Theory and Empirics of Stage-Dependent Intellectual Property Rights

Angus C. Chu, Guido Cozzi, Silvia Galli

March 2013 Discussion Paper no. 2013-06

School of Economics and Political Science,
Department of Economics

University of St. Gallen

Editor:	Martina Flockerzi University of St. Gallen School of Economics and Political Science Department of Economics Bodanstrasse 8 CH-9000 St. Gallen Phone +41 71 224 23 25 Fax +41 71 224 31 35 Email seps@unisg.ch
Publisher:	School of Economics and Political Science Department of Economics University of St. Gallen Bodanstrasse 8 CH-9000 St. Gallen Phone +41 71 224 23 25
Electronic Publication:	Fax +41 71 224 31 35 http://www.seps.unisg.ch

Theory and Empirics of Stage-Dependent Intellectual Property Rights [1]

Angus C. Chu, Guido Cozzi, Silvia Galli

Author's address:

Angus C. Chu
Durham University Business School
Durham University
UK. School of Economics
anguscccc@gmail.com

Prof. Guido Cozzi
FGN-HSG
Varnbüelstrasse 19
CH-9000 St. Gallen
Phone +41 71 224 23 99
Fax +41 71 224 28 74
Email guido.cozzi@unisg.ch
Website www.fgn.unisg.ch

Silvia Galli
University of St.Gallen
Department of Economics
silvia-galli3@gmail.com

[1]We would like to thank Elias Dinopoulos, Rachel Gri¢ th, Oleksandr Talavera, Fabrizio Zilibotti, and seminar participants at Academia Sinica, City University of Hong Kong, Durham University, the University of Hull, the University of Mainz, and Newcastle University for their helpful comments and suggestions. The previous version of this paper was circulated under the title "Innovating Like China: A Theory of Stage-Dependent Intellectual Property Rights".

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 intellectual property rights (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. Therefore, the growth-maximizing and welfare-maximizing levels of patent strength increase as the country evolves towards the world technology frontier, and this dynamic pattern is consistent with the actual evolution of patent strength in China. Furthermore, we use a dynamic panel regression model to provide empirical evidence that supports the key implication of our theoretical model.

Keywords

Economic growth, stage-dependent intellectual property rights.

JEL Classification

O31, O34, O40.

"China and others are entering the tricky middle-income stage of development in which the big advances from absorbing rich-world technology start to run out."
The Economist (2011)[1]

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.[2] 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 over time. For example, the Ginarte-Park index of patent rights in China gradually increased from 1.33 in 1985 to 4.08 in 2005.[3] In 1992, the statutory term of patent in China was lengthened from 15 years to 20 years.[4] Then, in compliance with the TRIPS agreement,[5] China reformed its patent system again in 2000.[6] 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.[7] Following these patent reforms, research and development (R&D) as a percentage of gross domestic product (GDP) in China increased from 0.7% in 1992 to 1.7% in 2009.[8] As for the inflow of FDI to China, it increased from

[1] The Economist, "The world economy: Catching up is very hard to do". September 24th - 30th, 2011.

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

[3] 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.

[4] 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.

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

[6] 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 of this patent reform in China.

[7] 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.

[8] See Hu and Jefferson (2009) who show that the patent reform in 2000 is a major factor for explaining the increase in patenting activities in China.

US$11 billion in 1992 to US$185 billion in 2010.[9]

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.[10] 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 characterized 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 stylized growth-theoretic model to formalize this commonly discussed 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. A recent study by Li (2010) provides an interesting case-study analysis on the biotechnology and pharmaceutical industries to demonstrate that China is in the process of transforming from an imitation-oriented economy to an innovation-oriented economy and that strengthening patent rights can play an important role in facilitating this transformation process. This finding is consistent with the implication of our analysis.

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 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

[9] Data from the World Development Indicators.

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

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. Specifically, we derive an analytical result that the growth-maximizing level of patent protection increases as the country evolves towards the world technology frontier. Furthermore, we provide a numerical result that the welfare-maximizing level of patent protection also increases as the country evolves towards the world technology frontier. These findings are consistent with the actual evolution of patent strength in China and other developing countries. Finally, we test the implication of our theoretical model using a dynamic panel regression model with cross-country data. We find that IPR protection has both positive and negative effects on economic growth, and the positive growth effect of IPR strengthens relative to the negative growth effect as a country evolves towards the technology frontier.

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 the static distortionary effect of markup pricing and the dynamic gain 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. Dinopoulos and Syropoulos (2007) and Davis and Sener (2012) analyze the effects of rent protection activities on innovation. Chu (2009) and Chu *et al.* (2012) analyze the effects of blocking patents on R&D and welfare. Recently, Acemoglu and Akcigit (2012) consider optimal state-dependent patent protection based on the endogenous technological gap between the leader and followers in an industry. 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.[11] A key

[11] 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), Dinopoulos and Segerstrom (2010), Branstetter and Saggi (2011) and Iwaisako *et al.* (2011).

question in this literature is whether strengthening Southern IPR protection stimulates or stifles Northern innovation. Grossman and Helpman (1991) find that strengthening Southern IPR protection either has no effect or a negative effect on Northern innovation.[12] 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) whereas 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 focuses on a different 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 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 paper relates mostly to studies on distance to frontier and convergence; see Acemoglu *et al.* (2003, 2006), Aghion *et al.* (2005), Howitt and Mayer-Foulkes (2005), Benhabib *et al.* (2012) and Gersbach *et al.* (2013). Our paper extends these influential studies by endogenizing an important economic institution that is the IPR system and analyzing how it evolves as an economy develops towards the world technology frontier.[13] Furthermore, we consider innovation and multiple channels of foreign technology transfer through imitation and FDI that are key features of the Chinese economy.

