Economic Growth with Imperfect Protection of Intellectual Property Rights*

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Abstract

The growth effects of intellectual property right (IPR) protection are examined in a quality-ladder model of endogenous growth. Stronger IPR protection, which reduces the probability of imitation, raises the reward for innovation. However, stronger protection reduces the number of competitive sectors, in which it is easier to innovate than in monopolistic sectors, thus concentrating researchers into fewer competitive sectors. As R&D projects take time until they are completed, concentration of R&D activity in a field raises the possibility of duplication of innovation, thereby hindering growth. In several settings, we show that imperfect, rather than perfect, protection maximizes growth.
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1 Introduction

In the last two decades, a number of countries have reformed their patent systems in order to strengthen the protection of intellectual property rights (hereinafter, IPRs). Such reforms are often justified by the view that stronger IPR protection should enhance economic growth by increasing the returns to innovation and, hence, the incentives to innovate. However, the relationship between IPR protection and growth is not as clear as is widely believed.[1] Figure 1 illustrates a scatter plot of the average growth rate and the level of IPR protection, using Rapp and Rozek's (1990) cross-country data on the level of patent protection. Although there is substantial variability across countries in both the level of IPR protection and the rate of economic growth, it is difficult to determine a clear relationship between these two variables in the figure.[2]

Given that stronger IPRs unambiguously provide greater incentives to innovate, the weak relationship observed between IPR protection and the rate of economic growth suggests that IPRs may have negative effects on economic growth. A well-known drawback of stronger IPRs is that they provide innovators with longer periods of monopoly on average and, therefore, tend to increase the number of monopolistic sectors within the whole economy. In the light of this tendency, earlier studies have demonstrated that consumer welfare is not necessarily improved when IPRs are strengthened, because consumers then face higher prices.[3] In this paper, we present

[1] Applications for patents in the United States have increased drastically since 1985; however, there is little evidence that this increase was caused by the strengthening of IPR protection. Changes in the management of R&D and the shift to more applied activities seem to have spurred patenting (Kortum and Lerner, 1998).

[2] Gould and Gruben (1996) ran regressions using the index by Rapp and Rozek (1990) and the average growth rate between 1960 and 1988. They found a positive but weak relationship between IPR protection and economic growth (see Table 2 of their paper). In addition, they pointed out that, on average, countries with level 'three' IPR protection grew more slowly than those with weaker (level 'two') IPR protection.

[3] Using endogenous growth models, Futagami, Mino, and Ohkusa (1999), Kwan and Lai (2003),

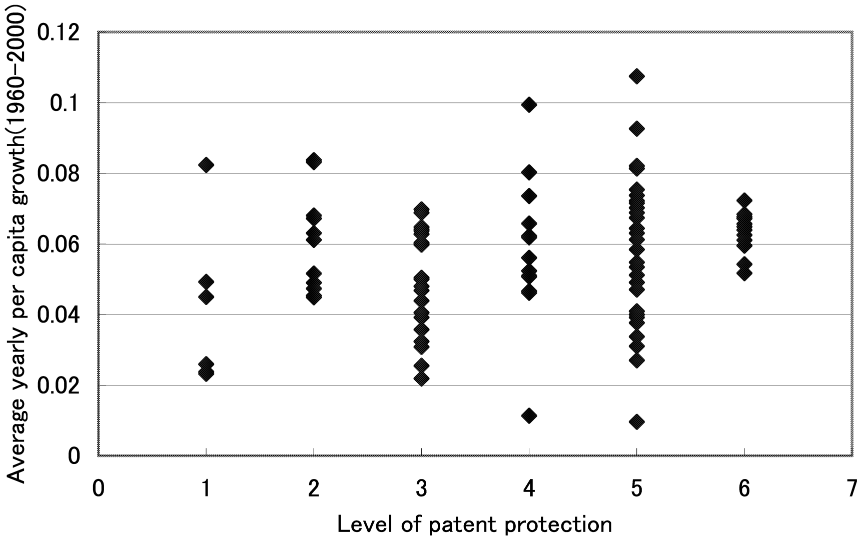

Figure 1: Average per capita growth rate 1960–2000 and the level of patent protection. The horizontal axis ranks the level of patent protection from one to six, where one corresponds to nations with no patent protection law and higher numbers indicate countries with patent laws that are more consistent with the minimum standards proposed by the United States Chamber of Commerce (1987). The average growth rate is taken from Heston *et al.* (2002).

a mechanism through which stronger IPRs negatively affect the long-term rate of economic growth, by focusing on the following two properties of R&D.

The first property is the difference in the environments for R&D provided by monopolistic and competitive sectors. In a monopolistic sector, where an incumbent holds the exclusive right to produce a state-of-the-art good, the incumbent has little incentive to further improve the product because it can secure monopoly profits without such efforts (the Arrow effect, 1962). Thus, in monopolistic sectors, innova-

and Iwaisako and Futagami (2003) showed that consumer welfare is maximized when protection of IPRs (achieved by, for example, increasing the difficulty of imitation, and providing longer and broader patents) is at an intermediate strength, rather than when it is at its strongest. However, all three studies found that strengthening IPRs always enhances economic growth. In addition, Grossman and Lai (2004) found that stronger IPRs were not necessarily welfare enhancing in a nonendogenous growth model.

tive efforts are made only by outside firms, which can succeed only when they create a good of higher quality than the incumbent's. Such *leapfrogging* innovations are more difficult to achieve than innovations in competitive sectors because the outside firms have no experience in producing state-of-the-art-quality goods. In addition, production of a new superior good often involves a similar process to the production of the current state-of-the-art goods and, therefore, the incumbent's IPRs may result in the production of the new superior goods being banned. Thus, *ceteris paribus*, it is more difficult for outside firms to invent new high quality goods in monopolistic sectors than it is in competitive sectors. Empirical studies by Blundell *et al.* (1995) and Nickel (1996) have shown that innovation is less active in more concentrated sectors.

The second property of R&D projects is that they take time and their outcomes (successes or failures) are revealed only after the projects are completed. This means that individual innovators must initiate R&D projects without knowing whether other innovators' projects will eventually succeed or fail. Thus, there is a nonnegligible probability that more than two innovators may independently succeed in innovating the same intermediate good of the same quality. Given the nonrivalry of the knowledge obtained by innovation, this *duplication* of innovations is not only futile from the viewpoint of economic growth, but also reduces the profits and incentives of innovators.[4] We show that the duplication of innovations is more likely to occur when there are fewer competitive sectors in an economy.

