity of majority-owned affiliates of US multinationals is no higher in countries that grant both product and process patents than it is in countries where only process patents are granted.

The price control and patent implementation interaction variable is omitted from the regressions for OECD countries due to a lack of variation in the small sample; most of them have some form of price control policy.

6.3. Regression Results for the Other Control Variables

In my numerous regression runs, the coefficients on the control variables have mostly been insignificant at the 5% level. This is indicative of the good covariate balances achieved through matching. The linear model does not need to adjust much for these covariates after the matching process. The full model controls for pharmaceutical exports to the US, GDP per capita PPP, GDP, GDP growth, the intellectual property rights composite score (IPR) by Ginarte and Park (1997), average years of schooling, economic freedom, Japanese and US foreign affiliate counts, UK legal origin, innovative potential, price control policy dummy, and pharmaceutical industry employment and output. I transform some of the variables by taking logarithms to fit the linear assumptions better. Because of the large amount of regressions completed, and because most coefficients on the control variables are statistically insignificant, it is meaningless to report all the results. I will only discuss some interesting results and their implications.

In almost all the regression runs, the coefficients on the "innovative potential" variable are positive and statistically significant at the 5% level when US patents is used as the outcome variable, and at the 10% level when R&D is used as the outcome variable. This illustrates the importance of a country's innovative potential in explaining the innovation differences between countries. While the true innovative potential of a country is obviously not directly observed, it can be partly captured in the variable constructed. The "innovative potential" variable is particularly important in regressions employing US patent awards as the response variable because, most likely, it also controls for the propensity of an innovator from any given country to patent their invention in the US. However, this propensity cannot be fully controlled for since innovators in the pharmaceutical industry may have different propensities compared to those in all other industries that this variable fails to capture.

The lagged pharmaceutical export to the US has statistically significant coefficients in the regressions with US patent awards as the response variable. This precisely echoes my intuition for controlling for the variable. The incentive to patent in the US is largely determined by the market potential innovators see and seek in the US. In addition, because trade between the two countries is a function of geographical distance, linguistic differences, and other variables that could affect foreign innovators' propensity for patenting in the US, controlling for trade values helps to control for these indirect variables. In fact, innovators of a given country are more likely to seek US patents if, historically, their country has exported more pharmaceuticals to the US market.

Although not statistically significant at the 5% level, the regressions show a negative relationship between a country's price control policy and the response variables. This finding is in agreement with others' (Grabowski & Vernon, 1992; Danzon, 1996) that price control policy tends to impair domestic innovation, evinced by the fewer patents obtained in the US and less R&D.

In all the fixed effect regressions, the F-statistics for the group of paired dummies are statistically significant at the 5% level, many of them are significant even at the 1% level. This reinforces the importance of pair-specific effects and again reconfirms the methodological significance of the matching technique.

Section 7. Discussions

The empirical findings that national patent protection alone does not lead to a positive jump in innovation, as estimated by US patent awards and R&D expenditure, is hardly surprising. Some developing countries have always had patent protection, yet domestically they do not have innovative potential and rely heavily on imports. For instance, patent application data from the EPO and awards data from the USPTO show that French West Africa never applied for or obtained any pharmaceutical patent from these two offices during 1978-2000, despite its well-established national patent laws.

It is also possible that the lack of a statistically significant increase in the US patent awards after national patent legislation is linked to data limitations, most of which are discussed in detail in Section 4 and Appendix I. First, the US patents data are only evaluated in years shortly after

national patent legislation for a number of sampling countries[48]. Second, as discussed in Section 4.1, the examination of US patent awards only captures the main innovations that reach the US patent granting standard. Third, the TRIPs agreements were not reached until the final moments of the Uruguay Round negotiation, and innovators may have been uncertain about the future of patent protection. The aforementioned difficulty developing countries face in training legal personnel and in enforcing their domestic patent laws can also add to innovators' hesitation to engage in R&D activities.

Nevertheless, the findings in this study have important policy implications. They vindicate Maskus' (2000) argument that "expectations that stronger IPRs alone will bring technical change and growth are likely to be frustrated" (p199). Countries with different degrees of development, general intellectual property strength, and economic freedom have varying innovative responses to changes in national patent law, as evidenced in the domestic pharmaceutical R&D levels and the number of drug patents obtained in the US. Most of these country characteristics indeed go hand in hand with each other. Kumar (1996) finds a positive relationship between the R&D intensity of US affiliates and the strength of the country's intellectual property rights only in developed countries, but not in developing ones. Many developed countries, including UK, Germany, and Switzerland, had opposed national patent legislation when they were technology importers (Chang, 2001). These countries took advantage of the freely accessible foreign technologies during their industrialization process. Evenson (1990) argues that countries have no interest in strong intellectual property rights until they become significant technology exporters. WTO advocates may argue that the TRIPs agreements already allow for adjustment time, since developing countries had a grace period of five years and the least developed countries had ten years[49]. However, it is unlikely to see developing countries transform from mere "technology importers" to even moderate "technology exporters" within this short timeframe.

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[48] Because the outcome variables are only observed up until 1999, the ten countries that implemented national pharmaceutical product patents in 1996-97 are naturally omitted in the regressions when using four- or five-year forward US patent awards or domestic R&D as the outcome variable specifications. I attempted to use the US patent awards ten years after the patent implementation as one outcome specification in a two-stage regression model, but only five of the sampling countries implemented their patents early enough to have observations for this particular outcome.

[49] I thank Dr. Calestous Juma for bringing up this concern.

Furthermore, it may be important for developing countries to have a discriminatory national patent system to help domestic companies move down their learning curves and gradually learn to innovate. National patenting could bring welfare gains to a country if innovation is stimulated and particularly if the innovation is originated by nationals. Previous research shows that, in many cases, domestic patent law mainly benefits foreign innovators since producer surplus is captured mostly by foreigners (Lanjouw 1998 and McFetridge 1996). Therefore, it is in the developing countries' interest to grant patents only to nationals but not foreigners. In addition, if patent laws in developing countries could help stimulate innovations that target nation- or region-specific diseases, then the optimal strategy for the developing countries is to grant patents to all innovators, including nationals and foreigners, but only for underdeveloped drugs. After all, why not tackle the source of the problem by targeting most drugs that are most urgently in need of development? Though economically sound, these policies are unlikely due to the WTO norms of non-discrimination and reciprocity. To borrow Schiff's (1971) phrases in answering the feasibility of a unilateral discriminatory patent policy, "economically, the answer is yes…[but] politically, the answer is no" (p26).

Section 8. Conclusions

After controlling for a list of country and industry level variables that are likely to affect innovative potentials, there is no statistically significant relationship between national pharmaceutical patent protection and US patent awards or domestic R&D. However, the interaction of national patent law implementation with development level is shown to have positive relationship with the domestic R&D expenditure and domestic pharmaceutical patent awards in the US, three to five years after national patent implementation. The interaction of national patent law implementation and the economic freedom index is positively related to the R&D expenditure in the OECD countries. Furthermore, there appears to be an optimal level of intellectual property rights regulation above which further enhancement of protection is actually associated with a decline in innovative activities. In short, for countries that have relatively low levels of development and market freedom,

the net domestic welfare change due to patent protection is clear: rent transfers to foreigners immediately follow the national patent legislation (Fig 2), while any benefits from additional innovation depend ultimately on the country's macroeconomic factors and require a substantial time-discount (Fig. 3a and b).