The rest of this study is organized as follows. Section 2 describes the theoretical model. Section 3 analyzes stage-dependent IPR protection and considers an extension of the baseline model. Section 4 presents empirical results. The final section concludes with a discussion.

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

[13] Wu (2010) also considers the effects of IPR protection in a Schumpeterian model of distance to frontier; however, he focuses on the existence of non-convergence traps and how patent protection affects the convergence of developing countries. Our study differs from his interesting analysis by introducing FDI to the distance-to-frontier model and by analyzing the growth-maxizing and welfare-maximizing paths of IPR protection in developing countries.

2 A simple model of distance to frontier

We consider a Schumpeterian growth model of distance to frontier.[14] 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. To facilitate tractable aggregation of social welfare, we follow a common specification in the literature to consider linear utility given by $u_t^j = E[c_t^j]$, where c_t^j denotes consumption by individual j. 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 domestic patent protection on imitation, which in turn affects FDI and innovation. This setup captures the main concerns of policymakers in China. We assume that domestic innovation is affected by domestic patent protection but not by foreign patent protection, and this assumption is consistent with the observation that the vast majority of inventions by residents in China is only patented domestically.[15]

A key difference between our model and the models in Acemoglu *et al.* (2003, 2006) 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 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 in a stylized way both the positive spillover effect and the negative market-stealing effect of foreign technologies on domestic technologies discussed in the empirical literature on technology diffusion.[16]

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

[14] 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).

[15] For example, according to data in WIPO (2012), residents in China made less than 20,000 patent applications abroad in 2011, which represent a mere 4.6% of the 435,608 patent applications made by residents in China in 2011.

[16] See for example Aitken and Harrison (1999), who find that "productivity in domestically owned plants declines when foreign investment increases. This suggests a negative spillover from foreign to domestic enterprises, which we interpret as a market-stealing effect."

imitation improves the incentives for technology transfer via FDI, and this theoretical finding is consistent with empirical evidence.[17] 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).[18]

In the model, we consider a specific sequence of actions by domestic innovators, foreign firms and domestic imitators. In particular, we assume that the action of domestic innovators is followed by foreign firms and then imitators.[19] 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.[20] 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.

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

[17] 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.

[18] See also Akiyama and Furukawa (2009), Furukawa (2007, 2010), Horii and Iwaisako (2007), Iwaisako and Futagami (2013) and Chu *et al.* (2012), who derive an inverted-U relationship between patent strength and innovation in the R&D-based growth model via other mechanisms.

[19] It is useful to note that this formulation allows for the possibility that domestic innovators may decide not to invest in innovation at an early stage of development when patent protection is too weak.

[20] See Section 5 for a discussion of 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[21] 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 $P_t(i) = 1/\alpha$.[22] Therefore, using (2), we can derive the amount of 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 the step size of innovation that is a choice variable.[23] 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

[21] The current patent length of 20 years in China and many other countries is indeed shorter than the average generation length of 25 years.

[22] In line with the standard treatment in this class of models, we assume that the monopolist of an industry is always able to charge the unconstrained monopoly price.

[23] It is useful to note that although a domestically invented technology may not be as advanced as foreign technologies, it was nevertheless patentable in China before its third amendment to patent laws when the novelty requirement for a patentable invention required only local novelty within China. After the recent passage of this third amendment, patentability in China is now based on global novelty. Nevertheless, domestic innovators may invent locally adapted inventions that are "sufficiently" different from foreign inventions and patentable in China.

period begins. When this probability p_t is high, the entrepreneur only has a small chance of capturing the monopolistic profit and 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 $\sigma > 2$.[24] 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

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

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 further increases to[25]

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

[24] 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.

[25] In Section 3.3, we consider a more general specification $\widehat{A}_t(i) = \widetilde{A}_t(i) + g^* A^*_{t-1} + \phi(A^*_{t-1} - A_{t-1})$.

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. In other words, (6) considers the case in which the domestic economy imports newly developed frontier technologies from abroad. Although newly developed technologies represent an important source of technology transfer to developing countries, it is conceivable that previously developed technologies that have not been adopted by developing countries also represent another important source of technology transfer. Therefore, we explore this extension in Section 3.3.

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 $i \in [0,1]$.[26] 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 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 either (a) domestic innovators or

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

(b) foreign firms. In the case of (a), another domestic individual is randomly chosen as an imitator, who has the ability to adapt the more advanced foreign technologies from other industries. We refer to this type of imitation as efficient imitation e_t.[27] 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.[28] 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.[29] 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."

