Innovating like China: a theory of stage-dependent intellectual property rights

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Abstract

Inspired by the Chinese experience, we develop a Schumpeterian growth model of distance to frontier in which economic growth in the developing country is driven by domestic innovation as well as imitation and transfer of foreign technologies through foreign direct investment. We show that optimal IPR protection is stage-dependent. At an early stage of development, the country implements weak IPR protection to facilitate imitation. At a later stage of development, the country implements strong IPR protection to encourage domestic innovation. Finally, we provide empirical evidence that supports this theoretical finding

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1 Introduction

In the late 1970's and early 1980's, the implementation of a modern intellectual property rights (IPR) system in China was subject to intense debates.[1] Proponents including Deng Xiaopeng, the Paramount leader of China at that time, saw the creation of a modern IPR system in China as a necessary means to attract foreign direct investment (FDI) and to provide incentives for domestic innovation. In 1982, the first intellectual property law under the leadership of Deng was drafted in China. Then, through a series of policy reforms, the strength of patent rights in China increased overtime. For example, the Ginarte-Park index of patent rights in China gradually increased from 1.33 in 1985 to 4.08 in 2005.[2] In 1992, the statutory term of patent in China was lengthened from 15 years to 20 years.[3] Then, in compliance with

[1] See for example Allison and Lin (1999) and La Croix and Konan (2002) for a discussion on the historical evolution of IPR in China.

[2] The Ginarte-Park index is on a scale of 0 to 5, and a larger number implies stronger patent rights. See Ginarte and Park (1997) and Park (2008a) for a detailed description of this patent index.

[3] As for the term of patent for utility model and design patents, it was lengthened from 5 years to 10 years. Also, this patent reform expanded patentable subject matter in China.

the TRIPS agreement,[4] China reformed its patent system again in 2000.[5] Recently, the Third Amendment to the Chinese Patent Law was approved in December 2008 and came into effect in October 2009 with the objective of building China into an innovative country with well-protected IPR by 2020.[6] In addition to strengthening patent rights, China also improved the protection for trade secrets by developing a comprehensive set of laws and regulations over the last two decades.[7] In a recent report issued by NERA Economic Consulting, Sepetys and Cox (2009, p. 3) nicely summarize the evolution of IPR in China as follows.

> In the early stages of development, with limited resources and limited capacity for research and development, there may be little or no IPR protection. Domestic industry will be character-

[4] The Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) is an agreement of the World Trade Organization. In summary, TRIPS establishes a minimum level of IPR protection that must be provided by all member countries.

[5] The policy changes include (a) providing patentholders with the right to obtain a preliminary injunction against the infringing party before filing a lawsuit, (b) stipulating standards to compute statutory damages, (c) affirming that state and non-state enterprises enjoy equal patent rights, and (d) simplifying the patent application process, examination and transfer procedures and unifying the appeal system. See for example Hu and Jefferson (2009) for an empirical analysis on this patent reform in China.

[6] See for example Yang and Yen (2010) for a review of the policy changes in this third amendment. In summary, the changes aim at (a) promoting patent applications, (b) encouraging exploitation of jointly owned patents, (c) heightening patentability requirement, (d) increasing statutory damages and administrative fines, (e) clarifying the granting of compulsory licenses, and (f) establishing protection for genetic resources.

[7] See for example Zuber (2008) for a discussion on the protection of trade secrets in China and the US.

> ized by imitation rather than innovation. Imitation allows for low-cost production, low prices for goods and services, and the stimulation of consumption and employment. A weak IPR regime may support technological growth and development through imitation in early stages of development. At subsequent stages of development, however, a weak IPR regime discourages domestic innovation. Innovation and technological development are drivers of economic growth. Economies that succeed in shifting into knowledge-based production are characterized by domestic innovation, typically supported with well-designed and adequately enforced IPR laws.

In this study, we develop a growth-theoretic model to formalize this insight on the evolution of IPR in developing countries using China as a timely example. For example, one objective of China's twelfth five-year plan (2011-2015) is to shift its reliance on foreign technology to domestic innovation. To analyze stage-dependent IPR for a developing country at different stages of development, we consider a Schumpeterian growth model of distance to frontier in which economic growth in the developing country is driven by domestic innovation as well as imitation and transfer of foreign technologies through FDI. We show that the model features an inverted-U effect of patent strength on domestic innovation under a certain parameter space. The intuition is as follows. On the one hand, increasing patent strength has a direct positive effect on domestic innovation by reducing imitation. On the other hand, the reduction in imitation leads to an increase in FDI that strengthens the displacement effect of foreign technologies on domestic innovation. As for the growth-maximizing and welfare-maximizing strengths of IPR protection, we show that they are stage-dependent. At an early stage of development, the country implements weak IPR protection to facilitate imitation of foreign technologies. At a later stage of development, the country implements strong IPR protection to encourage domestic innovation. Therefore, the optimal strength of IPR protection increases as the country develops towards the world technology frontier as in the case of China. Finally, we also provide cross-country empirical evidence based on panel data to support our theoretical finding.

This study relates to the literature on IPR and economic growth. This literature focuses on an important issue that is optimal IPR protection. An early study by Nordhaus (1969) finds that the optimal patent length should balance between static distortionary effects of markup pricing and dynamic gains from enhanced innovation. In a dynamic general-equilibrium model, Judd (1985) finds that the optimal patent length is infinite while Iwaisako and Futagami (2003) and Futagami and Iwaisako (2007) find that the optimal patent length can be finite in a version of the Romer model. Kwan and Lai (2003) show that extending the effective lifetime of patent would lead to a substantial increase in R&D and welfare whereas Li (2001) and O'Donoghue and Zweimuller (2004) consider the effects of patent breadth on R&D and economic growth. Recently, Chu (2009) analyzes the effects of blocking patents on R&D and welfare. However, this literature rarely considers optimal IPR protection in developing countries in which economic growth is driven by imitation and transfer of foreign technologies in addition to domestic innovation. We fill this gap in the literature by analyzing the optimal strength of IPR protection in a developing country at different stages of economic development.

Our study also relates to the literature on IPR and North-South product cycles.[8] A key question in this literature is whether strengthening Southern IPR protection would stimulate or stifle Northern innovation. Grossman and Helpman (1991) develop a North-South product-cycle model and find that strengthening Southern IPR protection either has no effect or a surprisingly negative effect on Northern innovation.[9] Lai (1998) shows that whether Southern IPR protection has a positive or negative effect on Northern innovation depends on the mode of technology transfer (i.e., imitation versus FDI) while Glass and Wu (2007) argue that the effect also depends on the type of technological innovation (i.e., quality improvement versus variety expansion). Instead of analyzing the effects of Southern IPR protection on Northern innovation, the present study considers a much less explored issue that is optimal IPR protection in the South as a function of its technology distance from the North.