This paper successfully tackles two obstacles in the economic literature of technological changes. The first obstacle arises from data deficiency and the second from methodological limitations. This study begins with a rigorous study design and constructs a database that approaches the ideal experimental data, given the limitations of observational studies. In the literature of technological advances, this study is among the first to adopt matched sampling method combined with fixed effects panel regressions (Rubin and Thomas, 2000). The lack of observation of counterfactual outcomes—what would have happened in the presence or absence of national patent law—for a given country, necessitates international comparisons. In previous studies involving developed countries, the natural benchmarks for comparisons are other developed countries, notably OECD countries, whose country level and industry level data are readily available in substantial detail. The choice of control groups becomes much more obscure when one intends to study countries at various income and developmental levels, as is the case here. One key innovation of this study is to apply the Mahalanobis matching method to overcome the missing data difficulties, and to match countries of similar characteristics. Fixed pair-effects regression models on the sample of matched countries control well the various country characteristics—both observed and unobserved—which are correlated with latent innovative potential and are important for explaining the R&D expenditure and US patent grants outcomes.

Although this study yields interesting results, it is only the first analysis of the many to follow on this topic. One of the next steps that I am carrying out is to carry out similar tests for other industries besides pharmaceuticals. Furthermore, this study alludes to many relevant questions. For instance, to test the changes in a country's US and Japanese FDI pre- and post-patent legislation, and the impact of national legislation on pharmaceutical trade balance, using pharmaceutical exports

and imports data for each country. In addition to testing the effects of patent coverage on innovation, the effects of patent duration[50] changes would also be an interesting topic to investigate.

Chapter 9. Bibiliography

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APPENDIX I. Data Appendix

A. The Choice of US Patent Awards Data as the Main Outcome Variable and the Details About the US Patent Data Listed by SIC and Country of Origin.

a. Choice of US patent awards as outcome variable over other alternatives.

There are three patent measures available in the data I gathered. One is the annual patent application data of each country from 1975-1997, published in the Industrial Property Statistics by World Intellectual Property Organization (WIPO). The second one is the annual data of the United States on patents awarded listed by industry and by country of origin from 1978-1999, collected in a "Patenting Trends in the US, 1999" CD-ROM published by the United States Patent and Trademark Office (USPTO). The third one is the patent applications and awards data from the European Patent Office (EPO) listed by country of origin from 1978-2000. All three sources of patent data are listed according to the innovator's country of residence.

The problem with the WIPO data is that it could be difficult to control for the idiosyncratic patent system differences in different countries. The number of patent applications may not be comparable across countries. In addition, the number of domestic patent applications in a country could be a direct outcome of the domestic patent system, instead of the indirect outcome of innovation activities. For example, a country without a domestic patent system will naturally have no domestic patent applications. Non-informative changes in the patent counts also occur in the cases of patent law modifications. For instance, when Japan's patent laws changed from limiting one-claim per patent application to allowing multi-claims in 1988, there was a significant drop in the number of patent applications that does not necessarily reflect a decrease in innovation activity.

The EPO patent application data are obtained with the kind help of Mr. Marc Nicolas at the EPO. Applications are filed directly under the European Patent Convention (EPC). The EPC is an agreement established in 1973. According to this convention, patent applications are submitted to the EPO, a supranational organization in Munich, where the application is examined and a patent can be granted for all the member states chosen by the applicants. Applications are all treated the same way, regardless of origin. When applying for a European patent, an applicant has to indicate for which country(ies) he/she seeks patent protection. This is shown on the application form by the

list of the member states with tick boxes. At the moment of filing, the choice is purely indicative and non-binding (since the change in 1997). At the stage when the applicant decides to continue in the examination phase, he/she has to pay designation fees: one set of fees per designated country with a maximum amount of 350 DEM.

There are several factors that make the EPO data less desirable as an estimate for innovation than the US patent data. First, the number of EPO member states has grown over the period of 1973-2000, from seven in 1973 to twenty in 2000. This enlargement may increase the incentives to apply for the EPO patent. The increase in the EPO patent applications or grants may simply be due to a switch from applying to individual national patents to applying to EPO patents, rather than the increase in innovation. In addition, the distortion of incentive to file EPO patent may not be uniform across innovators. An innovator who is interested in seeking protection in the new member countries is more likely to switch their patent applications from individual national offices to the EPO. Second, there are two fee reduction changes made to the EPO applications in 1997 and 1999, respectively. In particular, the July 1999 amendment increases the maximum amount designation fees to be equivalent to the designation of seven states. All additional designation is free. Search fees were also slightly reduced. The application data after 1997 may not be comparable to those before, due to a possible increase in the incentives to file. In addition, the incentive to file EPO patent applications may not increase uniformly for all innovators because the 1999 amendment will affect the innovators who are interested in designating more than seven states, but not the others.

The "Patenting Trends in the US" CD-ROM lists patent awards to innovators from ninety-three countries in total, including US itself, covering the years 1978-1999. The data are listed by industry, using the Standard Industrial Classification (SIC) codes. The patents for drug and medicine are classified to the SIC code 283[51]. The US observation is dropped mainly because it has extremely high patent counts compared to any other countries. This is partly attributable to the fact that US patents constitute domestic patenting for US innovators, but foreign patenting for innovators from other countries. There are therefore ninety-two countries in total in the sample, and all these

[51] The US Patent and Trademark Office (USPTO) Technology Assessment and Forecast (TAF) Branch, has established a concordance between the U.S. Patent Classification System (USPCS), used to classify U.S. patent grants and 55 product fields based on the 1972 Standard Industrial Classification (SIC) system. The data used are

countries have some propensity to file patents in the US, as reflected by a non-zero count of total US patent awards over all the years.

The Patent and Trademark Office (PTO), Technology Assessment and Forecast (TAF) Branch, has established a concordance between the U.S. Patent Classification System (USPCS) and fifty-five product fields based on the 1972 Standard Industrial Classification (SIC) system. U.S. patent grants are placed in more than one subclass of the USPCS if they disclose information pertinent to more than one subclass. One of these subclasses is designated as the 'original' classification of the patent, and the remainder, if any, are designated as 'cross-reference' classifications. In the "Patenting Trend in the US" CD-ROM, only a patent's 'original' classification is considered. Details on the concordance can be found in "Review and Assessment of the OTAF Concordance between the U.S. Patent Classification and the Standard Industrial Classification System: Final Report, OTAF, 1984". This CD-ROM lists patent grants by year of grant and by state or country of origin, for each product field. Patent origin is based on the residence, at the time of grant, of the first-named inventor listed on the patent. The product field used for this study is the "Drug and Medicine" sector, which is listed under SIC code of 283. In principle, patent application would be a better estimate than the patent awards data. This is because patent awards may introduce lags in processing times, making the exact corresponding year of innovative activity unpredictable. However, patent application data is not available from the USPTO. Pharmaceutical patent applications are normally filed near the end of pre-clinical work and issued in the clinical testing stage (Scherer & Weisburst, p1016, 1995).

b. Concerns using the US patent awards as innovation measures.