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 probability of a

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

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

[29] Similarly, we can also introduce another profit-sharing parameter between domestic innovators and domestic imitators without changing our main results. However, we think it is more natural for the domestic imitators, who have imitated the more advanced foreign technologies from other industries, to force out the domestic innovators who possess less advanced technologies.

successful efficient imitation in industry i given by

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

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

The return to inefficient imitation is $s\bar{\pi}\widehat{A}_t(i)$. 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

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

where $\bar{\iota}$ 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 $\iota_t s\bar{\pi}\widehat{A}_t(i) - I_t(i)$. Simple differentiation yields the probability of a successful inefficient imitation in industry i given by

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

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 both efficient and inefficient imitations. 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 $p_t = f_t + (1 - f_t)e_t$. 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

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

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.[30] 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

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

which in turn implies $\overline{f} < 1/\overline{\pi}$.[31] For the rest of the analysis, we assume that (P1) holds, so that the effect of patent protection on domestic innovation is monotonically positive. However, due to its negative effect on technology transfer through imitation, we will show that the overall effect of patent protection on economic growth follows an inverted-U shape that is consistent with recent empirical evidence as discussed before.

Proposition 4 *A stronger system of patent protection (i.e., a larger Θ_t) raises FDI intensity f_t. If (P1) holds, then a stronger system of patent protection also has a positive effect on domestic innovation in the developing country.*

For a given level of technology in an industry, (8) shows that a larger f_t also raises the amount of FDI. This finding is consistent with the time series behavior of FDI and patent strength in China as discussed in the introduction.

[30] 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 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.

[31] 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.

We derive the aggregate production function by substituting $P_t(i) = 1/\alpha$ and (2) to (1).

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

where $\zeta \equiv \alpha^{2\alpha/(1-\alpha)}$ is a composite parameter. The resource constraint on 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 amount of final goods used in the production of intermediate goods, (c) R_t is aggregate innovative R&D, (d) E_t is total expenditure on efficient imitation, (e) I_t is total expenditure on inefficient imitation, (f) F_t is total expenditure on FDI, and (g) NX_t is net export. 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

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

In other words, the domestic economy exports goods to pay for the monopolistic profits (net of FDI expenditure) earned by foreign firms. 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.

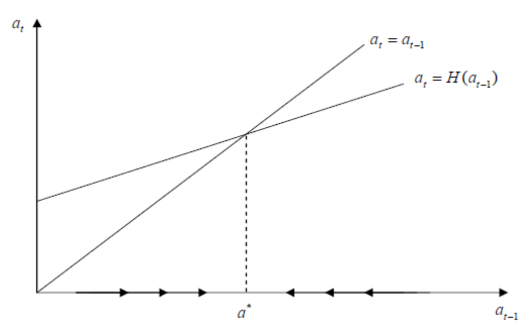

Figure 1: Convergence

Figure 1 shows that 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[32]

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

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

In this section, we first analytically characterize the growth-maximizing level of patent protection. Then, we provide a numerical simulation on the welfare-maximizing level of patent protection. Finally, we explore an extension of our baseline model.

3.1 Growth-maximizing IPR protection

We are interested in the level of patent protection that maximizes contemporaneous economic growth. 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 imitation) is relatively important for achieving a higher growth rate. In contrast, for an advanced country (i.e., a large a_{t-1}),

[32] (P2) also implies $g^* > \gamma$, which guarantees convergence.

domestic innovation γ_t becomes relatively important. This important property gives rise to a stage-dependent growth-maximizing level of patent protection.

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

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

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 $p_t = p_t^g$.

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

Therefore, 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). In other words, although patent protection has a monotonically positive effect on domestic innovation, it still has an inverted-U effect on economic growth because growth is driven by innovation, FDI and imitation. Furthermore, 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 over time. In addition, for a given stage of economic development, the growth-maximizing patent strength is decreasing in the growth rate of frontier technology.*

3.2 Welfare-maximizing IPR protection

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 simulate the welfare-maximizing path of patent strength Θ_t^u.

Our stylized model contains the following parameters $\{g^*, \beta, \alpha, s, \bar{\iota}, \bar{e}, \bar{\gamma}, \overline{f}, \sigma\}$ and variables $\{a_{t-1}, \Theta_t\}$. Some of these parameters such as $\{s, \bar{\iota}, \bar{e}, \bar{\gamma}, \overline{f}, \sigma\}$ are nonstandard, so we calibrate as many of them as possible using data of the Chinese economy. For the parameters that we cannot calibrate, we have to explore a range of values for robustness check. Therefore, this numerical exercise should be viewed as illustrative.

We consider 20 years in a generation. For the (inverse) distance-to-frontier variable, we set $a_{t-1} = 0.11$ to capture the relative labor productivity between China and the US in 2005. For the growth rate of frontier technologies, we set $g^* = (1 + 1.5\%)^{20} - 1$ to capture the long-run average annual TFP growth rate in the US. For the discount factor, we set β to match an annual discount rate of 10% to ensure that utility is bounded despite the high growth rate in China. For the labor share $1-\alpha$, we set α to 0.6 to match the 40% labor share of GDP in China.[33] For the profit-sharing parameter between foreign firms and domestic imitative firms, we set $s = 0.5$ as a benchmark and also consider $s \in \{0, 1\}$ for robustness check. For the innovation parameter, we set $\bar{\gamma} = 1$ as a benchmark and also consider other values $\bar{\gamma} \in \{0.5, 2\}$ for robustness check. For the imitation parameters, we set $\bar{e} = 1$ and consider the symmetric case of $\bar{\iota} = \bar{e}$ as a benchmark, but we also consider $\bar{\iota} \in \{0.5\bar{e}, 2\bar{e}\}$ for robustness check. For the FDI parameter, we set $\overline{f} = 9$. Finally, for the curvature parameter in the innovation cost function, we set $\sigma = 5$. Given these parameter values, the optimal value of Θ_t^u evaluated at $a_{t-1} = 0.11$ is 0.053. With this complete set of parameter values, we can then compute the following moments from the model and compare them to the data of the Chinese economy. We find that from the model, the annual growth rate of output is 7.5%, consumption as a share of GDP is 0.49, and FDI as a share of GDP is 0.032. These calibrated moments are in line with the data on China from the Penn World Table and the World Development Indicators.