An influential study by Grossman and Lai (2004) considers globally optimal IPR protection in an open-economy model featuring both developed and developing countries that have asymmetric innovative capability and market size. The present study differs from Grossman and Lai (2004) by considering a model in which (a) economic growth in the developing country

[8]See for example Grossman and Helpman (1991), Helpman (1993), Lai (1998), Yang and Maskus (2001), Glass and Saggi (2002a, 2002b), Glass and Wu (2007), Tanaka *et al.* (2007), Parello (2008) and Dinopoulos and Segerstrom (2010).

[9]Grossman and Helpman (1991) consider a tax (subsidy) on imitation that decreases (increases) Southern imitation, which is similar to the effects of IPR protection.

is driven by both domestic innovation and foreign technology transfer and (b) the relative importance of innovation and technology transfer changes endogenously as the country evolves towards the world technology frontier. These two features together imply that optimal IPR protection should be stage-dependent, which is an important property that is absent in all the abovementioned studies.

Finally, this study relates to the literature on distance to frontier and convergence; see for example Acemoglu *et al.* (2003, 2006), Aghion *et al.* (2005) and Howitt and Mayer-Foulkes (2005). Our study relates to this literature by considering IPR as a specific economic institution and shows that IPR policy can be an important policy variable that affects the convergence of developing countries. Finally, our study relates to a recent study by Wu (2010), who also considers the effects of IPR protection on the convergence of developing countries using a Schumpeterian model of distance to frontier. While Wu (2010) focuses on the existence of non-convergence traps, our study differs from his interesting analysis by characterizing the optimal path of IPR protection in developing countries and considering multiple channels of foreign technology transfer through FDI and imitation.

The rest of this study is organized as follows. Section 2 presents the theoretical model. Section 3 characterizes stage-dependent IPR protection. Section 4 presents the empirical evidence. The final section concludes with a discussion.

2 A simple model of distance to frontier

We consider a Schumpeterian growth model of distance to frontier.[10] The discrete-time model has four components (a) individuals, (b) final goods, (c) intermediate goods, and (d) R&D. In each period, there is a unit continuum of risk-neutral individuals indexed by j. Each individual j lives for one period, supplies one unit of labor and consumes final goods to maximize expected utility $u_t^j = E[c_t^j]$, where c_t^j denotes consumption by individual j.[11] Labor supply is used as an input for final goods, which can be consumed by individuals, devoted to various types of R&D activities or used as an input for intermediate goods. To model the effects of IPR, we consider a specific IPR parameter Θ_t that captures the effects of patent protection on imitation, which in turn affects FDI and innovation. This setup captures the main concerns of policymakers in China.

A key difference between our model and the models in Acemoglu *et al.* (2003, 2006) and Wu (2010) is in our formulation of the interaction between imitation of foreign technologies and domestic innovation in the developing country. In previous studies, imitation and innovation in an industry are assumed to be performed by the same firm implying that the interaction between imitation and innovation lies in the resource allocation across the two types of activities within a firm. In contrast, in our model, imitation and

[10] Our model borrows many elements from other Schumpeterian models of distance to frontier, such as Acemoglu *et al.* (2003, 2006), Aghion *et al.* (2005) and Howitt and Mayer-Foulkes (2005).

[11] Considering overlapping generations of households would not change our results so long as the utility function is linear, which allows for a simple aggregation of social welfare.

innovation in an industry are performed by two different firms capturing the realistic scenario in which domestic innovation in the developing country can be displaced by the importation of more advanced foreign technologies. In other words, our framework captures both the positive spillover effect and the negative market-stealing effect of foreign technologies on domestic innovation commonly discussed in the empirical literature on technology diffusion.[12]

Another key difference is that we take into consideration two channels of foreign technology transfer (a) FDI and (b) imitation. Within this framework, a stronger patent system makes imitation of foreign technologies more difficult. Consequently, the lower intensity of imitation improves the incentives for technology transfer via FDI, and this theoretical finding is consistent with empirical evidence.[13] As for the effects of stronger patent protection on domestic innovation, there are a direct positive effect from the decrease in imitation and an indirect negative effect from the increase in FDI (i.e., the displacement effect of foreign technologies on domestic innovation). Therefore, our model features an inverted-U effect of patent strength on domestic innovation that has been documented in recent empirical studies, such as Lerner (2009) and Qian (2007).[14]

[12] See for example Aitken and Harrison (1999).

[13] An early study by Lee and Mansfield (1996) finds a positive effect of IPR on FDI. Although subsequent studies produce mixed results, recent empirical studies tend to find a positive effect. For example, Javorcik (2004) finds that IPR has a positive effect on FDI in technology-intensive sectors of transition economies. Considering a more comprehensive set of countries, Branstetter *et al.* (2006) also find that strengthening IPR has a positive effect on technology transfer.

[14] See also Akiyama and Furukawa (2009), Furukawa (2007, 2010) and Horii and Iwaisako (2007), who derive an inverted-U relationship between patent strength and innovation in

In the model, we consider a specific sequence of actions by domestic innovators, foreign firms and domestic imitators. In particular, we assume that domestic innovation is followed by FDI and then imitation. This specific sequence of actions gives rise to the two important and realistic implications discussed above. First, domestic innovation may be displaced by foreign technologies. Second, a strengthening of patent protection that reduces imitation may encourage both domestic innovation and foreign technology transfer supporting the abovementioned rationales for implementing a modern IPR system in China.

Finally, as in previous studies, we assume that there is no trade in factors of production and the developing country takes the world technology frontier as given.[15] A slight modification from previous studies is that we allow for trade in final goods, so that foreign firms that perform FDI can retrieve their monopolistic profits out of the developing country.

2.1 Final goods

This sector is perfectly competitive, and firms take the output and input prices as given. Final goods Y_t (chosen as the numeraire) are produced by combining labor input with a unit continuum of differentiated intermediate goods $X_t(i)$ indexed by $i \in [0,1]$. We consider a standard production function.

$$Y_t = L_t^{1-\alpha} \left(\int_0^1 A_t^{1-\alpha}(i) X_t^{\alpha}(i) di \right), \tag{1}$$

the R&D-based growth model via other mechanisms.

[15] See Section 5 for a discussion on this assumption.

where $A_t(i)$ is the level of technology associated with $X_t(i)$. The supply of labor L_t is normalized to unity for all t. The conditional demand function for $X_t(i)$ is

$$X_t(i) = A_t(i) \left(\alpha / P_t(i)\right)^{1/(1-\alpha)}, \tag{2}$$

where $P_t(i)$ is the price of $X_t(i)$ for $i \in [0,1]$.