Chapter 4.1 discusses some concerns and suggested solutions on using US patents as an estimate of innovation, one other concern about the use of US patent awards is that there may be tax evasion incentives for some Multinational Enterprises to file from different countries. Such MNE patent application policies may contaminate the patent awards data. Because the data are listed according to the country of residence of inventor and not that of assignees, this MNE patenting

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U.S. utility patents granted during the period 1963 to 1999 (with aggregated patent counts for 1963-1977, and year-by-year listings for patents since 1978). Plant patents and design patents are not included.

complication does not influence my analyses. Suppose a US subsidiary located in China carries out innovation in pharmaceuticals: the patent award will always be listed under the entry of China as the country of origin. Only the "assignee"[52] of the patent will differ, being either the Chinese subsidiary or the US headquarters, depending on the MNE's preference.

It would be interesting to test the different changes in the MNE's innovations in a country that changed patent laws, and the changes in the national corporations. Unfortunately, such disaggregate data are not available for the US patent awards, European Patent Office (EPO) patent applications and grants, or the R&D expenditure variable. This does not hurt the main analyses of the study, however, as any patent filings of the residents reflect the domestic innovation level, whether the inventor is a foreigner or a national. If the innovator is a national, then Figure 3a and b in Chapter 2 promise a producer surplus for the country. But if the innovator is a foreigner in the country, typically an MNE subsidiary, then the fact that the innovation takes place in the country suggests that the research laboratory is in the country, and there are potential knowledge spillovers to benefit the country. Similarly, R&D expenditure, the alternative estimate of innovation, include R&D activities of both national companies and MNE and reflect domestic innovative incentives of a country.

One may also question the validity of estimating innovation with the US patent awards based on the doubt that innovators may simply change the location of patenting to domestic once a national patent law is in place. The US patent counts would then not capture these additional innovations. This may not be important given that US is the largest market in the World, and the marginal cost of filing an additional patent application is mitigated with the various international treaties since the 1950s (Notably the Patent Cooperative Treaty among the WIPO members in 1973).

Although the US patent awards data provides the best estimate available for this study, it is still worth acknowledging its limitations. The value of an innovation is not fully measured by the patent counts, because of the existence of asymmetric information between the innovators (patent applicants) and the patent offices (Cornelli and Schankerman 1999, and Scotchmer 1999). The

[52] Assignee refers to the party who claims the patent royalty. I thank Professor Mike Scherer for pointing out the difference between country listings of assignee and innovator.

renewal fee scheme could serve to overcome such problems, as the innovators decide which patent length they are willing to pay for, according to the importance of their innovations. Using the renewal data, Pakes and Schankerman (1998) find that the average European patent has an economic life of four years, with a confidence interval from 2.8 to 5.6 years. However, the distribution of patent life is very skewed, with only a few high value innovations that have correspondingly longer life spans. In light of this literature, I intended to further research by bringing renewal fees structure into the outcome variable. However, these data are not available for either the US patents or the European patents. According to the USPTO, only aggregate data are available for summarizing how many patents were renewed each year listed by year of grant.

The outcome estimate could be improved upon by bringing the propensity to patent in the US, as well as the propensity to patent patentable innovations. Evenson (1984) documents the number of US patent awards to twenty-five originating countries as percentages of total foreign patent awards to these countries in the year 1981. His table shows that the US has the highest percentage as compared to the other patent granting countries, although the US patent grants certainly cannot capture all the patentable innovations in all countries (Table 5.5, p106). Because only one year of data is listed in the table for the twenty-five countries, no statistical inference could be drawn upon for my study. In addition, such data for the pharmaceutical industry are not available separately[53].

B. Country covariates

"PAT" and "PATMOD" – These two indicator variables are constructed for the periods in this study by cross-referencing several different sources. Among them are the Ginarte and Park (1997) patent coverage index, the WIPO documents on harmonizing patent laws, the country reports and "Super 301 list" published by the U.S. Department of Commerce, and the compiled patent laws folio at the Harvard Law library. The Ginarte and Park index covers seventy of the countries in my sample. I

[53] I have contacted the International Patent Documentation Center (INPADOC), and was not able to obtain further data on the US pharmaceutical patent grants as a share of total world patents by country by year.

assigned the indicator values for the remaining twenty-two countries by looking up the other sources mentioned above. All sources are listed in Chapter 8. In a few cases, where different sources provide conflicting information on when a particular country started implementing pharmaceutical patents, I gained clarification by contacting individual patent offices.

GDP, real GDP growth, and GDP per capita PPP – These three variables are available for eighty-five out of the ninety-two sampling countries. They are obtained from the World Development Indicator (WDI) database published by the World Bank (2000). This database contains data for over 200 countries from 1960 to 2000, although the GDP per capita PPP data are only available from 1975 onwards.

Average Years of Schooling for Total Population -- This education attainment variable has data for sixty-five sampling countries[54] (Barro and Lee, 2000). Data is available at a five-year interval from 1960-1999. Although a more relevant estimate of the sector-specific human capital might be the average education attainment of employees in the pharmaceutical industry, such data is not available.

Economic freedom -- estimated using the Fraser Institute composite index, which takes into account a number of government policies and openness factors[55].

Legal family -- This index identifies the legal origin of the Company Law or Commercial Code of each country. The five origins are English Common Law, French Commercial Code, German Commercial Code, Scandinavian Commercial Code, and Socialist/Communist Laws (La Porta *et al.*, 1996). The legal origin variables are included considering their importance both for patent implementation and protection itself (Lerner, 2000a), and for appropriating the returns on investment (La Porta *et al.* 1996).

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[54] I intended to apply the perpetual inventory method to impute similar data for the other sampling countries, but unfortunately was not able to find data for the component variables for these countries. (The school enrollment data for these countries are missing in both the WDI and the UNESCO databases.)

[55] I thank Professor Park for his reference on this index. Please refer to the detailed component listings in the appendix table.

Innovative Potential -- The variable takes value 6 if patent awards surpass 1000, 5 if patent count is under 1000 but greater than 100, 4 if patent count is under 100 but greater than 6, 3 if patent count is between 6 and 1, and 1 if no patent is awarded at all[56].

Pharmaceutical industry employment and output -- extracted from the Industrial Statistics CD-ROM published by the United Nations Industrial Development Organization (UNIDO). The database lists these variables by country and by industry (as classified by the 4-digit International Standard Industrial Classification codes), covering the years 1978-1999. The pharmaceutical industry is listed under the code 3522. Comprehensive as it is, the database still has many missing values. The employment and output variables are observed for only fifty of the sampling countries. Data for these two variables are augmented with the OECD Structural Analysis (STAN) database, the UN Industrial Statistics Yearbook, and national statistical abstracts of some countries. Industry output data from these extra sources are converted to US dollars using the annual exchange rates published in the International Financial Statistics (IFS). The compatibility of the data from these different sources is verified using a random sample of countries where data are available in all these sources.

US FDI -- Because of confidentiality for MNEs, the detailed asset and R&D data at the foreign subsidiaries in the pharmaceutical industry are not released. Instead, Dr. Fritz Foley at the BEA kindly released the US foreign subsidiary counts listed by country, and he also provided me with the information that the correlations between these subsidiary counts and assets (and R&D outlays) when computed year by year lie between .724 and .934. Thus, the subsidiary counts can act as an estimate for the technology transfer from the US to the different countries.