Using the above parameter values, we simulate the optimal path of IPR policy Θ_t^u and find that it is increasing in a_{t-1}. This finding is also robust to other parameter values. Hence, these numerical simulations indicate that our theoretical prediction on the growth-maximizing policy also applies to the welfare-maximizing policy. In Figure 2, we show our benchmark simulation outcome.

[33] See for example Luo and Zhang (2010) for data on labor share in China.

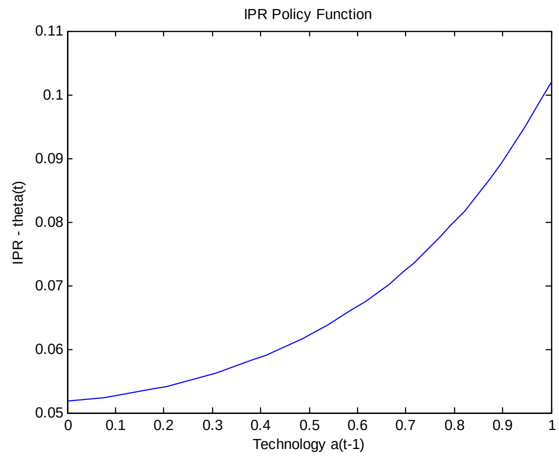

Figure 2: Optimal IPR policy

3.3 Extension: transfer of foreign technologies

In this subsection, we consider an extension of the baseline model. Specifically, we consider the case in which frontier technologies and also previously developed technologies that have not been adopted by the domestic economy are both important sources of technology transfer. In this case, we modify (6) to

$$\widehat{A}_t(i) = \widetilde{A}_t(i) + g^* A^*_{t-1} + \phi(A^*_{t-1} - A_{t-1}), \tag{37}$$

where $A^*_{t-1} - A_{t-1}$ is the distance between frontier and domestic levels of technology, and $\phi > 0$ is a parameter determining the importance of this channel of technology transfer. Under this specification, (16) becomes

$$A_t = p_t[g^* A^*_{t-1} + \phi(A^*_{t-1} - A_{t-1})] + (1 + \gamma_t)A_{t-1}, \tag{38}$$

where $p_t = [f_t + (1 - f_t)e_t]$. In other words, in addition to the average productivity improvement by $\gamma_t A_{t-1}$ in all industries, a fraction p_t of the industries experiences an additional productivity gain by $g^* A^*_{t-1} + \phi(A^*_{t-1} - A_{t-1})$ through either FDI or efficient imitation. Rearranging terms, we derive from (38) the growth rate of the domestic economy given by

$$g_t \equiv \frac{A_t}{A_{t-1}} - 1 = \frac{p_t(g^* + \phi)}{a_{t-1}} + \gamma_t - p_t\phi. \tag{39}$$

Differentiating g_t with respect to p_t yields

$$\frac{\partial g_t}{\partial p_t} = \frac{g^* + \phi}{a_{t-1}} - \frac{(\overline{\pi}\overline{\gamma})^{1/(\sigma-1)}}{(\sigma-1)(1-p_t)^{(\sigma-2)/(\sigma-1)}} - \phi. \tag{40}$$

Therefore, $\partial^2 g_t/\partial(p_t)^2 < 0$ continues to be given by (30) as before. Setting $\partial g_t/\partial p_t = 0$ in (40) yields the growth-maximizing p_t^g given by

$$p_t^g = 1 - \left[\frac{(\overline{\pi}\overline{\gamma})^{1/(\sigma-1)}}{(\sigma-1)} \frac{a_{t-1}}{g^* + \phi(1-a_{t-1})}\right]^{(\sigma-1)/(\sigma-2)}, \tag{41}$$

which remains decreasing in a_{t-1} and increasing in g^*. Given that $p_t = [f_t + (1-f_t)e_t]$ is the same as in Section 2 and strictly decreasing in Θ_t, there exists a unique level of growth-maximizing patent strength Θ_t^g that is increasing in a_{t-1} and decreasing in g^* as before.

4 Empirical evidence

In this section, we first analyze the cross-sectional relationship between patent strength and the distance to frontier. We obtain data on labor productivity relative to the US (i.e., US relative productivity is normalized to one) from the Penn World Table, and this variable, relative labor productivity (RLP), inversely measures the distance to frontier. To capture the strength of IPR, we consider the standard Ginarte-Park index of patent rights, which is available with one observation every 5 years for each country. Figure 3 presents a very clear positive relationship between IPR and RLP for data in 2005.[34] In other words, a country that is closer to the frontier tends to implement stronger patent rights.

[34] This positive relationship would also emerge if we look at data in other years.