Incorporating these two properties of R&D explicitly into the quality-ladder model of endogenous growth, this paper reexamines the relation between IPR protection and economic growth. We assume that innovations are imitated over time and that strengthening IPR protection reduces the probability of imitation. On the balanced growth path (BGP), stronger IPR protection increases the number of monopolistic sectors in which the state-of-the-art quality goods have not yet been imitated. Conversely, it reduces the number of competitive sectors in which the

[4] Jones (1995) incorporated the possibility of duplication into his model.

state-of-the-art quality goods have already been imitated and any firm can produce them. As innovation is assumed to be more difficult in monopolistic sectors, R&D is more concentrated in competitive sectors. The stronger IPR protection is, the fewer competitive sectors there will be and, therefore, the more researchers will engage in R&D in each competitive sector. However, when the time required to innovate is explicitly considered, the possibility of duplication of innovations increases with the number of researchers in the field, thereby reducing the expected return on R&D.[5] As a result, strengthening IPR protection does not necessarily facilitate economic growth. This paper examines the relative significance of the growth-enhancing and -reducing effects of IPRs and shows that the long-term growth rate is maximized by imperfect, rather than the perfect, protection of IPRs.

In the literature on IPR protection, most theoretical studies have concluded that stronger protection always enhances economic growth.[6] However, a few studies have pointed out that IPRs have negative effects on growth for various reasons. Helpman (1993) instigated the examination of the effects of tightening IPRs in the framework of a North–South economy. He showed that strengthening IPR protection (i.e., reducing the probability of imitation) in the South reduces the rate of innovation in the north in the long run. His result depended critically on the assumption that there was no movement of labor between the two countries, or, equivalently, between the monopolistic and competitive sectors. This paper considers a closed economy model without any restriction on the movement of workers across sectors.

Michel and Nyssen (1998) examined the impact of IPRs on growth in terms of patent length and found that the rate of economic growth is maximized when the patent length is finite, rather than infinite. In a variety-expansion model of endogenous growth, they assumed that the knowledge spillover from past R&D is

[5]This mechanism is consistent with findings by Kortum (1993) and Thompson (1996), who reported that the rate of return from R&D diminishes as the number of researchers increases.

[6]In addition to the studies mentioned in footnote 3, O'Donoghue and Zweimuller (2004) showed that stronger patent protection enhances innovation and economic growth.

limited during the term of patent protection. Based on this assumption, extending patent length reduces the knowledge spillover and, therefore, lowers the productivity of present R&D. The mechanism in their model is similar to our model, in which IPR protection prevents outside firms from obtaining experience in the production of state-of-the-art-quality goods. However, whereas Michel and Nyssen considered only the creation of new goods as an engine of growth, in our model, growth is driven by two types of innovation in existing sectors: leapfrogging in monopolistic sectors, and innovation after imitation in competitive sectors. We show that IPR policies affect the significance of these two sources of growth differently.

Finally, using models of *step-by-step* innovation, Aghion, Harris, and Vickers (1997) and Mukoyama (2003) showed that the growth rate increases with the ease of imitation or the rate of subsidy on imitation. In their models, two firms operate in each sector, and innovation is assumed to take place only in the "competitive" sector, where the two firms share the same level of technology.[7] The rate of economic growth clearly increases with the number of competitive sectors because the number of firms exerting efforts to innovate in each sector is fixed.[8] Our model does not rely on this mechanism as we allow the free entry of innovative activity in any sector, as is commonly assumed in other R&D-based endogenous growth models. Rather, in our model, where the time required to innovate is explicitly introduced, widespread competition promotes growth by diversifying researchers across broader fields, thereby reducing the possibility of unnecessary duplication.

The rest of the paper is organized as follows. Section 2 sets up the model. Section 3 explains how tightening patent protection affects the growth rate, assuming that leapfrogging is prohibitively difficult. Section 4 derives the BGP in a general setting

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[7] Aghion *et al.* (2001) found their result was robust even when the monopolist is allowed to carry out R&D.

[8] In particular, Aghion *et al.* (1997) assumed decreasing returns to individual R&D inputs by each firm, whereas, in the model of Mukoyama (2003), the level of R&D input is determined by the Nash equilibrium in the innovation race, which is independent of the number of competitive sectors.

and examines the relative importance of leapfrogging and innovation after imitation. Section 5 investigates an extended version of the model, in which strengthening IPRs not only reduces the imitation rate but also raises the difficulty of leapfrogging innovation. Section 6 concludes the paper. An appendix provides the proof of lemmas.

2 Model

This section sets up a discrete-time version of a quality-ladder model based on Grossman and Helpman (1991b). After describing households and production sectors in the first subsection, we explain how the environments for R&D differ between competitive and monopolistic sectors in the second subsection. The final subsection considers the evolution of the value of innovation and the number of monopolistic sectors in the economy, allowing for the possibility of imitation.

2.1 Households and production technologies

We consider a closed economy consisting of homogeneous and infinitely lived households of size L. Each household is endowed with a unit of labor in each period. The nominal market value of labor (i.e., the wage) is denoted by w_t, which is to be determined in equilibrium. The utility function of the representative household is given by:

$$U = \sum_{t=0}^{\infty} \beta^t \ln c_t, \tag{1}$$

where $\beta \in (0, 1)$ is a constant subjective discount factor and c_t is consumption of the final good in period t. Each household maximizes (1) subject to the intertemporal budget constraint $a_{t+1} - a_t = r_t a_t + w_t - P_t c_t$, where a_t denotes the per capita nominal financial asset,[9] r_t is the interest rate, and P_t is the price of the final good,

[9]The initial value of a_0 is determined by the initial value of IPRs: $a_0 = \mu_0 V_0 / L$, where the definitions of μ_0 and V_0 are given later. In fact, we do not need to keep track of the consumer's budget constraint thanks to Walras's law.

which is normalized so that the aggregate consumption expenditure becomes unity at each period: $P_t c_t L = 1$ for all t. This is a standard dynamic optimization problem, with its Euler equation being $(P_{t+1}c_{t+1})/(P_t c_t) = \beta(1 + r_{t+1})$. Note that, under our normalization of P_t, the left-hand side (LHS) of the Euler equation equals one for all t. Then, $1 = \beta(1 + r_t)$ must hold for all periods, implying that the interest rate is constant at $r_t = \beta^{-1} - 1 \equiv r$.

The final good is produced competitively using a continuum of different types of intermediate goods, indexed by $i \in [0, 1]$. We consider a standard quality-ladder setting, where each type of intermediate good potentially has several quality grades as a result of past product innovations. The quality grades of a given type of intermediate good, indexed by integers $j \geq 0$, are perfectly substitutable as inputs to the production of the final good, and have different marginal productivities. For each i and j, let $\tilde{x}_{it}(j)$ denote the units of the type i intermediate good of quality j, which are used in the final-good production. Then, the output Y_t is determined by the following production function:

$$Y_t = \exp\left\{\int_0^1 \ln\left[\sum_{j=0}^{q_{it}} \lambda^j \tilde{x}_{it}(j)\right] di\right\}, \tag{2}$$

where $\lambda > 1$ represents the size of the quality improvement obtained from one innovation and $q_{it} \geq 0$ is the highest (state-of-the-art) quality of the type i intermediate good (i.e., it represents the cumulative innovations that have occurred in sector i by date t). As the intermediate goods of the same type are perfect substitutes, the final good producers use the single quality that has the lowest quality-adjusted price, $\tilde{p}_{it}(j)/\lambda^j$, for every type of intermediate good.