2.2 Intermediate goods and domestic innovation

There is a unit continuum of intermediate goods indexed by $i \in [0,1]$, and each industry i is dominated by a temporary monopolistic leader. In each industry, an individual is randomly chosen as the entrepreneur, who is given the opportunity to innovate at the beginning of the period and potentially dominate the industry for the remaining period. In the next period, all relevant patents expire and the monopolistic position will be randomly assigned to another entrepreneur who performs the next innovation. This simple setup, which is in line with other Schumpeterian models of distance to frontier, simplifies the model by equating the return to R&D to the monopolistic profit in the current period, and this simplification allows us to focus on the dynamic aspects of distance to frontier. For each monopolist, producing one unit of intermediate goods requires one unit of final goods. The familiar profit-maximizing price is $P_t(i) = 1/\alpha$. Therefore, using (2), we can derive the amount of monopolistic profit as

$$\pi_t(i) = P_t(i)X_t(i) - X_t(i) = \overline{\pi} A_t(i), \tag{3}$$

where $\overline{\pi} \equiv (1-\alpha)\alpha^{(1+\alpha)/(1-\alpha)}$ is a composite parameter.

At the beginning of time t, the level of productivity in industry i is $A_{t-1}(i)$. An entrepreneur is given the opportunity to increase the level of productivity to $\widetilde{A}_t(i) = (1+\gamma_t)A_{t-1}(i)$, where γ_t is a choice variable. The expected return to innovation in industry i is $(1-p_t)\overline{\pi}[\widetilde{A}_t(i) - A_{t-1}(i)] = (1-p_t)\overline{\pi}\gamma_t A_{t-1}(i)$, where $p_t \in [0,1]$ is the endogenous probability (to be derived below) that the monopolistic position will be taken away either by a foreign firm or by a domestic imitator before production in this period begins. When this probability p_t is high, the entrepreneur only has a small chance of capturing the monopolistic profit and hence has less incentives to do R&D. This setup relates to the idea of intellectual appropriability discussed in Cozzi (2001) and Cozzi and Spinesi (2006). Under this interpretation, p_t can be viewed as the probability that the monopolistic position is stolen by another entrepreneur before the innovator manages to start production.

To increase the level of technology by a step size of γ_t in industry i, the entrepreneur has to devote $R_t(i)$ units of final goods to R&D. We consider a simple convex cost function given by

$$R_t(i) = \frac{(\gamma_t)^\sigma}{\sigma\overline{\gamma}} A_{t-1}(i), \tag{4}$$

where $\overline{\gamma}$ is a productivity parameter and $\sigma > 2$.[16] In (4), the scaling by $A_{t-1}(i)$ is common in the literature to capture increasing difficulty in innovation and to ensure a stationary γ_t on the balanced-growth path. The expected profit of R&D is $(1-p_t)\overline{\pi}\gamma_t A_{t-1}(i) - R_t(i)$. Simple differentiation yields the equilibrium step size of innovation given by

$$\gamma_t = [(1-p_t)\overline{\pi}\overline{\gamma}]^{1/(\sigma-1)} \tag{5}$$

[16] This parameter assumption $\sigma > 2$ ensures that the equilibrium growth rate is concave in p_t, so that the growth-maximizing level of patent protection is an interior solution.

for $i \in [0,1]$. Equation (5) shows that an increase in p_t reduces the incentives for innovation and decreases γ_t.

Proposition 1 *Weaker intellectual appropriability (i.e., a larger p_t) decreases the equilibrium step size of domestic innovation.*

2.3 Foreign direct investment

After the domestic entrepreneurs complete their R&D projects and before they sell their products, foreign firms may transfer recent technological developments from the world technology frontier to the developing country. This transfer of foreign technologies via FDI is a random process. If the process is successful in industry i, then the foreign firm takes away the monopolistic position from the domestic entrepreneur in that industry. Before this process of technology transfer begins, the level of productivity in industry i at time t is $\widetilde{A}_t(i) = (1+\gamma_t)A_{t-1}(i)$. If the technology transfer succeeds, then productivity in industry i increases further to

$$\widehat{A}_t(i) = \widetilde{A}_t(i) + g^* A^*_{t-1}. \tag{6}$$

A^*_{t-1} is the level of technology at the world technology frontier at time $t-1$ and evolves according to

$$A^*_t = (1+g^*)A^*_{t-1}, \tag{7}$$

where g^* is the exogenous growth rate of the world technology frontier.

The expected value of a successful transfer of foreign technologies via FDI in industry i is $(1-\iota_t s)\overline{\pi}\widehat{A}_t(i)$, where $\iota_t \in [0,1]$ is the probability that the transferred technologies will be imitated by a domestic firm in which case the foreign firm has to give away a share $s \in [0,1]$ of the market to the domestic imitator (to be discussed further below). To achieve a successful FDI project with probability f_t in industry i, the foreign firm has to devote $F_t(i)$ units of final goods. For analytical simplicity, we consider a quadratic cost function given by

$$F_t(i) = \frac{(f_t)^2}{2\overline{f}}\widehat{A}_t(i), \tag{8}$$

where $\overline{f}$ is a productivity parameter. The expected profit of FDI is $f_t(1-\iota_t s)\overline{\pi}\widehat{A}_t(i) - F_t(i)$. Simple differentiation yields the equilibrium intensity of FDI given by

$$f_t = (1-\iota_t s)\overline{\pi}\overline{f} \in [0,1] \tag{9}$$

for $i \in [0,1]$.[17] Equation (9) shows that either a larger probability of imitation ι_t or a larger share s of the market to be given away to the imitator reduces the incentives for technology transfer via FDI.