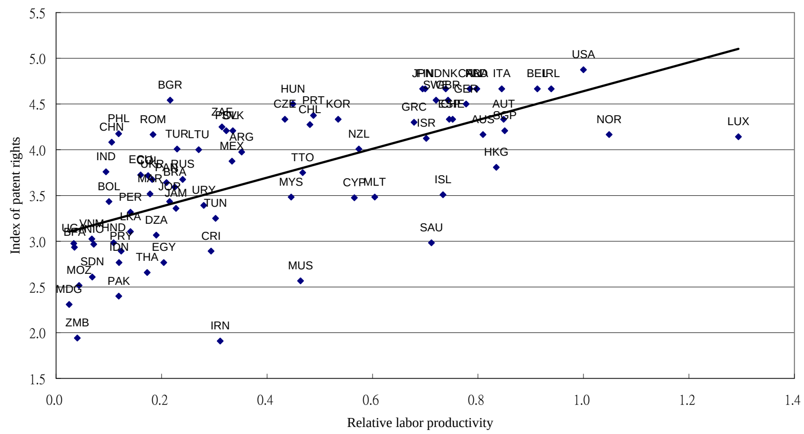

Figure 3: Relationship between IPR and distance to frontier

From our theoretical analysis, we learn that the result of stage-dependent IPR policy is driven by an important property of the model that the positive growth effect of IPR through innovation strengthens relative to the negative growth effect of IPR through imitation as a country evolves towards the technology frontier. Therefore, in the rest of our analysis, we consider a panel regression model to establish empirical evidence for these effects. In the empirical literature, it is well known that the growth effects of IPR protection differ across developed and developing countries; see for example Park (2008b) for a survey. In the following empirical framework, instead of treating developed and developing countries as separate groups, we use a distance-to-frontier variable to capture the degree of economic development as a continuous variable and find that it indeed has an interactive effect with IPR on economic growth. Specifically, we consider an unbalanced panel from 1970 to 2005 for 92 countries.[35]

We consider the following empirical specification.

$$growth_{i,t+1} = \delta_0 + \delta_1 IPR_{i,t} + \delta_2 IPR_{i,t} * RLP_{i,t} + \delta_3 RLP_{i,t} + \Gamma \chi_{i,t} + \varepsilon_{i,t},$$

where $growth_{i,t+1}$ is the growth rate of per capita GDP in country i, that is $\ln GDP_{i,t+1} - \ln GDP_{i,t}$. $IPR_{i,t}$ is the Ginarte-Park index of patent rights.[36] $RLP_{i,t}$ is relative labor

[35] We include all countries with available data for each variable in at least some years during this period.

[36] It is true that the Ginarte-Park index of patent rights may not be a perfect measure of relative patent strength across countries; however, so long as this mismeasurement is time invariant, it will be captured by country fixed effects.

productivity defined above. Vector $\chi_{i,t}$ denotes standard control variables including (a) education measured by the average years of schooling from the Barro-Lee data set, (b) the degree of openness measured by the sum of export and import over GDP from the Penn World Table, (c) an index of economic freedom from the annual report of Economic Freedom of the World, (d) country fixed effects and (e) period fixed effects. Differentiating growth with respect to IPR, we have

$$\frac{\partial growth_{i,t+1}}{\partial IPR_{i,t}} = \delta_1 + \delta_2 RLP_{i,t}.$$

Our hypothesis as implied by (28) and (29) is that $\delta_1 < 0$ and $\delta_2 > 0$. In other words, for a country that is far away from the world technology frontier (i.e., a small $RLP_{i,t}$), the effect of IPR on growth is negative. For a country that is close to the world technology frontier (i.e., a large $RLP_{i,t}$), the effect of IPR on growth becomes positive. In summary, our empirical results indeed show that $\delta_1 < 0$ and $\delta_2 > 0$.

We have considered a number of estimation techniques. The results are summarized in Table 1, in which the dependent variable is $growth_{i,t+1}$.

[Insert Table 1 here]

The first column of Table 1 reports the coefficients of the country fixed effects estimation, whereas the second column also includes period effects, which may reflect technical progress and business cycle components common to all countries, in addition to the persistent country-specific aspects such as geography, institutions, and initial efficiencies. Both country and period fixed effects are jointly significant with p-value lower than 1%. Similarly, country dummies are significant given period dummies, and period dummies are significant given country dummies. We have also performed Hausman tests based on the difference between fixed effects and random effects, which reject the random effects specification at less than 1% significance. To partially correct for the endogeneity of the explanatory variables, we have also reported in the third column the 2-stage least square coefficients for which the instruments are the lagged independent variables. Neither the signs nor the magnitude of the coefficients change much.

We have also undertaken dynamic panel estimations, in which the dependent variable is $\ln GDP_{i,t}$, while $\ln GDP_{i,t-1}$ is one of the regressors, along with $IPR_{i,t-1}$, $RLP_{i,t-1}$, $IPR_{i,t-1} * RLP_{i,t-1}$, and other controls. In this formulation, the growth rate is implicitly obtained as $\ln GDP_{i,t} - \ln GDP_{i,t-1}$. As well known since Caselli *et al.* (1996), in this kind of dynamic panel growth regressions there are serious omitted variable and endogeneity problems. Most notably, the current value of $\ln GDP_{i,t}$ is explained by its lagged value,