Each type of intermediate good is produced in a separate intermediate good sector. In every sector, production of one unit of the intermediate good of any quality requires one unit of labor, which means that the marginal cost of production equals the nominal wage, w_t. As the costs are the same for all qualities, only the state-of-the-art technology is used in equilibrium. Let $x_{it} \equiv \tilde{x}_{it}(q_{it})$ and $p_{it} \equiv \tilde{p}_{it}(q_{it})$ denote the amount and price of the state-of-the-art good in sector i. Note that the market value of total output from the final good production equals one because final goods are used only for consumption and we have normalized the aggregate consumption expenditure to one. In addition, the production function of the final good is a symmetric Cobb–Douglas function and the total number of sectors is one. Hence, the expenditure of the final good producers on each type of intermediate good is also one, implying that the demand function for each type of intermediate good is $x_{it} = 1/p_{it}$.

The equilibrium prices and quantities in the intermediate good sectors depend on whether they are monopolistic or competitive. An intermediate good sector is monopolistic when there is a firm that holds an IPR giving it the exclusive right to produce the highest-quality intermediate goods. A monopoly firm maximizes its profit by employing the limit-pricing strategy; that is, it sets a price that cannot be undercut by the next-best-quality good in terms of the quality-adjusted price. This price is[10] $p_{it} = \lambda w_t$. Given the demand function $x_{it} = 1/p_{it}$, the monopoly firm sells amount $x_{it} = 1/(\lambda w_t)$, obtaining the monopoly profit $\pi = (\lambda - 1)/\lambda$. In a competitive sector, where the technology to produce the highest-quality intermediate good is publicly available, firms compete with each other, pushing the price down to the marginal cost, $p_{it} = w_t$. In this case, $x_{it} = 1/w_t$.

2.2 R&D and the labor market equilibrium

In the model, economic growth is driven by innovations, which raise the quality of intermediate goods. Innovation may occur in competitive and monopolistic sectors as a result of R&D activities by workers. However, the environments for such activities are different depending upon whether R&D is undertaken in a competitive or a monopolistic sector.

[10]The quality-adjusted price of the monopoly firm is $(\lambda w_t)/\lambda^{q_{it}} = w_t/\lambda^{q_{it}-1}$. Recall that the marginal cost of producing any intermediate good is w_t. Thus, producers of the next-best-quality good can only set $\tilde{p}_{it}(q_{it} - 1) \geq w_t$, where $\tilde{p}_{it}(q_{it} - 1)$ denotes the price of the intermediate good of quality $q_{it} - 1$. Their quality-adjusted price must be $\tilde{p}_{it}(q_{it} - 1)/\lambda^{q_{it}-1} \geq w_t/\lambda^{q_{it}-1}$. Hence, they cannot undercut the quality-adjusted price of the monopolist.

Let us start by describing the environment for R&D in competitive sectors. When one worker conducts an R&D activity for one period in a particular competitive sector i, he or she has a small probability, $\widehat{a} > 0$, of successfully creating an innovated good. Any R&D activity takes one period to be completed. Hence, the innovated intermediate good can be produced only from the next period onwards. We assume away interaction between researchers. Then, given that the total number of researchers in the competitive sector is n_{it}, the probability that some of them successfully innovate is:[11]

$$G(n_{it}) = 1 - (1 - \widehat{a})^{n_{it}} = 1 - \exp(-an_{it}), \tag{3}$$

where $a \equiv -\ln(1 - \widehat{a})$. As $a \simeq \widehat{a}$, given that $\widehat{a}$ is sufficiently small, we use parameter a interchangeably with $\widehat{a}$ in the following. Let V_{t+1} denote the value of monopolizing this innovation at period $t+1$. Note that this value must be discounted by $\beta = 1/(1+r)$ because the fruits from the innovation can be reaped only in the next period, whereas the costs of the innovation must be incurred immediately. Then, the expected payoff per worker from R&D is written as $\beta V_{t+1} g(n_{it})$, where:

$$g(n_{it}) \equiv \frac{G(n_{it})}{n_{it}} = \frac{1 - \exp(-an_{it})}{n_{it}} \leq a, \tag{4}$$

with $g'(\cdot) < 0$, $g(0) = a$, and $\lim_{n\to\infty} g(n) = 0$.

Equation (4) implies that the payoff per worker decreases as the total number of researchers competing with each other in the sector increases. This is due to the possibility of *duplication*; even when two workers simultaneously innovate in the same sector, their total payoff is at most βV_{t+1}, rather than $2\beta V_{t+1}$, because of the nonrival nature of knowledge. We may assume that successful innovators share the profits from the innovation, βV_{t+1}, equally because they fear entering into Bertrand competition from the next period onwards and ending up with zero profits if they

[11] The probability that one researcher fails is $1 - \widehat{a}$. Assuming that there is no correlation between the successes or failures of innovation among the researchers, the probability that all n_{it} researchers simultaneously fail is $(1 - \widehat{a})^{n_{it}}$. From this, we obtain (3). If there is a positive correlation, the possibility of duplication increases and thus, function $g(\cdot)$ decreases with n_{it} more rapidly than in (4). This change would strengthen the growth-reducing effect of stronger IPRs.

fail to agree upon a division of profits. Alternatively, we can consider the case where one lucky innovator obtains the sole right to use that innovation, while others are prohibited. In either case, the expected return from engaging in R&D activities in sector i is $\beta V_{t+1} g(n_{it})$.

Innovation may also occur in monopolistic sectors. As the incumbent monopolist has little incentive to innovate in its own sector (the Arrow effect), any R&D that occurs is carried out by outsiders who try to leapfrog the current monopolist. However, in contrast to firms in competitive sectors, outside firms in monopolistic sectors cannot gain experience in producing goods with state-of-the-art technology. This limits the firms' ability to attain the information required to improve upon the current state-of-the-art technology. In addition, outside researchers must restrict their methods of innovation to avoid infringing the patents of the incumbent firm. For these reasons, the probability that an outside researcher in a monopolistic sector will succeed, denoted by $\widehat{b} \in (0, \widehat{a})$, is well below the probability of success in a competitive sector. We treat $\widehat{b}$ as an exogenously given parameter, until it is endogenized in section 5. Let m_{it} denote the total number of researchers in monopolistic sector i. Then, the probability that at least one of the researchers succeeds is:

$$H(m_{it}) = 1 - (1 - \widehat{b})^{m_{it}} = 1 - \exp(-b m_{it}), \tag{5}$$

where $b \equiv -\ln(1 - \widehat{b}) \simeq b$. The expected payoff that each researcher receives is $\beta V_{t+1} h(m_{it})$. Here, $h(m_{it}) \equiv H(m_{it})/m_{it}$, with $h'(\cdot) < 0$, $h(0) = b$, and $\lim_{m\to\infty} h(m) = 0$.