Proposition 2 *A higher rate of imitation (i.e., a larger ι_t) reduces the equilibrium intensity of FDI.*

2.4 Imitation and intellectual property rights

After the foreign firms complete their process of technology transfer, the domestic economy consists of two types of industries that are occupied by

[17] A parameter condition (P1) to be stated below will ensure that $f_t < 1$.

either (a) domestic innovators or (b) foreign firms. In the case of (a), another domestic individual is randomly chosen as an imitator, who has the ability to adapt foreign technologies from other industries. We refer to this type of imitation as efficient imitation e_t.[18] In the case of (b), a domestic individual is randomly chosen as an imitator, who has the ability to imitate existing foreign technologies in the industry. We refer to this type of imitation as inefficient imitation ι_t.[19] Both types of imitation are random. If the imitation process is successful, then the imitator takes away (a) the monopolistic position from the domestic innovator in the case of efficient imitation e_t or (b) some market share $s \in [0, 1]$ from the foreign firm in the case of inefficient imitation ι_t. For $s = 0$, the imitator is unable to take away any market share from the foreign firm. For $s = 1$, the imitator takes away the entire market share from the foreign firm. The general case of $s \in (0, 1)$ captures the scenario, in which the foreign firm and the domestic imitator collude and share the monopolistic profit as in Segerstrom (1991). Under this general case, the domestic imitator is able to take away some market share from the foreign firm because domestic firms often have a competitive advantage over foreign firms through local knowledge and local network in developing countries. For example, Branstetter *et al.* (2006) note that when a foreign firm "...transfers this knowledge to local employees, there is a risk that these employees will defect to a local manufacturer, taking sensitive technology with them. These employees are able to combine the patented and unpatented elements of the firms' technology, effectively competing with it in the local market."

[18] We call this efficient imitation because it raises the level of technology in the industry.

[19] We call this inefficient imitation because it contributes nothing to the industry's level of technology.

The return to efficient imitation is $\overline{\pi}\widehat{A}_t(i)$. To achieve an efficient imitation with probability e_t in industry i, the imitator has to devote $E_t(i)$ units of final goods to imitative R&D. Again, we consider a simple quadratic cost function given by

$$E_t(i) = \Theta_t \frac{(e_t)^2}{2\overline{e}} \widehat{A}_t(i), \tag{10}$$

where $\overline{e}$ is a productivity parameter for efficient imitation and $\Theta_t \in (0, \infty)$ is a policy variable determining the level of patent protection at time t. This formulation captures the idea that a stronger system of patent protection (i.e., a larger Θ_t) makes imitation more difficult and potentially improves intellectual appropriability by domestic innovators. The expected profit from efficient imitation is $e_t\overline{\pi}\widehat{A}_t(i) - E_t(i)$. Simple differentiation yields the equilibrium intensity of efficient imitation given by

$$e_t = \min\{\overline{e}\overline{\pi}/\Theta_t, 1\} \tag{11}$$

for $i \in [0, 1]$.

The return to inefficient imitation is $s\overline{\pi}\widehat{A}_t(i)$. To achieve an inefficient imitation with probability ι_t in industry i, the imitator has to devote $I_t(i)$ units of final goods to imitative R&D. Again, we consider a simple quadratic cost function given by

$$I_t(i) = \Theta_t \frac{(\iota_t)^2}{2\overline{\iota}} \widehat{A}_t(i), \tag{12}$$

where $\overline{\iota}$ is a productivity parameter for inefficient imitation. This formulation captures the idea that a stronger system of patent protection makes the imitation of foreign technologies more difficult and improves intellectual appropriability by foreign firms. The expected profit is $\iota_t s\overline{\pi}\widehat{A}_t(i) - I_t(i)$. Simple differentiation yields the equilibrium ι_t given by

$$\iota_t = \min\{\bar{\iota} s \overline{\pi} / \Theta_t, 1\} \tag{13}$$

for $i \in [0, 1]$.

Proposition 3 *A stronger system of patent protection (i.e., a larger Θ_t) reduces both types of imitation.*

Proposition 3 shows that stronger patent protection reduces efficient and inefficient imitation. The reduction in inefficient imitation increases foreign technology transfer via FDI from Proposition 2. As for domestic innovation, stronger patent protection has a direct positive effect by reducing efficient imitation and an indirect negative effect by increasing FDI. In (5), the probability p_t is given by $f_t + (1 - f_t)e_t$. In other words, at the time of innovation, a domestic innovator may be subsequently displaced by a foreign firm with probability f_t or by a domestic imitator with probability $(1 - f_t)e_t$. Differentiating $p_t = f_t + (1 - f_t)e_t$ with respect to Θ_t yields

$$\frac{\partial p_t}{\partial \Theta_t} = (1 - e_t) \underbrace{\frac{\partial f_t}{\partial \Theta_t}}_{>0} + (1 - f_t) \underbrace{\frac{\partial e_t}{\partial \Theta_t}}_{<0}. \tag{14}$$

Equation (14) shows that a larger Θ_t increases p_t through f_t (i.e., the displacement effect of foreign technologies) and decreases p_t through e_t (i.e., the direct effect of reducing domestic imitation). Applying (9), (11) and (13), we find that

$$\frac{\partial p_t}{\partial \Theta_t} < 0 \Longleftrightarrow \iota_t > \frac{1}{2s} \left(\frac{s^2 \bar{\iota}}{\overline{e}} - \frac{1 - \overline{\pi} \overline{f}}{\overline{\pi} \overline{f}} \right). \tag{15}$$

Recall that domestic innovation γ_t is decreasing in p_t from Proposition 1. Therefore, if and only if (15) holds, then patent strength Θ_t would have a monotonically positive effect on domestic innovation γ_t. In other words, for a sufficiently small ι_t (or equivalently, a sufficiently large Θ_t), it is possible for $\partial\gamma_t/\partial\Theta_t$ to become negative (i.e., $\partial p_t/\partial\Theta_t > 0$) implying an inverted-U effect of Θ_t on domestic innovation γ_t. The negative effect of patent protection on domestic innovation arises from the displacement effect of foreign technology transfer via FDI.

For a developing country, it is unlikely that the level of patent protection has reached this level.[20] Therefore, we impose the following sufficient condition to ensure that $\partial\gamma_t/\partial\Theta_t > 0$ for $\Theta_t \in (0, \infty)$. This parameter condition is given by

$$\overline{f} < \frac{1}{\overline{\pi}(1 + s^2\overline{\iota}/\overline{e})}, \tag{P1}$$

which in turn implies $\overline{f} < 1/\overline{\pi}$.[21] For the rest of the analysis, we assume that (P1) holds.

Proposition 4 *Given (P1), a stronger system of patent protection (i.e., a larger Θ_t) has a positive effect on domestic innovation in the developing country.*

[20] See for example Park (2008b) for a survey of empirical studies on patent strength and innovation. Upon surveying the empirical literature, Park (2008b) concludes that although an inverted-U effect of patent strength on innovation is theoretically plausible, empirical evidence seems to suggest that the level of patent protection in most countries is still on the upward-sloping side of the curve.

[21] This condition is sufficient for $f_t < 1$ in (9).