$\ln GDP_{i,t-1}$, which is necessarily correlated with the fully persistent country fixed effects[37]. Moreover, most of the other explanatory variables are typically endogenous or predetermined (see Caselli *et al.* 1996). Both problems lead to biased and inconsistent OLS estimators, and this issue is commonly addressed by estimating first-differenced equations and instrumenting the first differences of the endogenous right hand side variables with the levels of the variables lagged two periods and more, and using GMM. We have undertaken regressions using different versions of the Arellano and Bond's (1991) first-differenced GMM estimators which in general confirm our main results. However, this estimator, may not perform well if variables are persistent, as remarked by Bond *et al.* (2001), because the lagged levels are weak instruments for future first-differences[38]. In this case, Blundell and Bond's (1998) system GMM estimator[39] is a more appropriate estimator[40]. Since all our variables are very persistent[41], we have undertaken Blundell and Bond's (1998) system GMM estimations in order to check for robustness. As the reader can see[42], despite the dynamic panel specification, the coefficients of the main explanatory variables, which are reported in the fourth column of Table 1, are roughly in line with those of the static panel regressions of the first three columns. The diagnostic tests are as expected,with overidentification restrictions accepted by Sargan test and Hansen test - as are accepted the (not reported) Difference-in-Hansen tests of the exogeneity of the instruments - and with Arellano-Bond tests rejecting the null of no first-order serial correlation and accepting the null of no-second-order serial correlation. Finally, the residuals of all our regressions have been tested for unit roots, which are always excluded at less than 1% significance.

Therefore we conclude by saying that the available cross-country evidence seems to robustly suggest that the beneficial growth effect of IPR strengthens relative to the negative effect as a country evolves towards the world technological frontier. This finding provides

[37] This is a case of the general dynamic panel bias highlighted by Nickell (1981).

[38] In our attempts with Arellano and Bond (1991) first-differenced GMM regressions, once eliminating instrument proliferation using STATA's **collapse** command and all possible lag restrictions, we have always obtained lagged per capita GDP coefficients that are lower than those of the corresponding Within Groups estimators, which is known to be biased downward. This is a powerful tool to detect bias in first-differenced GMM, as recommended in the growth literature by Bond *et al.* (2001).

[39] This estimator complements Arellano and Bond (1991) first-differenced GMM by instrumenting the level equations using the lagged first-differences of the series, as suggested by Arellano and Bover (1995).

[40] A relevant point has been made by Bobba and Coviello (2007) regarding the positive effect of education on democracy, visible in the system GMM analysis rather than in the difference GMM analysis (in Acemoglu *et al.*, 2005).

[41] The unit root is accepted for all variables in almost all the panel unit root tests we have undertaken.

[42] We have used STATA command **xtabond2** for the dynamic panel regressions. STATA outputs are available upon request. We have used the two-step robust options adjusted for small samples, and with orthogonal deviations (recommended for unbalanced panels). The reported estimates used **lag(2 3) collapse** to avoid instrument proliferation, but they are remarkably stable to alternative lag restrictions over all the available range.

empirical evidence for the IPR and growth mechanics highlighted in our theoretical model.

5 Conclusion

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 determines the optimal level of IPR protection in the country at a given stage of 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 actual evolution of the IPR system in China and supported by empirical evidence.

In terms of policy implications, our finding suggests that it is optimal for a developing country to gradually strengthen its IPR protection. In other words, requiring a developing country, such as China, to immediately raise its level of patent protection on par with developed countries would hurt its social welfare. In a National Academy of Sciences report, Merrill *et al.* (2004, p. 13) state that "patents exist in most countries, and the degree to which countries at different stages of economic development should adhere to the same standards of patentability, conform to the same rules, and follow the same administrative procedures is an enormously complex although extremely important set of issues. [...] readers should not infer that what we recommend for the United States we believe less-developed countries should adopt." Our finding of stage-dependant IPR policy reiterates their concern and provides a justification for the WTO's procedure that when the TRIPS Agreement was implemented in developed countries in 1996, developing countries and least developed countries were given an extension of 4 years and 11 years respectively to apply the agreement's provisions.

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.

References

[1] Acemoglu, D., Aghion, P., and Zilibotti, F., 2003. Vertical integration and distance to frontier. *Journal of the European Economic Association*, 1, 630-638.

[2] Acemoglu, D., Aghion, P., and Zilibotti, F., 2006. Distance to frontier, selection, and economic growth. *Journal of the European Economic Association*, 4, 37-74.

[3] Acemoglu, D., and Akcigit, U., 2012. Intellectual property rights policy, competition and innovation. *Journal of the European Economic Association*, 10, 1-42.

[4] Acemoglu, D., Johnson, S., Robinson, J. A., and P. Yared, 2005. From education to democracy? *American Economic Review*, 95, 44-49.

[5] Aghion, P., Howitt, P., and Mayer-Foulkes, D., 2005. The effect of financial development on convergence: Theory and evidence. *Quarterly Journal of Economics*, 120, 173-222.

[6] Aitken, B., and Harrison, A., 1999. Do domestic firms benefit from direct foreign investment? Evidence from Venezuela. *American Economic Review*, 89, 605-618.

[7] Akiyama, T., and Furukawa, T., 2009. Intellectual property rights and appropriability of innovation. *Economics Letters*, 103, 138-141.

[8] Allison, J., and Lin, L., 1999. The evolution of Chinese attitudes toward property rights in invention and discovery. *University of Pennsylvania Journal of International Economic Law*, 20, 735-791.

[9] Arellano, M. and S. Bond, 1991. Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. *Review of Economic Studies*, 58, 277-297.