Japanese FDI -- Similarly, I obtained the Japanese foreign subsidiary counts data in pharmaceutical industry from Professor Paul Beamish at the University of Western Ontario. Because the US and Japanese R&D spending per subsidiary can be quite different, I decided to keep the two counts as

[56] These threshold values are taken by tabulating the quartiles of the variable on total US patent awards in all other industries.

separate variables rather than merging them together in the regression specifications. These two variables are fully observed for all the ninety-two sampling countries.

Country's Pharmaceutical Exports to the US -- The World Trade Analyzer database produced by Statistics Canada provides a data source for the imports of US listed by country and by industry from 1980-1996. The database lists the different industries according to the Standard International Trade Classification (SITC), under which code fifty-four corresponds to the medicinal and pharmaceutical products. Since the database covers only the manufacturing industries, the pharmaceutical exports refer to the manufactured products. The data for the pharmaceutical exports to the US (or, equivalently, US imports) are available for all the sampling countries.

Price Control -- This variable is constructed by cross-referencing several sources, including the country reports published by the US Department of Commerce, the Economic Intelligence Unit (EIU) database, the price control component of the Fraser Institute economic freedom index, the OECD report for pharmaceutical industry, Danzon 1997, and other documents online via the Google search engine.

IPR Strength Score -- It is an unweighted sum of five component indices, including the domestic patentability of seven product categories, the membership a country has in international agreements, the duration of national patent protection, protection of losses from compulsory licensing, revocation of patents, *et cetera*, and the enforcement evaluation of a patent system (Ginarte and Park, 1997). The inclusion of this variable also helps to control for the enforcement of national pharmaceutical patent laws, correcting possible loopholes that the simple patent coverage indicator does not account for—the lack of enforcement of national patent laws in some countries.

qIPR – It is a categorical variable that takes on values 1 to 5 for the corresponding quintiles of the IPR strength Score. Five dummy variables for each quintile of IPR are then generated by tabulating the qIPR variable.

Treat – It is a predicted outcome variable from the regression of patent implementation indicator variable on the process patent indicator and the set of interaction variables.

Another two industry level variables that are considered to be relevant for innovation are the capital investments and the number of firms in the domestic market. Unfortunately, these two variables are missing a large number of data in the UNIDO database. Although these two variables could be relevant for innovation outcome, they are not directly linked to the decision of patent legislation. Econometric theory says that such omitted variables will not bias the regression coefficient of innovation on the patent law indicator variable.

C. Imputation of the R&D data

The Analytical Business Enterprise Research and Development (ANBERD) database provides R&D expenditure data listed by industry for sixteen of the largest OECD R&D performing countries: Australia, Belgium, Canada, Denmark, Finland, France, West Germany as well as Germany, Ireland, Italy, Japan, the Netherlands, Norway, Spain, Sweden, the United Kingdom and the United States. Industrial research & development (R&D) is defined as R&D activities carried out in the business enterprise sector, regardless of the origin of funding. While the government and higher education sectors also carry out R&D activities, industrial R&D remains the most closely linked to the creation of new products. To make the data comparable across nations over time, the ANBERD estimates are measured in current PPP$, where the PPP's are based on a comparison of consumer goods' prices. Although the consumer goods' prices could effectively adjust the wage differentials across nations, the expenditure on equipment should ideally be converted using capital goods prices. However, data on either capital goods prices or producer prices are too sparse for me to reconvert the R&D. In addition, I find R&D data for twenty-three OECD countries in the OECD Health Care CD-ROM, which includes the fifteen countries (except East Germany) found in the ANBERD. The original data is listed at national currency units. To merge this data with the ANBERD data, I convert the R&D data into PPP dollars. This is done by first converting the R&D data from national currency measure to US dollars using the current year market exchange rate

published in the IFS, and then dividing the R&D at current year US dollars by the PPP based on consumer prices published in the Penn World Table (PWT 5.6)[57]. Because the PPP index is only available from 1978-1992, the values for years after 1992 are computed by using the consumer price index published in the IFS. This study uses the equation below to impute these later year PPP values:

$PPP_{t+1} = PPP_t * (CPI_{t+1} / CPI_t)$, where t denotes year t. After this conversion, the data obtained from the Health Care CD-ROM almost equal that of the ANBERD database for the fifteen countries whose data are collected in both databases. The minimum value of the R&D spending among these fifteen countries is 1.79 million PPP$, and the maximum difference in values between R&D data from the two databases is only 91.3 PPP$.

A more crude measure than the R&D expenditure may be the R&D personnel, including scientists, engineers, technicians and any other employees involved in R&D. This variable is even less available than the R&D expenditure, it is only observed for ten OECD countries from 1987-1996, with data missing in certain years. This variable is also used in one of the regression specifications to test robustness of results.

Total R&D expenditure at the country level comes from the World Development Indicator database, and is defined as the "current and capital expenditures on creative, systematic activity that increases the stock of knowledge". Fundamental and applied research and experimental development work leading to new devices, products, or processes are included in the expenditure account. There are many missing data points, especially in the years before 1990. I use simple interpolation to fill in missing R&D data in the cases where I can, since the total R&D time series tends to be smooth.

I specify the model below to impute in industry level R&D for the non-OECD countries:

$\log(R\&D_j) = \beta_0 + \beta_1 * \log(TOTRD_j) + \beta_2 * \log(GNP_j) + \beta_3 * \log(output_j) + \beta_4 * \log(employment_j) + \varepsilon_j$.

Where $R\&D_j$ is the pharmaceutical R&D of country j, $TOTRD_j$ is the country-level R&D expenditure, $output_j$ and $employment_j$ refer to those in the pharmaceutical industry of country j, and ε_j denotes the residual.

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[57] "An Expanded Set of International Comparisons, 1950-1988" by Robert Summers and Alan Heston, Quarterly

My rationale for this model starts from the conjecture that industry R&D as a share of industry output in country j can be predicted by the total R&D as a share of the GNP of the country j. (GNP is used instead of GDP because the country level R&D is measured as the percentage of GNP in the WDI database.) The share of industry R&D certainly cannot be predicted perfectly by the total R&D share, because R&D intensity and productivity in the pharmaceutical industry differ from country to country. This provides the basis for bringing more industry-level variables into the model. Danzon (1997) points out that R&D is risky and its average cost is high in truly innovative drugs. Risky innovation increases the time and capital costs of developing drugs, which in turn raises input costs and employment level. The model specified above yields an $R^2 = .99$ for regressions on the twenty-three OECD countries in all the five periods. In all the five regression runs, R&D expenditure is positively correlated with industry employment and country level R&D, but negatively correlated with output and GNP, at the 1% statistical significance level. The US pharmaceutical company foreign affiliate counts may also help to predict the pharmaceutical R&D, but I choose not to include this variable, because the function of US FDI in the OECD countries can be very different from that in the other countries. The imputation gives fifty pharmaceutical R&D observations.

The findings associated with the imputed R&D may well be capturing the change of these imputing components due to national patent legislation. My original rationale for bringing this imputed R&D variable includes testing the change in pharmaceutical industry-level variables after national patenting, however, total domestic R&D tends to have a substantial weight in predicting pharmaceutical R&D compared to the other variables in the imputation model. Regression runs using this imputed pharmaceutical R&D may potentially be testing the response of total R&D to national patent law. This may also lead to an insignificant change of the R&D outcome detected in regressions. However, it is worth noting that regression on imputed R&D only constitutes a small part of the analyses, and other regression results overwhelmingly show similar insignificant coefficients on the patent indicators.