2.5 Aggregation

At the beginning of time t, the level of technology is industry i is $A_{t-1}(i)$. Then, the domestic innovator increases the level of technology to $\widetilde{A}_t(i)$. After that, if either a foreign firm or a domestic imitator succeeds in transferring foreign technologies into industry i, then the level of technology would further increase to $\widehat{A}_t(i)$. The transfer of foreign technologies succeeds with probability f_t while the efficient imitation of foreign technologies succeeds with probability e_t. Using the law of large numbers, we derive the following law of motion for aggregate technology $A_t \equiv \int A_t(i)di$ in the developing country.

$$A_t = [f_t + (1 - f_t)e_t]g^* A^*_{t-1} + (1 + \gamma_t)A_{t-1}. \tag{16}$$

Intuitively, (16) states that the industries experience an average productivity improvement by $\gamma_t A_{t-1}$ through domestic innovation and a fraction $f_t + (1 - f_t)e_t$ of the industries experiences an additional productivity improvement by $g^* A^*_{t-1}$ through either FDI or efficient imitation.

The aggregate production function can be obtained by substituting $P_t(i) = 1/\alpha$ and (2) into (1) to derive

$$Y_t = \zeta A_t, \tag{17}$$

where $\zeta \equiv \alpha^{2\alpha/(1-\alpha)}$ is a composite parameter. The resource constraint for final goods is

$$Y_t = C_t + X_t + R_t + E_t + I_t + F_t + NX_t, \tag{18}$$

where (a) C_t is aggregate consumption, (b) X_t is the total amount of final goods used in the production of intermediate goods, (c) R_t is aggregate innovative R&D, (d) E_t is aggregate expenditure on efficient imitation, (e) I_t

is aggregate expenditure on inefficient imitation, (f) F_t is aggregate expenditure on FDI, and (g) NX_t is net export that is equal to the monopolistic profit (net of FDI expenditure) captured by foreign firms. Using $P_t(i) = 1/\alpha$ and (2), we obtain

$$X_t = \alpha^{2/(1-\alpha)} A_t. \tag{19}$$

From (4), aggregate innovative R&D is

$$R_t = \frac{(\gamma_t)^\sigma}{\sigma\overline{\gamma}} A_{t-1}. \tag{20}$$

From (10), aggregate expenditure on efficient imitation is

$$E_t = (1 - f_t)\Theta_t \frac{(e_t)^2}{2\overline{e}}[(1 + \gamma_t)A_{t-1} + g^* A^*_{t-1}]. \tag{21}$$

From (12), aggregate expenditure on inefficient imitation is

$$I_t = f_t\Theta_t \frac{(\iota_t)^2}{2\overline{\iota}}[(1 + \gamma_t)A_{t-1} + g^* A^*_{t-1}]. \tag{22}$$

From (8), aggregate expenditure on FDI is

$$F_t = \frac{(f_t)^2}{2\overline{f}}[(1 + \gamma_t)A_{t-1} + g^* A^*_{t-1}]. \tag{23}$$

As for the net export of final goods, it is given by

$$NX_t = \left(f_t(1 - \iota_t s)\overline{\pi} - \frac{(f_t)^2}{2\overline{f}} \right) [(1 + \gamma_t)A_{t-1} + g^* A^*_{t-1}]. \tag{24}$$

Finally, aggregate consumption is

$$C_t = \zeta(1 - \alpha^2)A_t - (R_t + E_t + I_t + F_t + NX_t). \tag{25}$$

2.6 Convergence

If we define $a_t \equiv A_t/A_t^*$ as an inverse measure of the developing country's distance to the world technology frontier, then the law of motion for a_t is

$$a_t = [f_t + (1-f_t)e_t]\left(\frac{g^*}{1+g^*}\right) + \left(\frac{1+\gamma_t}{1+g^*}\right)a_{t-1} \equiv H(a_{t-1}). \tag{26}$$

Equation (26) is plotted in Figure 1 for a constant value of Θ.

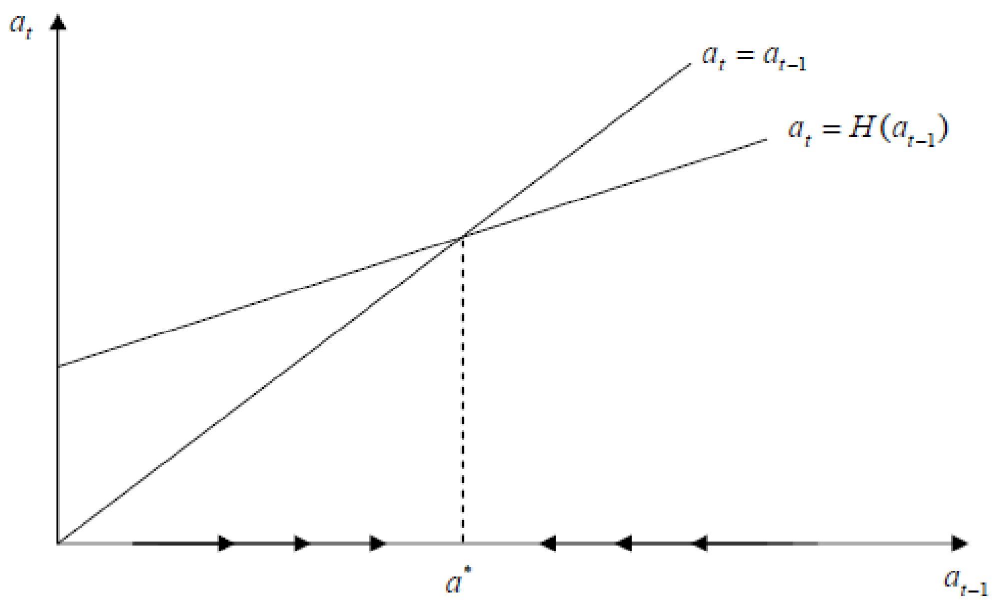

Figure 1 - Convergence and Distance to Frontier

In this case, a_t converges to a unique steady-state value given by

$$a^* = \frac{f+(1-f)e}{1-\gamma/g^*}. \tag{27}$$

To ensure that $a^* \in (0,1)$, we naturally assume

$$g^* > \frac{\gamma}{1-p} = \frac{(\overline{\pi}\overline{\gamma})^{1/(\sigma-1)}}{(1-p)^{(\sigma-2)/(\sigma-1)}}, \tag{P2}$$

where $p = f + (1 - f)e$. At the steady state, the developing country grows at the same rate as the world technology frontier despite the fact that the step size of domestic innovation γ is smaller than g^*. However, if the developing country fails to obtain foreign technologies (i.e., $f = e = 0$), then it would diverge from the rest of the world because domestic innovation alone is insufficient for the country to catch up with the world technology frontier. Furthermore, (27) shows that stronger patent protection has opposing effects on the steady-state level of distance to frontier. On the one hand, a larger Θ stimulates domestic innovation γ and FDI f implying a positive effect on a^*. On the other hand, it discourages efficient imitation e implying a negative effect on a^*.