[10] Arellano, M. and G. Bover, 1991. Another look at the instrumental variable estimation of error-components models. *Journal of Econometrics*, 68, 29-52.

[11] Benhabib, J., Perla, J., and Tonetti, C., 2012. Catch-up and fall-back through innovation and imitation. NBER Working Paper No. 18091.

[12] Blundell, R. and S. Bond, 1998. Initial conditions and moment restrictions in dynamic panel data models. *Journal of Econometrics*, 87, 115-143.

[13] Bobba, M. and D. Coviello, 2007. Weak Instruments and weak identification in estimating the effects of education on democracy. *Economics Letters*, 96, 301-306.

[14] Bond, S., Hoeffler, A., and J. Temple, 2001. GMM Estimation of Empirical Growth Models, Economics Papers 2001-W21, Economics Group, Nuffield College, University of Oxford.

[15] Branstetter, L., Fisman, R., and Foley, C., 2006. Do stronger intellectual property rights increase international technology transfer? Empirical evidence from US firm-level panel data. *Quarterly Journal of Economics*, 121, 321-349.

[16] Branstetter, L., and Saggi, K., 2011. Intellectual property rights, foreign direct investment and industrial development. *Economic Journal*, 121,1161-1191.

[17] Caselli, F., Esquivel, G., and F. Lefort, 1996. Reopening the convergence debate: a new look at cross-country growth empirics. *Journal of Economic Growth*, 1, 363-389.

[18] Chu, A., 2009. Effects of blocking patents on R&D: A quantitative DGE analysis. *Journal of Economic Growth*, 14, 55-78.

[19] Chu, A., Cozzi, G., and Galli, S., 2012. Does intellectual monopoly stimulate or stifle innovation? *European Economic Review*, 56, 727-746.

[20] Cozzi, G., 2001. Inventing or spying? Implications for growth. *Journal of Economic Growth*, 6, 55-77.

[21] Cozzi, G., and Spinesi, L., 2006. Intellectual appropriability, product differentiation, and growth. *Macroeconomic Dynamics*, 10, 39-55.

[22] Davis, L., and Sener, F., 2012. Private patent protection in the theory of Schumpeterian growth. *European Economic Review*, 56, 1446-1460.

[23] Dinopoulos, E., and Segerstrom, P., 2010. Intellectual property rights, multinational firms and economic growth. *Journal of Development Economics*, 92, 13-27.

[24] Dinopoulos, E., and Syropoulos, C., 2007. Rent protection as a barrier to innovation and growth. *Economic Theory*, 32, 309-332.

[25] Furukawa, Y., 2007. The protection of intellectual property rights and endogenous growth: Is stronger always better? *Journal of Economic Dynamics and Control*, 31, 3644-3670.

[26] Furukawa, Y., 2010. Intellectual property protection and innovation: An inverted-U relationship. *Economics Letters*, 109, 99-101.

[27] Futagami, K., and Iwaisako, T., 2007. Dynamic analysis of patent policy in an endogenous growth model. *Journal of Economic Theory*, 132, 306-334.

[28] Gersbach, H., Schneider, M., and Schneller, O., 2013. Basic research, openness, and convergence. *Journal of Economic Growth*, 18, 33-68.

[29] Ginarte, J., and Park, W., 1997. Determinants of patent rights: A cross-national study. *Research Policy*, 26, 283-301.

[30] Glass, A., and Saggi, K., 2002a. Licensing versus direct investment: Implications for economic growth. *Journal of International Economics*, 56, 131-153.

[31] Glass, A., and Saggi, K., 2002b. Intellectual property rights and foreign direct investment. *Journal of International Economics*, 56, 387-410.

[32] Glass, A., and Wu, X., 2007. Intellectual property rights and quality improvement. *Journal of Development Economics*, 82, 393-415.

[33] Grossman, G., and Helpman, E., 1991. Endogenous product cycles. *Economic Journal*, 101, 1214-1229.

[34] Grossman, G., and Lai, E., 2004. International protection of intellectual property. *American Economic Review*, 94, 1635-1653.

[35] Helpman, E., 1993. Innovation, imitation, and intellectual property rights. *Econometrica*, 61, 1247-1280.

[36] Horii, R., and Iwaisako, T., 2007. Economic growth with imperfect protection of intellectual property rights. *Journal of Economics*, 90, 45-85.

[37] Howitt, P., and Mayer-Foulkes, D., 2005. R&D, implementation and stagnation: A Schumpeterian theory of convergence clubs. *Journal of Money, Credit and Banking*, 37, 147-177.

[38] Hu, A., and Jefferson, G., 2009. A great wall of patents: What is behind China's recent patent explosion? *Journal of Development Economics*, 90, 57-68.

[39] Iwaisako, T., and Futagami, K., 2003. Patent policy in an endogenous growth model. *Journal of Economics*, 78, 239-258.

[40] Iwaisako, T., and Futagami, K., 2013. Patent protection, capital accumulation, and economic growth. *Economic Theory*, forthcoming.

[41] Iwaisako, T., Tanaka, H., and Futagami, K., 2011. A welfare analysis of global patent protection in a model with endogenous innovation and foreign direct investment. *European Economic Review*, 55, 1137-1151.

[42] Javorcik, B., 2004. The composition of foreign direct investment and protection of intellectual property rights: Evidence from transition economies. *European Economic Review*, 48, 39-62.

[43] Judd, K., 1985. On the performance of patents. *Econometrica*, 53, 567-586.