The number of researchers in each sector, competitive or monopolistic, is determined by the free-entry condition. We assume a complete insurance market so that the risk of engaging in R&D activities can be fully diversified. Workers compare the expected return from engaging in R&D for one period with the payoff from working as a production worker for that period, w_t. There are two conditions that must be satisfied in equilibrium: (i) the expected payoff from R&D should not exceed the market wage in equilibrium, and (ii) R&D should provide an expected return at least equal to w_t when some workers engage in R&D.[12] These requirements determine n_{it} and m_{it} as follows:[13]

$$n_{it} = n_t = N(w_t/\beta V_{t+1}) \equiv \begin{cases} g^{-1}(w_t/\beta V_{t+1}) & \text{if } w_t/\beta V_{t+1} < a, \\ 0 & \text{if } w_t/\beta V_{t+1} \geq a, \end{cases} \tag{6}$$

$$m_{it} = m_t = M(w_t/\beta V_{t+1}) \equiv \begin{cases} h^{-1}(w_t/\beta V_{t+1}) & \text{if } w_t/\beta V_{t+1} < b, \\ 0 & \text{if } w_t/\beta V_{t+1} \geq b. \end{cases} \tag{7}$$

Equations (6) and (7) show that the number of researchers in each sector is determined by $w_t/\beta V_{t+1}$, which represents the cost of R&D relative to the discounted value of innovation that a researcher can obtain if he or she succeeds. Researchers participate in R&D activities in competitive sectors when this relative cost is lower than the probability of success, a, and they carry out R&D in monopolistic sectors if the relative cost is lower than the probability of success there, b. Observe that, given the discounted value of innovation, βV_{t+1}, the number of researchers in every competitive or monopolistic sector, is a decreasing function of the market wage. That is, if the cost of R&D rises, the number of R&D competitors must decrease so that the reduced possibility of duplication compensates for the rise in the R&D cost.

The equilibrium market wage at each period is determined so that the aggregate labor demand for both production and R&D is equalized to the aggregate labor supply. Recall that the demand for production workers in each intermediate good sector is determined by the amount of sales, which is $1/w_t$ in the competitive sectors and $1/(\lambda w_t)$ in the monopolistic sectors. Let μ_t denote the number of monopolistic

[12] In mathematical terms, $\beta V_{t+1} g(n_{it}) \leq w_t$ with equality when $n_{it} > 0$ for all competitive intermediate good sectors, and $\beta V_{t+1} h(m_{it}) \leq w_t$ with equality when $m_{it} > 0$ for all monopolistic sectors.

[13] As expression $w_t/\beta V_{t+1}$ appears frequently, to minimize notations, we write it this way rather than $w_t/(\beta V_{t+1})$.

sectors in the economy. Then, labor market clearing requires that:[14]

$$(1 - \pi\mu_t)/w_t + (1 - \mu_t)N(w_t/\beta V_{t+1}) + \mu_t M(w_t/\beta V_{t+1}) = L. \quad (8)$$

The LHS of (8) gives the aggregate labor demand, with the first term representing the number of production workers and the second and third terms representing the total number of researchers in the competitive and the monopolistic sectors, respectively. It is easily confirmed that the aggregate labor demand is downward sloping with respect to w_t, and that it increases unboundedly when $w_t \to 0$, and shrinks toward zero as $w_t \to \infty$. Those properties guarantee that, given μ_t and V_{t+1}, there exists a unique level of w_t at which the aggregate labor demand coincides with the aggregate labor supply, L. Once the equilibrium value of w_t is obtained, n_t and m_t are found from (6) and (7).

2.3 Evolution of the economy

The state of the economy is characterized by the number of monopolistic sectors, μ_t, and the value of innovation, V_t. This subsection describes the evolution of the economy over time.

There are two reasons why a firm's monopoly in a particular intermediate good sector ends. The first is leapfrogging. If a successful innovation occurs in a monopolistic sector, the incumbent monopolist is replaced by the successful innovator in the following period. As shown by (5), leapfrogging occurs with a probability of $H(m_t)$ during each period. The second cause is imitation. Even though the IPRs of a monopoly firm are protected to a certain extent, other firms may find a different method of producing goods similar to the monopolist's without infringing upon the monopolist's patent. We assume that such imitation occurs with a constant probability of $\delta \in [0, 1]$ in each period and that it allows any firm to produce the state-of-the-art-quality intermediate good from the next period onwards. Param-

[14]Recall that $\pi = (\lambda - 1)/\lambda$. The total number of production workers is $(1 - \mu_t)/w_t + \mu_t/(\lambda w_t) = (1 - \mu_t + \mu_t/\lambda)/w_t = (1 - \pi\mu_t)/w_t$.

eter δ measures the weakness of IPR protection; in an economy with strong IPR protection, δ is close to zero and imitation rarely occurs, whereas, with weak IPR protection, δ is large and imitation is frequent.

If imitation occurs, it turns a monopolistic sector into a competitive one. A subtle point is that both leapfrogging and imitation may occur simultaneously within one period. In this case, a new monopoly firm emerges in the following period and the imitation of the current state-of-the-art product has no impact on the new monopolist. Without a systematic correlation between these two types of event, the coincidence occurs with a probability of $\delta H(m_t)$. Thus, the number of monopolistic sectors that change to competitive ones in the following period is $\delta(1 - H(m_t))\mu_t$. On the other hand, out of $1 - \mu_t$ competitive intermediate good sectors, $G(n_t)(1 - \mu_t)$ sectors develop into monopolistic ones through successful innovations. The net change in μ_t for one period is determined by the difference between these two flows:

$$\mu_{t+1} - \mu_t = (1 - \mu_t)G(n_t) - \delta\mu_t(1 - H(m_t)). \tag{9}$$

Next, let us examine how the value of innovation evolves over time. Recall that V_t represents the value of holding a valid (not imitated) IPR at period t. If a monopoly firm holds this right, it earns a profit of $\pi = (\lambda - 1)/\lambda$. In addition, this IPR is still valid at period $t + 1$ if neither imitation nor leapfrogging has occurred during period t. Its present value is βV_{t+1}, and this value is realized with a probability of $(1 - \delta)(1 - H(m_t))$. In sum, V_t is determined by a backward dynamics, as follows:

$$V_t = \pi + \beta(1 - \delta)(1 - H(m_t))V_{t+1}, \tag{10}$$

together with a transversality condition, $\lim_{T\to\infty} \beta^T V_T = 0$, which is required for ruling out bubble prices.