3 Stage-dependent IPR protection

The growth rate of technology in the developing country at time t is

$$g_t \equiv \frac{A_t}{A_{t-1}} - 1 = p_t \frac{g^*}{a_{t-1}} + \gamma_t, \tag{28}$$

where $p_t = f_t + (1 - f_t)e_t$. This equation shows that for a backward country (i.e., a small a_{t-1}), obtaining foreign technologies through p_t (i.e., FDI and efficient imitation) is relatively important for achieving a higher growth rate. In contrast, for an advanced country (i.e., a large a_{t-1}), domestic innovation γ_t becomes relatively important. Differentiating (28) with respect to p_t yields

$$\frac{\partial g_t}{\partial p_t} = \frac{g^*}{a_{t-1}} - \frac{(\overline{\pi}\overline{\gamma})^{1/(\sigma-1)}}{(\sigma-1)(1-p_t)^{(\sigma-2)/(\sigma-1)}}, \tag{29}$$

$$\frac{\partial^2 g_t}{\partial p_t^2} = -\frac{(\overline{\pi}\overline{\gamma})^{1/(\sigma-1)}(\sigma-2)}{(\sigma-1)^2(1-p_t)^{1+(\sigma-2)/(\sigma-1)}} < 0. \tag{30}$$

The second-order condition implies that the growth rate g_t in the developing country is globally concave in p_t, whereas the first-order condition implies a growth-maximizing p_t^g given by

$$p_t^g = 1 - \left(\frac{(\overline{\pi}\overline{\gamma})^{1/(\sigma-1)}}{g^*(\sigma-1)} a_{t-1} \right)^{(\sigma-1)/(\sigma-2)} \in (0,1), \tag{31}$$

which is decreasing in a_{t-1} and increasing in g^*. To see that $p_t^g > 0$ for any $a_{t-1} < 1$,

$$g^* > \frac{(\overline{\pi}\overline{\gamma})^{1/(\sigma-1)}}{(1-p)^{(\sigma-2)/(\sigma-1)}} > \frac{(\overline{\pi}\overline{\gamma})^{1/(\sigma-1)}}{(\sigma-1)} > \frac{(\overline{\pi}\overline{\gamma})^{1/(\sigma-1)}}{(\sigma-1)} a_{t-1}, \tag{32}$$

where the first inequality follows from (P2), and the second inequality follows from $1 - p < (\sigma - 1)^{(\sigma-1)/(\sigma-2)}$, where $\sigma > 2$.

Because $p_t = f_t + (1 - f_t)e_t \in [\overline{\pi}\overline{f}, 1]$, the following parameter condition ensures that there exists a value of $\Theta_t \in (0, \infty)$ that equates $p_t = p_t^g$.

$$\overline{f} < \frac{p_t^g}{\overline{\pi}}. \tag{P3}$$

In other words, the growth-maximizing p_t^g can be mapped into a unique level of growth-maximizing patent strength Θ_t^g that is increasing in a_{t-1} because p_t is monotonically decreasing in Θ_t given (P1). Intuitively, the growth-maximizing level of patent protection increases as the developing country evolves toward the world technology frontier. This finding of a stage-dependent growth-maximizing patent protection is driven by the property that the relative importance between foreign technologies and domestic innovation on the developing country's growth rate changes endogenously as it evolves towards the world technology frontier. Also, it is interesting to note that in the case of an increase in g^*, p_t^g increases and Θ_t^g decreases for a given

a_{t-1}. Intuitively, when the technology frontier grows at a faster rate, it is more efficient for the developing country to imitate foreign technologies than to invest in domestic innovation by implementing a weaker patent system.

Proposition 5 *As a developing country evolves towards the world technology frontier, the growth-maximizing patent strength increases overtime. In addition, for a given stage of development, the growth-maximizing patent strength is decreasing in the growth rate of frontier technology.*

As for the welfare-maximizing patent strength, we consider a government that chooses Θ_t as a function of a_{t-1} to maximize aggregate welfare of current and future individuals given by $\sum_{t=1}^{\infty} \beta^{t-1} U_t$, where $U_t \equiv \int u_t^j dj$. The assumption of risk neutrality implies that aggregate welfare of individuals at time t is simply given by aggregate consumption at time t (i.e., $U_t = C_t$). Substituting (20) - (24) into (25) yields

$$C_t = [\zeta(1-\alpha^2)p_t - \Phi_t]g^* A_{t-1}^* + \left(\zeta(1-\alpha^2) - \frac{(\gamma_t)^\sigma}{\sigma\overline{\gamma}(1+\gamma_t)} - \Phi_t\right)(1+\gamma_t)A_{t-1}, \tag{33}$$

where $\Phi_t \equiv (1-f_t)\Theta_t(e_t)^2/(2\overline{e}) + f_t\Theta_t(\iota_t)^2/(2\overline{\iota}) + f_t(1-\iota_t s)\overline{\pi}$. The government's objective is

$$\max_{\Theta_t} \sum_{t=1}^{\infty} \beta^{t-1} C_t = A_0^* \max_{\Theta_t} \sum_{t=1}^{\infty} [\beta(1+g^*)]^{t-1} c_t, \tag{34}$$

where $c_t \equiv C_t/A_{t-1}^*$. Using (33), we can rearrange terms to obtain

$$c_t = [\zeta(1-\alpha^2)p_t - \Phi_t]g^* + \left(\zeta(1-\alpha^2) - \frac{(\gamma_t)^\sigma}{\sigma\overline{\gamma}(1+\gamma_t)} - \Phi_t\right)(1+\gamma_t)a_{t-1}. \tag{35}$$

Given (34) and (35), we can solve for the socially optimal policy as a time-invariant dynamic programming, using the following Bellman equation.

$$v(a_{t-1}) = \max_{\Theta_t} c_t + \beta(1+g^*)v(a_t), \tag{36}$$

where the law of motion for a_t is given by (26). Substituting (26) and (35) into (36), we derive an expression only in a_{t-1}, parameters, and policy variable Θ_t. Given the analytical complexity of this problem, we consider a numerical approach (described in Appendix A) to solve for the welfare-maximizing path of patent strength Θ_t^u. All the simulations we have obtained so far confirm that Θ_t^u is strictly increasing in a_{t-1}. Hence, these numerical simulations indicate that our theoretical prediction on the growth-maximizing policy also applies to the welfare-maximizing policy.

Proposition 6 *For a wide range of parameters, we find that the welfare-maximizing patent strength* Θ_t^u *is increasing in* a_{t-1}.