Journal of Economics, May 1991.

APPENDIX II. Mahalanobis Distance Calculations

The matching distance follows the standard Mahalanobis metric calculation, and takes the form (square root of ($(Xa - X_b)'(invcov)(Xa - X_b)$)), where Xa and X_b denote the vectors of covariates for countries A and B respectively, and invcov denotes the inverse of the pooled variance-covariance matrix of the covariates that are observed for the country that switched policy. This pooled variance-covariance matrix is calculated in a similar fashion as that in a multivariate analysis of variance (MANOVA)[58]. The intuition of the Mahalanobis distance formula can be explained as the following. Starting with the simple case of a two-dimensional coordinate system, the Pythagorean theorem implies that the distance between any two points is equal to the square root of $(x1-y1)^2 + (x2-y2)^2$. Further geometry extends this result to the n-dimensional space: d(A, B) = sqrt $[(x1-y1)^2+(x2-y2)^2 +\ldots+(xn-yn)^2]$. Simple Euclidean distance, motivated by the Pythagorean theorem, is unsatisfactory for our statistical purposes for two reasons. First, each coordinate contributes equally to the calculation of Euclidean distance. Second, the coordinates are assumed to be orthogonal to each other, which does not apply to practical cases where the covariates are correlated with each other. The inclusion of the VC matrix in the Mahalanobis formula adjusts for the above two factors[59]. The inclusion of the VC matrix also gives rise to another advantage of the Mahalanobis matching -- it matches the interactions of the country covariates automatically, even though these interaction variables are not generated and included as additional matching covariates (Rubin 1973). Therefore, Mahalanobis matching results in a composite score for all the country covariates.

One limitation of the Mahalanobis matching method is that it is not designed to match categorical variables, such as the legal families and price control variables used in this study. Inclusion of these categorical variables most likely complicates the VC calculations and makes the matching inaccurate. To overcome this difficulty and still include the important discrete variables in

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[58] In calculating the pooled variance-covariance (henceforth abbreviated as VC) matrix for the control group and the group of countries that switched policies, the two groups are centered around their own means respectively. In cases when the switched group is so small that the VC matrix is singular (when the degree of freedom is 0 or negative), then only the VC matrix of the control group is used. The final formula for calculating the pooled VC is: $((DF_t-1)*VC_t + (DF_c-1)*VC_c)/(DF_t + DF_c - 2)$, where DF stands for degree of freedom, and subscript t refers to the treatment group, and c refers to the control group.

[59] Please see Johnson and Wichern (1992) for detailed mathematical derivations.

matching[60], I use the propensity score of these categorical variables as a summary statistic, which is continuous, to be one of the matching variables. That is, I calculate the implied probability of having national pharmaceutical patent law (the estimated propensity score), which is simply the predicted value from the logistic regression of the patent implementation indicator on the non-continuous variables. This propensity score can be perceived as a one-dimensional composite score of the discrete variables, for the reasons discussed in the previous section. This new variable—the propensity score—is then included as one of the matching covariates, together with all other continuous variables.

Missing data prevents a complete matching of all the covariates in one pass, because different observations are missing different variables, and this complicates the calculation of the variance-covariance matrix used in the Mahalanobis distance. I modify this method by matching in two passes. In the first pass I use only the country level variables that are observed for almost all the sampling countries. I group the observations according to their missing patterns in these covariates before matching. This first pass matching orders the countries in the two control groups according to their Mahalanobis distances to each of the new-patent countries. I keep a list of countries that are the closest or the next-closest matches to each of the new-patent countries, together with the new-patent countries, to form a reduced sample of countries. There are eighteen countries in this reduced sample that have missing data in industry level covariates. I then search for data for these countries by looking through their National Statistical Abstracts and the UN Industrial Statistics Yearbook. I was able to fill in most of the missing values so that the reduced sample is ready for the second matching pass. There are still a few countries in this reduced sample whose industry data are not found, these observations have to be dropped out of the second pass of matching. In this second pass, I pair up the countries using all the matching covariates. This two-stage matching method narrows down the list of countries I need to look for industry data, and makes such task possible in the timeframe of this project.

I use all the matching covariates to make the final matches. To test the robustness of the matching algorithm, I tried several specifications of matching covariates. For each specification, the key variables (such as GDP per capita PPP, pharmaceutical industry employment and exports to the

[60] Please see Chapter 4.2 for the list of discrete variables.

US) are included with different combinations of other control variables. Several rounds of matching using different combinations of matching variables are performed until the balances of covariates are the best. I checked all the variable values for the matched pairs, and the matching seem to make practical sense.

APPENDIX III. Robustness Results

a. Robustness Checks on the R&D outcome (appendix for Chapter 6.1.2)

Instead of using R&D in the same year as the domestic patent implementation as a basis for comparison, lagged year R&D (both one-year and two-year) are used in a series of robustness regression tests. There were no statistically significant coefficients on the "PAT" or "PATMOD".

Although the majority of regression results provide no evidence to reject the null hypothesis that national patent law has no direct effect on R&D incentives, there may still be instances where some individual countries had increases in R&D. Only, these increases were masked by the insignificant results of all the other countries within the sample. In order to detect such instances, I plot the residuals against the predicted values for each regression run, and find no abnormal observations in most cases. The only exception is in the regression using one-period forward R&D expenditure for the OECD countries. There are two countries with high positive residuals—Canada and Norway, while a large negative residual attributable to Turkey. This finding involving Canada corroborates that of Pazderka (1999) and McFetridge (1996), highlighting Canada's boost in R&D following its 1987 Act to abolish compulsory licensing for pharmaceuticals[61]. Norway, on the other hand, increased its domestic R&D from $9.92 million in the period of 1983-5 to $32.10 million in the next period (1986-90), although it did not have pharmaceutical product patents until 1992. A closer reading of the data reveal that R&D increased in Norway at a rather gradual pace since 1986, with an annual growth rate of approximately 30%, peaking in 1993, to finally plateau and decline in the late 1990s. It could be that Norwegian domestic innovators increased their R&D activities in

[61] My data divulge an increase from an average annual value of $118.70 million in the period of 1986-90 to $285.90 million in the period of 1991-5. Most of the increase in Canadian R&D occurred after 1988; its domestic average R&D during the period of 1983-5 was $54.04.

earlier years in anticipation of the upcoming patent law. However, the implication that this response started six years ahead of the actual implementation is unpersuasive. Given that the increase in Canadian R&D is in a large part due to the political commitment of the PMAC, this observation alone does not provide enough evidence to reject the null hypothesis in the one-period forward R&D regression.

Regression models are also applied on the R&D scientists, technicians and engineers (RSE). This variable is only observed for ten OECD countries, and the results for these countries corroborate those obtained in the regressions of R&D expenditures (Table 12-17). Because there are very few observations, coefficients are only estimated when using period comparisons of RSE. My attempt to compare RSE changes for one-year and two-year forward fails to yield estimates on the patent implementation indicator.

b. Other Robustness Checks (appendix for Chapter 6)

As Chapter 5.2 suggested, various robustness checks are performed. These include: using regression Model 2 instead of Model 1, applying random effects regression model instead of fixed-effects, and regression analyses using the independent variables of the lagged year instead of the averaged values over pre-patent-change period. In addition, Considering the possibility that the constructed "innovative potential" variable may be capturing the differential in patent awards in pharmaceuticals from those in the other industries due to the implementation of pharmaceutical patent protection, robustness regressions not including this control variable are carried out. The regression results have been consistent over all specifications. Once again, this robustness is partly attributed to the matching procedure. The main finding in all cases is that the implementation of national patent protection in the sampled countries only bring about statistically significant increases in the US patent awards to domestic innovators and in R&D expenditure, conditional on economic freedom conditions and domestic development.