The equilibrium dynamics is characterized by equations (9) and (10). Once n_t and m_t are eliminated by (6), (7), and (8), we see that they constitute an autonomous system of difference equations in terms of μ_t and V_t.[15] The initial number of monopolistic sectors, μ_0, is historically given, whereas the initial value of an IPR, V_0,

[15] Let us define function $W(\mu_t, V_{t+1})$ as the equilibrium level of w_t given μ_t and V_{t+1}, as deter-

is determined so that the transversality condition is not violated. Along the equilibrium path, the growth rate of output is obtained by taking the difference in the log of Y_t. From (2), it is:

$$\gamma_{Y_{t+1}} \equiv \ln Y_{t+1} - \ln Y_t = (\ln \lambda) \int_0^1 (q_{i\,t+1} - q_{it}) di + \int_0^1 (\ln x_{i\,t+1} - \ln x_{it}) di. \quad (11)$$

Equation (11) shows that the growth rate can be decomposed into changes in qualities and changes in quantities. On the right-hand side (RHS) of (11), the integral in the first term corresponds to the total number of sectors in which innovation occurs at period t. It is the sum of the number of leapfroggings, $\mu_t H(m_t)$, and the number of innovations in the competitive sectors, $(1-\mu_t)G(n_t)$. The second term is the aggregate change of (the log of) output in the intermediate good sectors. Recall that the intermediate good output is $1/(\lambda w_t)$ in a monopolistic sector, and $1/w_t$ in a competitive sector. By substituting these quantities into (11), the growth rate can be expressed as:

$$\gamma_{Y_{t+1}} = (\ln \lambda)[(1-\mu_t)G(n_t) + \mu_t H(m_t)] - (\ln \lambda)(\mu_{t+1} - \mu_t) - (\ln w_{t+1} - \ln w_t). \quad (12)$$

The growth effects of IPR policies can be understood by examining how changes in δ affect the endogenous variables in expression (12). The following three sections are devoted to this task, starting from a special but still informative case, moving toward a general setting, and then on to a more realistic extension.

3 Growth without leapfrogging

This section examines the growth effects of IPR policies by focusing on an extreme case in which leapfrogging is prohibitively difficult. Note that, from (8) and (10), there is a lower bound for the cost of R&D relative to the discounted value of inno-

mined by (8). Then, (9) and (10) can be written as $\mu_{t+1} = \big[1-\delta+H\big(M(W(\mu_t, V_{t+1})/\beta V_{t+1})\big)\big]\mu_t + G\big(N(W(\mu_t, V_{t+1})/\beta V_{t+1})\big)(1-\mu_t)$, and $V_t = \pi + \beta(1-\delta)\big[1 - H\big(M(W(\mu_t, V_{t+1})/\beta V_{t+1})\big)\big]V_{t+1}$.

vation,[16]

$$w_t/\beta V_{t+1} \geq r/((\lambda-1)L) \equiv z^{\min}. \tag{13}$$

As a benchmark, this section considers a case in which the probability of successful leapfrogging, b, is even lower than this lower bound:

Assumption 1. $b < z^{\min}$.

Under Assumption 1, (7) and (13) imply that $m_t = 0$ for all t; that is, no researchers operate in the monopolistic sectors and, therefore, leapfrogging never occurs. Without the risk of being leapfrogged, the value of an innovation is influenced only by the probability of being imitated, which is directly controlled by IPR policies. Substituting $m_t = 0$ for all t into (10) and then applying the transversality condition, we find that the value of innovation is constant over time:

$$V_t = \frac{\pi}{1-\beta(1-\delta)} \equiv \overline{V}(\delta) \quad \text{for all } t. \tag{14}$$

The number of researchers in each competitive sector, n_t, is determined by the free-entry condition (6) and the labor-market-clearing condition (8). Given that $m_t = 0$ and $V_t = \overline{V}(\delta)$ for all t, these conditions can be restated as follows:

$$\frac{1-\pi\mu_t}{L-(1-\mu_t)n_t} \geq \beta\overline{V}(\delta)g(n_t), \quad \text{with equality if } n_t > 0. \tag{15}$$

Condition (15) has an intuitive interpretation. The LHS of (15) represents the production workers' wage. Note that the number of production workers, $L-(1-\mu_t)n_t$ in the denominator, decreases as n_t rises. Then, the nominal wage that each production worker receives increases because the total aggregate consumption expenditure is normalized to unity. Hence, the production workers' wage is upward sloping, as shown by Figure 2. The RHS of (15) is the expected payoff of R&D in the competitive

[16]Note that, from (8), the equilibrium wage cannot be lower than $(1-\pi)/L$ as otherwise the labor demand for production, $(1-\pi\mu_t)/w_t$, exceeds the labor supply, L. Note also that $V_{t+1} \leq \pi/(1-\beta) = (\lambda-1)/(\lambda(1-\beta))$ from (10) and the transversality condition. Therefore, using $r = \beta^{-1}-1$ and $\pi \equiv (\lambda-1)/\lambda$, we have $w_t/\beta V_{t+1} \geq r/((\lambda-1)L) \equiv z^{\min}$.

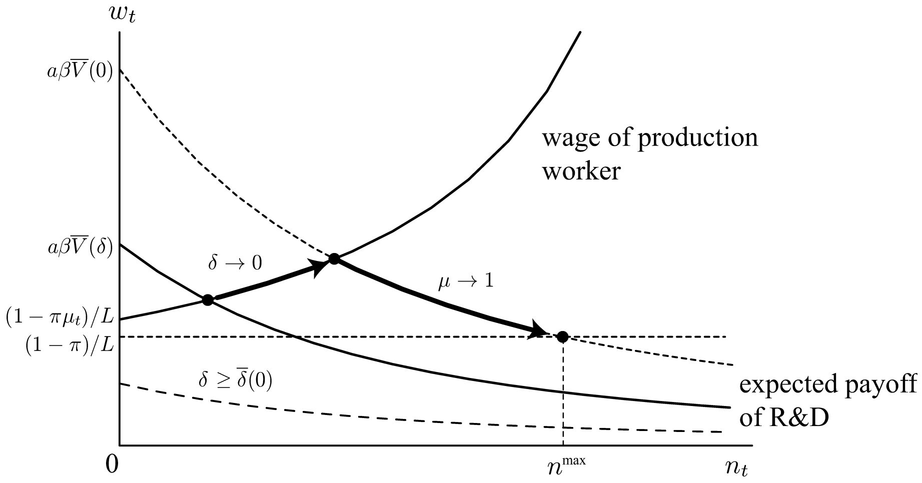

Figure 2: Determination of n_t and w_t when R&D occurs only in competitive sectors. The dashed curve at the bottom of the figure shows that there is no interior solution when IPR protection is too weak ($\delta \geq \overline{\delta}(0)$). The expected payoff of R&D shifts up as δ decreases toward 0, and the wage for production shifts down as μ increases toward 1. The result of both changes is an increase of n_t toward $n^{\max} \equiv g^{-1}(z^{\min})$.