In Figure 2, we show a typical simulation outcome, obtained using the following parameter values: $\beta = 0.8$, $\bar{f} = 1$, $\bar{\imath} = 1$, $\bar{e} = 1$, $\alpha = 0.30$, $\bar{\gamma} = 0.03$, $\sigma = 3$, $s = 0.5$, and $g^* = 0.05$. As a_{t-1} increases, the optimal IPR policy $\Theta_t^u(a_{t-1})$ also increases.

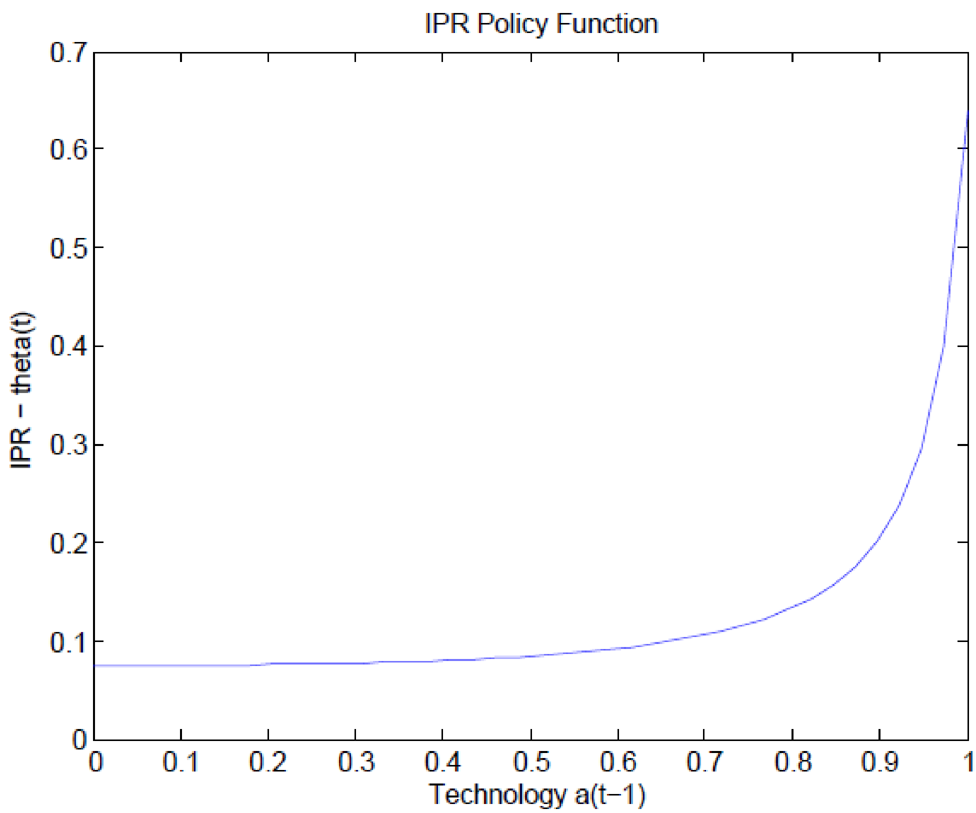

Figure 2 - Optimal IPR Policy

4 Empirical evidence

The theoretical finding of stage-dependent IPR protection is consistent with the empirical pattern of patent rights. Figure 3 plots the Ginarte-Park index of patent rights for a large number of countries at various points in time against their labor productivity relative to the US (i.e., US Relative Productivity is normalized to one). The Ginarte-Park index is available from 1960 to 2005 with one observation every 5 years for each country. To avoid reverse causality and to average out business cycles, we plot the Ginarte-Park index in any given year (e.g., 2005) against the average Relative Productivity from the previous 4 years (e.g., 2001 to 2004). Hence we have 120 countries each with a time series of up to length 10. The graph shows a clear pattern: countries that are closer to the world technology frontier implement stronger patent rights.

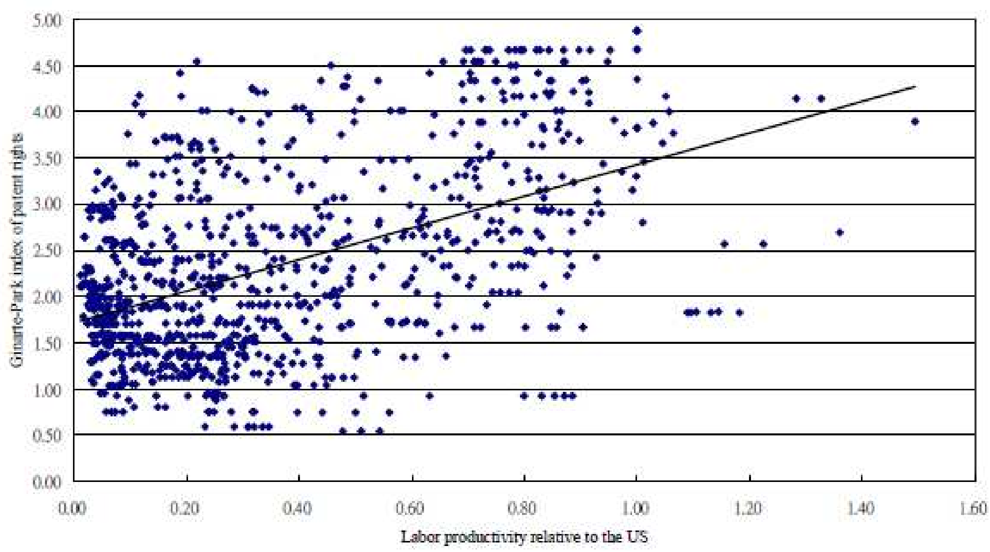

Figure 3 - Patent Protection and Distance to Frontier

To provide a formal statistical test on this empirical relationship, we regress the Ginarte-Park index on Relative Productivity (i.e., the inverse of distance to frontier) and control for time and country fixed effects. The regression results are reported in Table 1, in which we see that the inverse of distance to frontier has a positive and significant effect on the patent index. The Likelihood Ratio tests performed show that the (country, time, and combined) fixed effects are all statistically significant at the 1% significance level.[22]

constant	1.715*** (40.93)	1.056*** (12.55)	1.849*** (11.99)
relative productivity	1.711*** (18.56)	1.799*** (26.65)	0.815*** (5.09)
1965	No	0.128 (1.23)	0.112* (1.70)
1970	No	0.188* (1.82)	0.161** (2.48)
1975	No	0.134 (1.32)	0.152** (2.34)
1980	No	0.259** (2.56)	0.300*** (4.58)
1985	No	0.321*** (3.20)	0.367*** (5.62)
1990	No	0.425*** (4.25)	0.467*** (7.23)
1995	No	0.978*** (9.84)	1.025*** (15.96)
2000	No	1.448*** (14.67)	1.490*** (23.42)
2005	No	1.758*** (17.76)	1.791*** (28.15)
country fixed effects	No	No	Yes
R^2-adjusted	0.25	0.60	0.85
No. of observations	1026	1026	1026
F-statistics	344.63***	155.49***	44.44***

Student's t-test values are in parentheses.
* Statistically significant at 10%
** Statistically significant at 5%.
*** Statistically significant at 1%.