To test the overall importance of patent treatment on innovation, a propensity score "treat" is generated as a summary score of all the patent protection characteristics. I regress the patent implementation indicator variable on the process patent indicator variable, the interaction variables

between the patent implementation indicator "PAT" and per capita GDP in PPP terms, between "PAT" and IPR score variable, between "PAT" and economic freedom, between "PAT" and education attainment, between "PAT" and price control indicator. The variable "treat" is then the predicted outcome variable from this regression. Seemingly Unrelated Regression is then carried out regressing the US patent awards of various years on "treat" and a set of country covariates. There are still no statistically significant coefficients on the "treat" variable (Table 6).

C. Supplementary results

In order to compare the relationship between the two types of FDI and the outcome variable, I examine the correlation matrix for the US and Japanese foreign affiliate counts and the US patent awards and discover some positive correlations. In general, the correlation coefficient is larger for the US foreign subsidiary counts than for the Japanese one. This finding could be explained by the fact that the propensity to patent in the US increases as a given country forms closer ties with the US, evidenced by the larger number of US foreign affiliates. While the correlation matrix for the foreign affiliate counts and R&D expenditures for the sampled OECD countries also indicate positive correlations among all variables, the relative magnitude differ. The Japanese foreign affiliate counts have higher correlation coefficients for R&D (.30) than the US foreign affiliate counts (.03). One possible explanation is that the OECD countries have similar levels of US FDI, so the marginal benefit of Japanese FDI on their R&D is greater than that of the US FDI. The matrix plots also indicate correlations between foreign direct investments from the two sources—Japan and US (.38).

Exhibit: **Matching Results – matched country pairs by applying the Mahalanobis Matching.**

year of new patent laws	new-patent countries	no-patent countries	always-patent countries
Period 1	**(1978-82)**		
1983	Denmark	Norway	Sweden
Period 2	**(1983-85)**		
1986	Taiwan	Hungary	HongKong
1987	Canada	Norway	Netherland
1986	Korea	Thailand	Singapore
1987	Austria	Finland	Australia
Period 3	**(1986-90)**		
1993	Brazil	Argentina	Korea
1991	Chile	Uruguay	Panama
1991	China	India	Korea
1992	Spain	Argentina	Belgium
1995	Finland	Slovenia	Australia
1992	Greece	Poland	Singapore
1992	Hungary	Romania	Israel
1992-1993	Indonesia	Egypt	Philippines
1991	Mexico	Argentina	Korea
1992	Norway	Slovenia	Australia
1992	Portugal	Romania	Hong Kong
1992-1993	Thailand	Colombia	Philippines
Period 4	**(1991-95)**		
1996	Bolivia	Paraguay	Zimbabwe
1996	Colombia	Egypt	Philipines
1997	Ghana	Jordan	Kenya
1996	Iceland	Slovenia	Luxemburg
1996	Peru	Guatemala	Algeria
1996 or 1997	Turkey	Iran	South Africa
1997	Romania	Bulgaria	Chile
1996	Ecuador	Tunisia	El Salvador
1996	Venezuala	Costa Rica	Chile

Table 1. Mean Characteristics of New-patent and No-patent Countries

	New-patent countries		No-patent countries		t-statistic[a]	
Country Level Covariates	Before Matching	After Matching	Before Matching	After Matching	Before Matching	After Matching
GDP (in billions of 1995 constant USD)	148.99 (164.29)	145.60 (158.50)	76.04 (112.48)	76.04 (112.48)	2.38**	2.38**
Real GDP growth	3.44 (2.85)	3.97 (2.81)	2.97 (3.33)	2.73 (2.37)	.81	1.64*
GDP per capita PPP	7201.05 (4946.28)	7102.51 (5264.23)	4248.35 (3203.33)	5727.53 (3531.82)	3.21***	1.12
Economic Freedom	6.07 (1.49)	6.21 (1.31)	5.18 (1.41)	5.67 (1.30)	2.90***	1.54*
Legal Origin of UK	.12 (.33)	.15 (.36)	.07 (.26)	.12 (.33)	.92	.35
Legal Origin of France	.39 (.50)	.48 (.51)	.54 (.50)	.50 (.51)	-1.56*	-.13
Legal Origin of Socialist	.27 (.45)	.11 (.32)	.29 (.46)	.31 (.47)	-.21	-1.77*
Legal Origin of Scandinavian	.12 (.33)	.15 (.36)	.05 (.21)	.08 (.27)	1.24*	.81
Price Control Indicator	0.52 (0.51)	0.74 (0.45)	0.66 (0.48)	0.76 (0.44)	-1.46*	-.16
Education	6.84 (2.21)	6.81 (2.15)	5.49 (1.83)	6.48 (1.88)	2.92***	.58
A. IPR	2.47 (.85)	2.55 (.80)	2.02 (.68)	2.15 (.58)	2.46**	1.97**
B. Innovative Potential	2.58 (1.30)	2.70 (1.07)	2.02 (.88)	2.27 (.78)	2.35**	1.67*
Industrial Level Covariates						
Labor	29.98 (76.30)	28.07 (73.60)	22.40 (43.78)	15.47 (26.16)	.47	.84
C. Output (in millions of USD)	1094.94 (1283.19)	1046.10 (1213.58)	649.34 (862.73)	668.26 (722.29)	2.37**	1.38*
Pharmaceutical Exports to the US	7.29 (12.37)	8.71 (13.23)	1.93 (5.22)	1.68 (3.39)	2.45**	2.67**
Number of subsidiaries of US MNE	5.45 (8.50)	6.52 (8.97)	3.48 (6.89)	2.77 (4.31)	1.49*	1.93**
Number of subsidiaries of Japanese MNE	1.30 (2.88)	1.59 (3.12)	.36 (1.38)	.31 (1.19)	2.86***	1.90**
Indicator for missing variable "labor"	.24 (.44)		.50 (.50)		-2.78***	
Number of observations	33 (maximum)	26	159 (maximum)	26		

Source: Author's calculations from the sample data of four reference periods prior to patent implementation, where control covariates are used. Standard deviations in parentheses. The industrial level employment and output variables are only observed for thirty-nine out of the eighty-five sampled countries. The statistics are calculated for the observed values. Significance levels are referenced for each variable according to their degree of freedom: * = .10, ** = .05, *** = .01.

[a]—t-statistics obtained by regressing the patent implementation indicator on each covariate and a constant.