sectors. It is downward sloping with respect to n_t because of the increasing possibility of duplication. If IPR protection is very weak, or if the possibility of imitation δ is very high, the expected payoff of R&D is lower than the wage for any positive value of n_t. Therefore, no worker engages in R&D (i.e., $n_t = 0$). A straightforward calculation shows that this is the case when $\delta \geq \overline{\delta}(\mu_t)$, where:[17]

$$\overline{\delta}(\mu_t) \equiv \frac{a\pi L}{1-\pi\mu_t} - r \tag{16}$$

gives the level of IPR protection required to activate R&D activities. Observe from (16) that if $a \leq r/(\pi L)$, no R&D occurs regardless of the degree of IPR protection, which means that growth is not possible. Conversely, if $a \geq (1+r)/(\pi L)$, innovation is so easy that R&D take place without any IPR protection. Therefore, the realistic

[17]Note that $\delta \geq \overline{\delta}(\mu_t)$ is equivalent to $(1-\pi\mu_t)/L \geq a\beta\overline{V}(\delta) = \beta\overline{V}(\delta)g(0)$. As function $g(n_t)$ is strictly decreasing with respect to n_t, the above inequality implies that $(1-\pi\mu_t)/(L-(1-\mu_t)n_t) \geq (1-\pi\mu_t)/L > \beta\overline{V}(\delta)g(n_t)$ for all $n_t > 0$.

case is:

$$r/(\pi L) < a < (1+r)/(\pi L), \tag{17}$$

so that $\overline{\delta}(0) \equiv a\pi L - r \in (0,1)$. We assume (17) throughout the paper.

Under (17), R&D takes place provided that IPR protection is reasonably tight.[18] When $\delta < \overline{\delta}(\mu_t)$, there exists a unique interior intersection between the two curves depicted in Figure 2 because the expected return from R&D is higher than the production workers' wage when $n_t = 0$, and it converges to zero as $n \to \infty$. At the intersecting point, workers are indifferent between these two types of activity and, thus, the free-entry condition for R&D is satisfied. In addition, Figure 2 shows the effect of IPR policies on R&D activities. When IPR protection is strengthened, the probability of imitation δ falls towards zero and, as a result, the value of innovation $\overline{V}(\delta)$ in (14) rises. The curve that corresponds to the expected payoff of R&D shifts up, increasing both w_t and n_t in equilibrium. As w_t is inversely related to the number of production workers, this means that stronger IPRs cause a reallocation of labor from production to R&D.

Although such a reallocation directly enhances economic growth by increasing the rate of innovation in each competitive sector, it also indirectly affects the long-term rate of economic growth by changing the evolution of the number of monopolistic sectors. Let $\psi(\mu_t, \delta)$ denote the equilibrium number of researchers in each competitive sector, determined by condition (15). By substituting $n_t = \psi(\mu_t, \delta)$ and $m_t = 0$ for (9), we obtain the following changes in μ_t:

$$\mu_{t+1} - \mu_t = -\delta\mu_t + (1-\mu_t)G(\psi(\mu_t, \delta)). \tag{18}$$

Once μ_0 is given by the initial condition, the subsequent evolution of μ_t is determined by (18). The pattern of evolution is dependent on the weakness of IPR protection, δ, and so is the long-term value of μ_t. The following lemma states this dependence.

Lemma 1. *For every $\delta \in [0,1]$, there exists a fixed point of (18). Suppose that the*

[18]Note that, because $\overline{\delta}'(\mu_t) > 0$, (17) implies $\overline{\delta}(\mu_t) \geq \overline{\delta}(0) > 0$ for all $\mu_t \in [0,1]$.

fixed point is unique,[19] *and let it be denoted by* $\mu^*(\delta)$*. Then,* μ_t *converges to* $\mu^*(\delta)$ *from any initial* μ_0*. In addition,* $\mu^*(\delta)$ *satisfies: (i)* $\mu^*(\delta) > 0$ *and* $\mu^{*\prime}(\delta) < 0$ *for* $\delta < \overline{\delta}(0)$*, (ii)* $\mu^*(0) = 1$*, and (iii)* $\mu^*(\delta) = 0$ *for* $\delta \geq \overline{\delta}(0)$*.*
Proof: see the Appendix.

The intuition behind Lemma 1 is straightforward. As explained above, stronger IPR protection increases the number of researchers and, therefore, the flow of innovation. In addition, it reduces the flow of imitation. For every given μ_t, both of these changes imply that more sectors change from being competitive to being monopolistic than vice versa. Provided that the fixed point is unique, these changes also imply an increase in the level to which μ_t converges in the long run (hence, $\mu^{*\prime}(\delta) < 0$).

As shown by Figure 2, the curve representing the market wage shifts down as the equilibrium number of monopolistic sectors increases over time (see the LHS of equation 15). This shift further increases the number of researchers in each competitive sector, n_t, but this increase is not growth enhancing. To see why, note that more researchers operate in each competitive sector simply because they are concentrated in a smaller number of competitive sectors. In fact, the aggregate number of researchers, $(1-\mu_t)n_t$, tends to decrease as IPR protection becomes very tight ($\delta \to 0$) because the number of competitive sectors where R&D is carried out becomes vanishingly small ($\mu^*(\delta) \to 1$ from Lemma 1), whereas the number of researchers per sector is bounded by a finite number, $n^{\max} \equiv g^{-1}(z^{\min})$, from (6) and (13).[20] This tendency can be confirmed from the fall in the market wage in figure 2, which implies a reallocation of workers from R&D activities to production, given our normalization of prices. In addition, as more researchers operate in the same intermediate good sector, the risk of duplication rises. That is, as the number of competitive sectors

[19] We have experimented with various combinations of parameters and found that (18) has an unique fixed point for every combination of parameters we have chosen.

[20] Note that such a bound exists because of the possibility of duplication. That is, if more than $n^{\max}$ researchers operate in a sector, the probability that duplication will occur is so high that the expected return is below the lowest possible wage.

decreases, research must be carried out in a narrower range of fields, which causes more duplication and reduces the flow of innovation, net of duplication.[21]

The long-term rate of growth under a given strength of IPR protection, denoted by $\gamma_Y^*(\delta) \equiv (\ln Y_{t+1} - \ln Y_t)^*$, is obtained by substituting $\mu_t = \mu_{t+1} = \mu^*(\delta)$, $w_{t+1} = w_t$, and $m_t = 0$ into (12):

$$\gamma_Y^*(\delta)/(\ln \lambda) = (1 - \mu^*(\delta))n^*(\delta)g(n^*(\delta)), \tag{19}$$

where $n^*(\delta) \equiv \psi(\mu^*(\delta), \delta)$ and, therefore, $n^*(\delta)g(n^*(\delta)) \equiv G(\psi(\mu^*(\delta), \delta))$. The RHS of equation (19) suggests that there are three ways in which IPR protection affects the rate of long-term growth. First, in the long run, stronger protection reduces the number of competitive sectors, $(1 - \mu^*(\delta))$. Protection should be not so strict that it shuts out all imitation because, in that case, the flow of imitations vanishes, all sectors become monopolistic in the long run ($\mu^*(0) = 1$ from Lemma 1), and R&D becomes impossible. Second, as we saw above, stronger IPR protection (smaller δ) increases the number of researchers in each competitive sector, $n^*(\delta)$, directly and indirectly. In particular, protection must be stronger than $\overline{\delta}(0)$ because, otherwise, no one will find it profitable to participate in R&D activities. This can be confirmed by: $n^*(\overline{\delta}(0)) = \psi(\mu^*(\overline{\delta}(0)), \overline{\delta}(0)) = \psi(0, \overline{\delta}(0)) = 0$ from Lemma 1 and the definition of $\overline{\delta}(\cdot)$. Third, stronger protection (a larger δ) raises the risk of duplication, which lowers $g(n^*(\delta))$ (recall that $g'(n) < 0$).