[44] Kwan, Y., and Lai, E., 2003. Intellectual property rights protection and endogenous economic growth. *Journal of Economic Dynamics and Control*, 27, 853-873.

[45] La Croix, S., and Konan, D., 2002. Intellectual property rights in China: The changing political economy of Chinese-American interests. *World Economy*, 25, 759-788.

[46] Lai, E., 1998. International intellectual property rights protection and the rate of product innovation. *Journal of Development Economics*, 55, 133-153.

[47] Lee, J.-Y., and Mansfield, E., 1996. Intellectual property protection and US foreign direct investment. *Review of Economics and Statistics*, 78, 181-186.

[48] Lerner, J., 2009. The empirical impact of intellectual property rights on innovation: Puzzles and clues. *American Economic Review*, 99, 343–348.

[49] Li, C.-W., 2001. On the policy implications of endogenous technological progress. *Economic Journal*, 111, C164-C179.

[50] Li, Y., 2010. *Imitation to Innovation in China: The Role of Patents in Biotechnology and Pharmaceutical Industries*. Northampton, Mass.: Edward Elgar Publishing.

[51] Luo, C., and Zhang, J., 2010. Declining labor share: Is China's case different? *China & World Economy*, 18, 1-18.

[52] Merrill, S., Levin, R., and Myers, M., 2004. *A Patent System for the 21st Century*. Washington, DC: National Academies Press.

[53] Nickell, S., 1981. Biases in dynamic models with fixed effects. *Econometrica*, 49, 1417-1426.

[54] Nordhaus, W., 1969. *Invention, Growth, and Welfare*. Cambridge, Mass.: The MIT Press.

[55] O'Donoghue, T., and Zweimuller, J., 2004. Patents in a model of endogenous growth. *Journal of Economic Growth*, 9, 81-123.

[56] Parello, C., 2008. A north-south model of intellectual property rights protection and skill accumulation. *Journal of Development Economics*, 85, 253-281.

[57] Park, W., 2008a. International patent protection: 1960-2005. *Research Policy*, 37, 761-766.

[58] Park, W., 2008b. Intellectual property rights and international innovation. In K. Maskus (ed.) *Frontiers of Economics and Globalization*, vol. 1, Handbook Series, Elsevier Science.

[59] Qian, Y., 2007. Do national patent laws stimulate domestic innovation in a global patenting environment? A cross-country analysis of pharmaceutical patent protection, 1978–2002. *Review of Economics and Statistics*, 89, 436–453.

[60] Segerstrom, P., 1991. Innovation, imitation, and economic growth. *Journal of Political Economy*, 99, 807-827.

[61] Sepetys, K., and Cox, A., 2009. Intellectual property rights protection in China: Trends in litigation and economic damages. *NERA Economic Consulting* Working Paper.

[62] Tanaka, H., Iwaisako, T., and Futagami, K., 2007. Dynamic analysis of innovation and international transfer of technology through licensing. *Journal of International Economics*, 73, 189-212.

[63] Wu, H., 2010. Distance to frontier, intellectual property rights, and economic growth. *Economics of Innovation and New Technology*, 19, 165-183.

[64] Yang, G., and Maskus, K., 2001. Intellectual property rights, licensing, and innovation in an endogenous product-cycle model. *Journal of International Economics*, 53, 169-187.

[65] Yang, W., and Yen, Y., 2010. The dragon gets new IP claws: The latest amendments to the Chinese patent law. *IPO Articles and Reports*.

[66] WIPO, 2012. World Intellectual Property Indicators. *WIPO Economics & Statistics Series*.

[67] Zuber, J., 2008. Trade secrets rules, regulation and enforcement in China and the US: A comparative analysis. *China Intellectual Property*, May-June 2008, 51-55.

Table 1. Regression results

Dependent Variable: $Growth_{it+1}$

IPR_{it}	-0.049***	-0.031*	-0.062*	-0.061**
	(-3.51)	(-1.79)	(-1.68)	(-2.03)
RLP_{it}	-0.584***	-0.612***	-0.770***	-0.408***
	(-5.83)	(-6.28)	(-4.97)	(-2.76)
IPR_{it}*RLP_{it}	0.055**	0.058**	0.093**	0.068***
	(2.48)	(2.29)	(3.21)	(2.03)
Country fixed effects	Yes	Yes	Yes	Yes
Period fixed effects	No	Yes	Yes	Yes
2-Stage LS	No	No	Yes	No
Dynamic System-GMM	No	No	No	Yes
R^2-adjusted	0.58	0.60	0.58	-
No. of observations	558	558	464	466, No. of instruments =21
F-statistics	6.61***	6.59***	4.25***	Sargan Overid.Test: Prob>chi2 = 0.151; Hansen Overid. Test: Prob>chi2 = 0.394
DW	2.10	2.10	2.29	AR(1) pval=0.006 AR(2) pval=0.162

Hausman Test of Cross-Section

Random Effects: 90.4***

Student's *t*-test values are in parentheses.

* Statistically significant at 10%. ** Statistically significant at 5%. *** Statistically significant at 1%.

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[43]:

1. We select a grid of points[44] 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[45] 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 $v_1(a_i) = v_{1i}$;
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[46];
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[47].

---

[43] All computations have been performed using Matlab. The .m files used are available upon request.

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

[45] Identically equal to zero.

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

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