Table 2. Mean Characteristics of New-patent and Always-patent Countries

	New-patent countries		Always-patent countries		t-statistic	
Country Level Covariates	Before Matching	After Matching	Before Matching	After Matching	Before Matching	After Matching
GDP (in billions of 1995 constant USD)	148.99 (164.29)	145.60 (158.50)	422.80 (1080.06)	162.94 (264.18)	-3.11***	-.29
Real GDP growth	3.44 (2.85)	3.97 (2.81)	2.47 (3.90)	4.63 (3.02)	1.65*	-.82
GDP per capita PPP	7201.05 (4946.28)	7102.51 (5264.23)	9396.01 (6518.03)	8486.38 (5974.89)	-2.18***	-.90
Economic Freedom	6.07 (1.49)	6.21 (1.31)	6.46 (1.85)	6.86 (1.43)	-1.26	-1.69*
Legal Origin of UK	.12 (.33)	.15 (.36)	.45 (.50)	.44 (.51)	-4.72***	-2.47**
Legal Origin of France	.39 (.50)	.48 (.51)	.31 (.46)	.41 (.50)	.92	.54
Legal Origin of Socialist	.27 (.45)	.11 (.32)	.09 (.28)	0 0	2.27**	1.68*
Legal Origin of Scandinavian	.12 (.33)	.15 (.36)	.05 (.21)	.04 (.19)	1.24	1.41*
Price Control Indicator	0.52 (0.51)	0.74 (0.45)	0.54 (0.50)	0.70 (0.47)	-.28	.30
Education	6.84 (2.21)	6.81 (2.15)	7.35 (2.71)	7.60 (2.17)	-1.04	-1.31
D. IPR	2.47 (.85)	2.55 (.80)	3.24 (.64)	3.12 (.54)	-4.32***	-2.67**
E. Innovative Potential	2.58 (1.30)	2.70 (1.07)	3.19 (1.71)	3.07 (1.00)	-2.36**	-1.23
Industrial Level Covariates						
Labor	29.98 (76.30)	28.07 (73.60)	36.09 (60.90)	11.87 (17.53)	1.43*	1.11
F. Output (in millions of USD)	1094.94 (1283.19)	1046.10 (1213.58)	4819.99 (10559.58)	1136.58 (2317.89)	-3.48***	-.18
Pharmaceutical Exports to the US	7.29 (12.37)	8.71 (13.23)	43.58 (106.97)	8.37 (14.70)	-4.35***	.09
Number of subsidiaries of US MNE	5.45 (8.50)	6.52 (8.97)	6.74 (9.75)	6.85 (8.56)	-.78	-.14
Number of subsidiaries of Japanese MNE	1.30 (2.88)	1.59 (3.12)	1.46 (4.52)	2.41 (4.64)	-.26	-.76
Indicator for missing variable "labor"	.24 (.44)		.40 (.49)		1.76**	
Number of observations	33 (maximum)	26	176 (maximum)	26		

Source: Author's calculations from the sample data of the four reference periods prior to national patent implementation, where control covariates are used. Standard deviations in parentheses. The industrial level employment and output variables are only observed for all countries in the reduced matched sample. The statistics are calculated for the observed values. The t-statistics is obtained by regressing the covariate on the patent implementation indicator and a constant within the subclass. Significance levels: * = .10, ** = .05, *** = .01.

Table 3. Mean Characteristics of the New-patent Countries and Countries With No Patent Law Changes in the OECD countries (The reduced sample does not include US, UK, Japan, Germany, and Italy)

	Complete Sample		Reduced Sample		t-statistics	
	New-patent countries	No-legal-change countries	New-patent countries	No-legal-change countries	Complete Sample	Reduced Sample
Price control	0.24	0.11	0.24	0.17	1.83**	0.90
	(0.43)	(0.32)	(0.43)	(0.38)		
US subsidiary counts	7.24	14.61	7.24	10.05	-4.06***	-1.55*
	(10.87)	(12.10)	(10.87)	(9.46)		
Japanese subsidiary counts	0.12	1.91	0.12	0.58	-5.59***	-5.77***
	(0.33)	(5.53)	(0.33)	(0.87)		
Employment in Pharmaceuticals	11.53	51.89	11.53	11.61	-10.73***	-0.04
	(10.89)	(53.81)	(10.89)	(9.50)		
Output in pharmaceuticals	1228.23	8128.28	1228.23	1501.44	-8.22***	-1.07
	(1427.97)	(13348.67)	(1427.97)	(1459.25)		
GDP growth	2.93	2.50	2.93	2.48	1.84**	1.86**
	(1.46)	(1.24)	(1.46)	(1.32)		
Economic freedom	6.76	7.36	6.76	7.28	-3.78***	-3.16***
	(0.90)	(1.28)	(0.90)	(1.23)		
GDP	179.46	983.70	179.46	209.85	-8.71***	-1.23
	(145.15)	(1561.53)	(145.15)	(143.47)		
GDP per capita PPP	12061.55	13689.39	12061.55	13320.63	-2.22**	-1.66*
	(4365.54)	(4991.05)	(4365.54)	(4874.86)		
UK Legal Family	0.07	0.31	0.07	0.30	-5.00***	-4.42***
	(0.26)	(0.46)	(0.26)	(0.46)		
French Legal Family	0.48	0.34	0.48	0.34	1.70**	1.64*
	(0.51)	(0.47)	(0.51)	(0.47)		
Socialist Legal Family	0	0	0	0		
	(0)	(0)	(0)	(0)		
German Legal Family	0.02	0.14	0.02	0.04	-3.78***	-0.44
	(0.15)	(0.35)	(0.15)	(0.19)		
Scandinavian Legal Family	0.43	0.21	0.43	0.33	2.70***	1.21
	(0.50)	(0.41)	(0.50)	(0.47)		
Average Years of Schooling	8.03	8.80	8.03	8.85	-2.16**	-2.25**
	(2.23)	(1.78)	(2.23)	(1.77)		
Ginarte and Park IPR index	2.77	3.60	2.77	3.40	-7.33***	-5.40***
	(0.70)	(0.62)	(0.70)	(0.65)		
Innovative Potential variable	3.33	3.92	3.31	3.57	-1.82**	-1.19
	(0.98)	(0.51)	(1.18)	(0.79)		
Number of observations	42	304	42	196		

Source: Author's calculation from the sample data of OECD countries in the four reference periods prior to national patent implementation, where control covariates are used. The statistics are calculated for the observed values. The t-statistics is obtained by regressing the covariate on the patent implementation indicator and a constant within the subclass. Significance levels: * = .10, ** = .05, *** = .01.

Table 4. Regression Results for the Main Independent Variable – The Indicator Variable for Product Patent Legislation [d]

	New-patent and No-patent Countries Fixed Effects Regressions (OLS)			New-patent and Always-patent Countries Fixed Effects (OLS)		
Specifications	Implementation indicator	Modification indicator	PPP & implement interact	Implement a-tion indicator	Modifica-tion indicator	PPP & implement interact
Forward 3 years USP [a]	1.575 3.379	.189 .768	.917*** .468	2.72 5.17	.196 .772	.827** .433
Forward 4 years USP [b]	3.03 6.30	.07 .47	-.45 .73	7.19 9.62	.11 .60	1.02 1.15
Forward 5 years USP[b]	4.373 3.576	.832 * .466	-.133 .330	-3.270 5.365	.152 .531	-.432 .488
Forward 3-5 years average US patents [a]	-3.667 2.239	-.041 .151	.424 ** .193	2.550 1.540	1.057** .494	-.409 .301
Forward one period R&D [c]	-5.331 6.546	-.394 .613	.838 ** .435	-5.690 5.404	-.469 .458	.555** .367

Source: Results obtained in the regressions of the outcome variable on the patent implementation indicator, process indicator, interaction variable between PPP and implementation, and country covariates.

a. Regression using the complete set of country covariates.

b. Regression using the key country covariates due to fewer observations. The pairs where the new-patent country implemented patent law after 1995 do not have corresponding four year later US patent awards data. Simplified model also helps to identify key coefficients. Control covariates that bear no statistically significant coefficients in preliminary complex model are dropped. The country covariates entered regression include log(GDP), log(GDP per capita PPP), log(export to the US), log(innovative potential).

c. This regression is applied on the countries whose pharmaceutical industry R&D data are imputed. There are sixty-one observations that have the imputed R&D data for the period of patent implementation, and forty-six observations that have imputed R&D for the period after patent implementation. Due to the limited sample size, the regression has to be carried out on a reduced set of control covariates, including economic freedom, education, innovative potential, US and Japanese foreign direct investment, and IPR.

d. For all the tables here, the first line records the mean and the second one records the standard error.