Growth is enhanced by stronger IPR protection through the second term, but is inhibited through the first and third terms of (19). The overall effect of stronger IPRs on growth can be either positive or negative depending on the relative magnitude of these three effects. In particular, the above analysis implies that the relationship between IPR protection and growth is nonmonotonic, as summarized below.

Proposition 1. *Under assumption 1, protection of IPRs should be neither too strict ($\delta = 0$) nor too loose ($\delta \geq \overline{\delta}(0)$) because, in either case, the resulting long-term rate of*

[21] If the total number of researchers is denoted by R, the aggregate flow of innovation (net of duplication) is $(1 - \mu)G(R/(1 - \mu))$. From (3) we can confirm that this expression decreases as $(1 - \mu)$ falls.

growth would be zero. There exists a noncorner level of IPR protection, $\delta \in (0, \overline{\delta}(0))$, under which the long-term rate of growth is maximized.

The latter half of the proposition is confirmed by noting that the rate of economic growth given by (19) is positive if and only if $\delta \in (0, \overline{\delta}(0))$ and that it is continuous in δ.[22]

The proposition states that a growth-maximizing IPRs policy should be an intermediate one under the assumption that leapfrogging is impossible. But how does the result depend on the assumption? The next section investigates the general case in which R&D can be conducted in both the competitive and the monopolistic sectors and shows that the above result continues to hold under a certain condition.

4 Growth with imitation and leapfrogging

In this section, we dispense with Assumption 1 and examine the effect of IPR protection on the long-term rate of growth in an economy where innovation can occur in both the competitive and the monopolistic sectors. One complexity introduced in this setting is that we need to keep track of the different intensities of R&D between the monopolistic sectors, m_t, and the competitive sectors, n_t. Nonetheless, the analysis can be kept tractable by focusing on a single variable, $z_t \equiv w_t/\beta V_{t+1} > 0$, which represents the cost of R&D relative to the discounted value of innovation. The point is that both intensities are functions only of z_t; i.e., $n_t = N(z_t)$ and $m_t = M(z_t)$ from (6) and (7). In addition, the probability that innovation occurs in a particular sector, competitive or monopolistic, depends only on z_t. Specifically, from (3) and (5):

$$G(n_t) = n_t g(n_t) = z_t N(z_t), \quad H(m_t) = m_t h(m_t) = z_t M(z_t). \tag{20}$$

[22] To more clearly confirm the latter half of the proposition, note that the outflow from the monopolistic sectors (imitation) must coincide with the inflow to the monopolistic sectors (innovation) on the BGP. Specifically, using (9) and $\mu_{t+1} = \mu_t$, equation (19) can be rewritten as: $\gamma_Y^*(\delta) = (\ln \lambda)\delta\mu^*(\delta)$. From Lemma 1, there is a level of $\delta \in (0, \overline{\delta}(0))$ under which the flow of imitation, $\delta\mu^*(\delta)$, is maximized.

The flow of innovation determines the number of monopolistic sectors in the long run. Let z denote the long-run level of z_t. Then, by substituting (20) for (9) and equating μ_{t+1} to μ_t, the value of μ_t in the long run is obtained as a function of z and δ:[23]

$$\mu^*(z,\delta) = \frac{zN(z)}{\delta(1-zM(z)) + zN(z)}. \tag{21}$$

Similarly, from (6), (7), (8), and (10), the values of V_t and w_t on the BGP are calculated as follows:

$$V^*(z,\delta) = \frac{\pi}{1-\beta(1-\delta)(1-zM(z))}, \tag{22}$$

$$w^*(z,\delta) = \frac{1-\pi\mu^*(z,\delta)}{L-(1-\mu^*(z,\delta))N(z)-\mu^*(z,\delta)M(z)} \quad \text{for } z > \underline{z}(\delta), \tag{23}$$

where $\underline{z}(\delta) \in (0,a)$ denotes the level of z at which the number of researchers, $(1-\mu^*(z,\delta))N(z) - \mu^*(z,\delta)M(z)$, coincides with L.[24]

Equations (20)-(22) express the BGP of the economy in terms of z and δ. As z is an endogenous variable, its dependence on δ needs to be clarified. From the definition of z, it must satisfy an identity:

$$z = w^*(z,\delta)/\beta V^*(z,\delta) \equiv Z(z,\delta). \tag{24}$$

That is, the value of z on the BGP is determined as a fixed point of function $Z(z,\delta)$. The following lemma establishes the existence of the fixed point and how it is affected by IPR policies.

Lemma 2. *For every $\delta \in [0,1]$, there exists a fixed point $z > \underline{z}(\delta)$ that satisfies (24). Suppose that the fixed point is unique and let it be denoted by $z^*(\delta)$. Then, $z^{*\prime}(\delta) > 0$*

[23] Here, we recycle the notation $\mu^*(\cdot)$. Its definition differs from $\mu^*(\delta)$, as defined in the previous section.

[24] From the fact that $N(z)$ and $M(z)$ are weakly decreasing, it follows that the number of researchers is weakly decreasing with respect to z. In addition, the latter approaches infinity when $z \to 0$ and reaches zero when $z = a$. Therefore, $\underline{z}(\delta) \in (0,a)$ is well defined. It is obvious that z cannot be smaller than $\underline{z}(\delta)$ as otherwise the number of researchers exceeds the population.