Table 1 - Regression Results

[22] Despite its limitations, also the Hausman Test rejects the insignificance of (only country, due to panel unbalancedness) cross-sectional fixed effects at the 8% significance level.

Even if panel data analysis is usually considered less at risk of spurious regression (Baltagi, 2001, Hsiao, 2003), which is especially true here due to the relatively large number of cross-sectional units, the presence of unit roots in the level of the variables - the Ginarte-Park index and Relative Productivity - has been tested. Regarding Relative Productivity, Levin, Lin, and Chu's test rejects a common unit root, but Im, Pesaran and Shin's test, the Augmented Dickey-Fuller test, and the non-parametric Phillips-Perron tests for individual unit roots all accept the null hypothesis of individual unit roots. All tests reject unit roots in the first-differenced variable. Regarding the Ginarte-Park index, Levin, Lin, and Chu's test rejects a common unit root, and Im, Pesaran and Shin's test rejects the individual unit root hypothesis. However, the Augmented Dickey-Fuller test and the non-parametric Phillips-Perron test for individual unit roots both accept the null hypothesis of individual unit roots. All tests reject unit roots in both first-differenced variables.[23]

Despite non-stationarity, we have undertaken a dynamic panel generalized method of moment analysis, using Arellano-Bond 2-step procedure, but the results, while providing a coefficient of Relative Productivity equal to 0.612048 (significant at less than 1%), also yield a coefficient for the one period lagged Ginarte-Park index equal to 1.175237 (significant at less than 1%), which confirms instability.

Because both the Ginarte-Park index and Relative Productivity are I(1) processes, we move on to undertake a battery of panel cointegration tests. The data suggests the inclusion of a deterministic trend in the cointegration

[23] In all tests, we have considered Akaike, Schwartz, and Hannan-Quinn criteria for selecting the correct lag lengths, without obtaining contradictory results.

tests. As a result, all Kao's tests reject the null hypothesis of no cointegration at the 1% significance level; 9 out of 11 of Pedroni's cointegration tests reject the null hypothesis of no cointegration at the 1% significance level; and all Johansen-based cointegration tests reject the null hypothesis of no cointegration at the 1% significance level.[24]

Undertaking the Johansen cointegrated VAR analysis also leads to a positive and significant coefficient of Relative Productivity in the unique cointegrating relationship found, though its value of around 3 is higher than that of the other estimations undertaken. Nevertheless, we can safely conclude this section by saying that despite all limitations of our data set, there appears to be robust evidence of a positive relationship between Relative Productivity and the Ginarte-Park index of patent rights. This empirical finding is consistent with our main theoretical result: as a country evolves towards the world technology frontier, its patent strength increases overtime.

5 Discussion

In this study, we have developed a simple Schumpeterian growth model of distance to frontier to analyze the evolution of IPR protection in developing countries. Although our model is stylized, we believe that it captures the essence of the key issue that is the interrelation between economic development and optimal IPR protection. Specifically, an appropriate IPR system contributes to the economic development of a country, which in turn deter-

[24] We have performed our empirical analysis using EViews. Data and intermediate software-generated tables are available upon request.

mines the optimal level of IPR protection in the country at a given stage of its development. In summary, we find that the optimal strength of IPR protection increases as a developing country evolves towards the world technology frontier, and this theoretical finding of stage-dependent IPR protection is consistent with the historical evolution of the IPR system in China and also supported by empirical evidence.

Finally, in the theoretical model, we consider a developing country that takes the world technology frontier as given. Although it is arguable that technological progress in developed countries may be affected by the level of IPR protection in developing countries, it is still an open debate among existing studies (cited in the introduction) as to whether Southern IPR protection has a positive or negative effect on Northern innovation. Therefore, we leave this important but controversial issue to future research.

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Not for publication

Appendix A: Numerical solution of the optimal IPR policy

Recall that the government's objective is

$$\max_{\Theta_t} \sum_{t=1}^{\infty} \beta^{t-1} C_t = A_0^* \max_{\Theta_t} \sum_{t=1}^{\infty} \left[\beta(1+g^*)\right]^{t-1} c_t,$$

where c_t is given by (35). Given the analytical complexity of this problem, we consider a numerical approach to solve for the welfare-maximizing path of patent strength. In our numerical analysis, we simulate numerically the value function, $v(a_{t-1})$, and the policy function $G(a_{t-1}) \equiv \Theta_t$, adopting a standard value-function iteration method, according to which[25]:

1. We select a grid of points[26] for $[0, 1]$, i.e. the state space of a_i, where now $i \in 1, ..., N$ indexes the i-th point in the grid (not time);

2. We start from an initial guess[27] of $v_0(a)$;

3. We obtain numerical solutions for

$$\begin{aligned} v_{1i} &= \max_{\Theta_i} c_i + \beta(1+g^*) v_0(a_i) \\ \text{for all } i &\in 1, ..., N; \end{aligned}$$

4. We obtain a (cubic) polynomial spline approximation of $v_1(a)$ such that $v_1(a_i) = v_{1i}$;

[25] All computations have been performed using Matlab. The .m files used are available upon request from the authors.

[26] This number is $N = 40$ in our simulations.

[27] Identically equal to zero.

5. We iterate this procedure, this time starting from the new function $v_1(a_i)$, obtaining

$$\begin{aligned} v_{2i} &= \max_{\Theta_i} c_i + \beta(1+g^*)v_1(a_i) \\ \text{for all } i &\in 1, ..., N; \end{aligned}$$

6. Obtain a polynomial spline approximation of $v_2(a)$ such that $v_2(a_i) = v_{2i}$: this is necessary for the maximization to take place in the continuous space $[0, 1]$, thereby admitting solutions for Θ_i corresponding to values of a not necessarily in the chosen grid[28];

7. We keep repeating the maximization and approximation, until the change in v_{ni} and in the policy variables does not exceed a tolerance value[29].

[28] Otherwise $v_1(a_i)$ would not be defined.

[29] of 10^{-4}, and the number of iterations do not exceed a maximum number of loops, set equal to 80 in our simulations.