Table 5. Regression Results for the Interaction Variables of Patent Implementation: IPR, average years of schooling, and economic freedom index.

	New-patent and No-patent Countries Fixed Effects Regressions (OLS)			New-patent and Always-patent Countries Fixed Effects (OLS)		
Specification	IPR & Implement'n	Education & Im'n	Ecfree & Im'n	IPR interact Implement'n	Education & Im'n	Ecfree & Im'n
Forward 3 years USP [a]	-.256 .687	.441*** .129	.313 .866	.835 .879	.487** .369	.144 .195
Forward 4 years USP [b]	.41 .56	-.11 .18	.31 1.58	-.638 ** .255	-.177 .214	.442 .975
Forward 5 years USP [c]	-.382 .201	.428** .150	-1.576 1.631	-.158 .526	.199 .182	.010 .659
Forward 3-5 years average US patents [c]	.084 .101	-.094 .068	.255 .449	-.480* .263	-.043 .088	-.087 .666
Forward one period R&D [d]	.159 .820	-.181 .374	.329 .304	.207 .460	.593** .242	.433 1.297

Source: Results obtained in the regressions of the outcome variable on the interaction of general IPR strength and patent implementation indicator, education and implementation interaction, economic freedom and implementation interaction, and country covariates. Notes a-d is the same as in Table 4.

Table 6. Regression Results for the Interaction Variables of Patent Implementation: Price Control Policy and High-income Country Indicators.

	New-patent and No-patent Countries Fixed Effects (OLS)		New-patent and Always-patent Countries Fixed Effects (OLS)	
Specifications	Price control & implem'n	High-income & implem'n	Price & implem'n	High-income & implem'n
Forward 1 period USP [a]	-.256 * .138	1.535 *** .499	-.132 .221	.255 .637
Forward 3 years USP [a]	-.933 .766	1.755*** .519	-.463 .579	-.465 .948
Forward 4 years USP [b]	-.05 .39	.583 .568	.216 .411	3.995*** .982
Forward 5 years USP [c]	-.458 .473	.759 1.072	.730** .315	.316 .606
Forward 3-5 years average	-.154	.774***	.013	-.379

US patents [c]	.150	.192	.245	.382
Forward one period R&D [d]	.495 .421	.780 ** .390	-.724 ** .350	.284 .496

Source: Results obtained in the regressions of the outcome variable on the interaction of price control and patent implementation, interaction between high income country indicator and implementation indicator, and country covariates. Notes a-d is the same as in Table 4.

Table 7. Seemingly Unrelated Regression Results[62]

	New-patent and No-patent Countries Fixed Effects Regressions (OLS)		New-patent and Always-patent Countries Fixed Effects (OLS)	
Specifications	Treat	Log(GDP)	Treat	Log(GDP)
Forward 3 years USP [a]	-.052 .192	.149 .234	.121 .211	.127 .312
Forward 4 years USP [b]	-.074 .097	.547*** .118	-.448 .115	.515*** .170
Forward 5 years USP[b]	.049 .139	-.132 .170	-.387 .147	.503** .217
Forward 3-5 years average US patents [a]	.004 .097	.226* .119	-.228 .116	.418** .172

	New-patent and No-patent Countries Fixed Effects Regressions (OLS)			New-patent and Always-patent Countries Fixed Effects (OLS)		
Specifications	QIPR1	QIPR3	QIPR5	QIPR1	QIPR3	QIPR5
Forward 3 years USP [a]	-.702* .337	-.185 .320	-.109 .302	-.485 .326	-.049 .527	-.002 .281
Forward 4 years USP [b]	.173 .173	.154 .165	.059 .159	.686*** .178	.754** .287	-.134 .153
Forward 5 years USP[b]	.326 .234	-.567** .220	-.299** .195	.472** .227	.367 .367	.038 .196
Forward 3-5 years average	-.038 .169	-.124 .159	-.116 .148	.277 .180	.383 .291	-.052 .155

[62] The full regression model is $RESPONSE_{i,j,t+n} = \beta_0+\beta_1*Treat_{i,j}+\beta_2*logGDP_{i,j}+\beta_3*logLabor_{i,j}+\beta_4*logUSFDI_{i,j}+\beta_5*logLegor\_UK_{i,j}+\beta_6*log(export)_{i,j}+\beta_7*qIPR1_{i,j}+\beta_8*qIPR3_{i,j}+\beta_9*qIPR5_{i,j}+\beta_{10}*RESPONSE_{i,j,t}+\varepsilon_{i.}$ Not all coefficients are recorded due to their statistical insignificance and space limitations.

US patents [a]						

Table 8. Regression Results for the Main Independent Variable, Interaction Variables of PPP and IPR with PAT for the OECD Sampling Countries with R&D Expenditure as Outcome Variable

	New-patent and No-change Countries Fixed Effects (OLS)— R&D.			New-patent and No-change Countries Fixed Effects (OLS)— RSE		
Specifications	PAT	PPP*PAT	IPR*PAT	PAT	PPP*PAT	IPR*PAT
Forward 1 period R&D	-2.40 3.477	.498 .627	-.402*** .036	-3.77 5.628	.352*** .047	-.938*** .151
Forward 1 years R&D	-1.493 3.261	.257** .129	-.261*** .057			
Forward 2 years R&D	1.742** (#) .811	.606*** .1606	-.795*** .060			

Source: Regression results. Each cell lists the coefficient mean (first line) and standard error (second line).

*, **, and *** refer to statistical significances detected at 10%, 5%, and 1% levels, respectively. The results from the normal, Laplace, and Huber regressions are in agreement in most cases and the normal regression results are recorded.

(#) Results from the Huber regression is recorded here, because the normal and Laplace regressions were highly influenced by the one outlier observation. See Section 6.1.2.

Table 9. Regression Results for the Interaction Variable of Education and Economic Freedom with PAT for the OECD Sampling Countries with R&D Expenditure as Outcome Variable

	New-patent and No-change Countries Fixed Effects (OLS)— R&D.		New-patent and No-change Countries Fixed Effects (OLS)— RSE	
Specifications	Educ*PAT	Ecfree*PAT	Educ*PAT	Ecfree*PAT
Forward 1 period R&D	.614** .241	1.308*** .165	.126 .140	1.37 1.47
Forward 1 year R&D	-.205 .157	.394** .183		
Forward 2 years R&D	.263* .183	3.128*** .415		