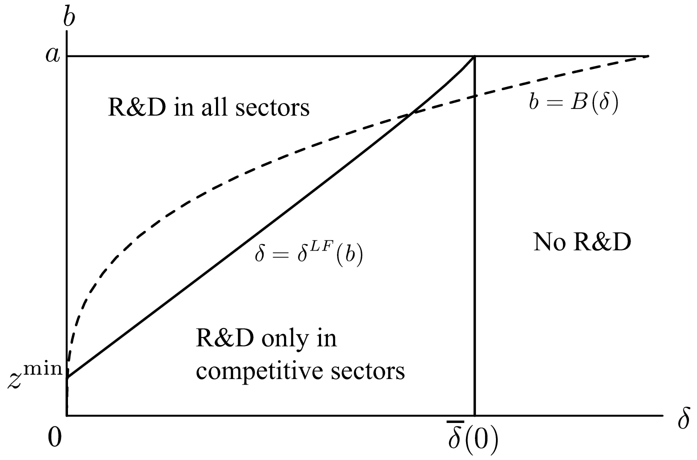

Figure 3: The degree of IPR protection and R&D activities. Calculated numerically by setting $\lambda = 1.5$, $\beta = 0.95$, $L = 10^8$, and $a = 1/L$. Under these parameter values, $\overline{\delta}(0) \approx 0.28$ and $z^{\min} \approx 0.11a$. Function $B(\delta)$ is introduced in Section 5.

for all $\delta \in [0, 1]$. *In addition, there exists a continuous function* $\delta^{LF}(b)$ *such that:*

$$z^*(\delta) \begin{cases} \geq a & \text{if } \delta \geq \overline{\delta}(0); \\ \in [b, a) & \text{if } \delta \in [\delta^{LF}(b), \overline{\delta}(0)); \\ < b & \text{if } \delta < \delta^{LF}(b). \end{cases}$$

Function $\delta^{LF}(b)$ *is zero for all* $b \leq z^{\min}$, *strictly increasing in* b *for all* $b \in (z^{\min}, a)$, *and* $\lim_{b \to a} \delta^{LF}(b) = \overline{\delta}(0)$.
Proof: see the Appendix.

Lemma 2 shows that, when stronger IPR protection reduces the rate of imitation, δ, then the long-term level of $z_t \equiv w_t/\beta V_{t+1}$ falls. Recall that the numbers of researchers in the competitive sectors, $n_t = N(z_t)$, and the monopolistic sectors, $m_t = M(z_t)$, are decreasing in z. Therefore, property $z^{*\prime}(\delta) > 0$ means that stronger IPR policies increase the number of researchers and, hence, the probability that innovation occurs in every sector. In addition, Lemma 2 gives the degree of IPR protection required to activate R&D in the competitive and monopolistic sectors (see figure 3). As $N(z_t) > 0$ if and only if $z_t < a$, the lemma shows that protection must be stronger than $\overline{\delta}(0)$ in order to make researchers in competitive sectors willing to incur the cost of R&D. The degree of IPR protection must be even tighter (i.e., $\delta < \delta^{LF}(b)$, where $\delta^{LF} < \overline{\delta}(0)$) to provide workers with sufficient incentives to participate in R&D activities in the monopolistic sectors because $m_t > 0$ if and only if $z_t < b$ (recall that $b < a$). In fact, the increasing property of $\delta^{LF}(b)$ means that the more difficult innovation is in the monopolistic sectors, the more stringent IPR protection must be to activate R&D in those sectors.

To summarize, Lemma 2 states that tighter IPRs policies stimulate R&D in both the competitive and the monopolistic sectors and that such policies are necessary for leapfrogging to occur, particularly when leapfrogging is difficult. However, we cannot conclude from these findings that tighter IPRs policies enhance growth because IPRs policies also affect the composition of the economy, or, more specifically, the number of monopolistic sectors in the economy. Even when IPR protection increases the number of researchers in both types of sectors, the aggregate research efforts may decline if IPR protection reduces the number of competitive sectors, in which more research efforts occur than in monopolistic sectors. In addition, with more researchers in each competitive sector, the possibility of duplication rises and the efficiency of R&D activities erodes.

To see the overall effect more concretely, substitute (20), (21), and $z = z^*(\delta)$ into (12) and use the fact that w_t is constant in the long run to represent the long-term rate of growth as a function of δ:

$$\gamma_Y^*(\delta)/\ln\lambda = \mu^*(z^*(\delta),\delta)z^*(\delta)M(z^*(\delta)) + (1-\mu^*(z^*(\delta),\delta))z^*(\delta)N(z^*(\delta)). \tag{25}$$

Equation (25) shows that the long-term rate of growth is proportional to the sum of the leapfrogging flow in the monopolistic sectors and the innovation flow in the competitive sectors. Note that, from (20), (21), and Lemma 2, both $z^*(\delta)M(z^*(\delta))$ and $\mu^*(z^*(\delta),\delta)$ are decreasing in δ,[25] with $M(z^*(\delta)) > 0$ if and only if $\delta < \delta^{LF}(b)$ and $\mu^*(z^*(\delta),\delta) > 0$ if and only if $\delta < \overline{\delta}(0)$. Thus, the flow of leapfrogging, given by the first term in (25), is decreasing in the probability of imitation δ for all $\delta < \delta^{LF}(b)$

[25]Note that, from (7) and(20), $z_t M(z_t) = h(m_t)m_t = H(m_t) = H(M(z_t))$. Thus, from $H'(m) > 0$, $M'(z) < 0$, and $z^{*\prime}(\delta) > 0$, $z^*(\delta)M(z^*(\delta)) \equiv H(M(z^*(\delta)))$ is decreasing in δ.

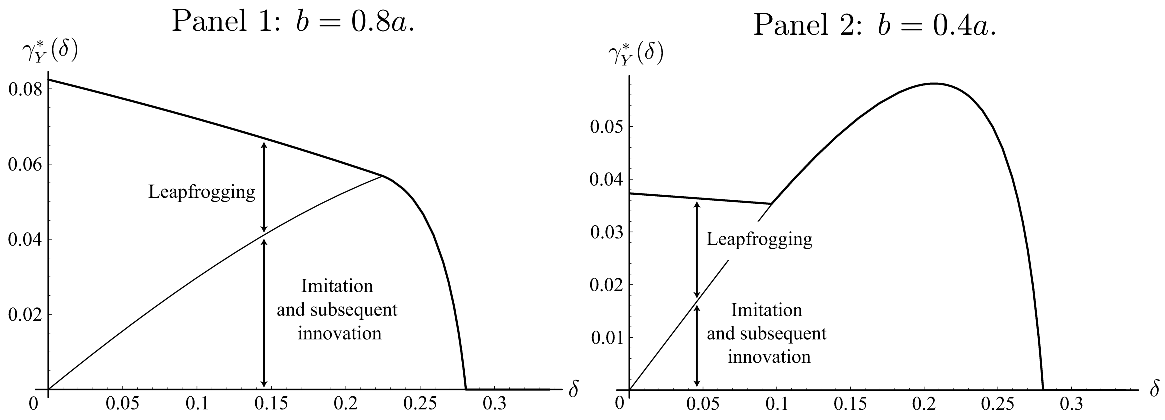

Figure 4: Growth rate on the BGP as a function of δ. The parameters are $\lambda = 1.5$, $\beta = 0.95$, $L = 10^8$, and $a = 1/L$ (the same as in Figure 3).

and it shuts down when $\delta \geq \delta^{LF}(b)$. The flow of leapfrogging is actually maximized when the degree of IPR protection is most strict ($\delta = 0$). The flow of innovation in competitive sectors is represented by the second term on the RHS of (25). Note that $\mu^*(z^*(\delta), \delta) = 1$ if $\delta = 0$ from (21), and that $N(z^*(\delta)) = 0$ whenever $\delta \geq \overline{\delta}(0)$ from Lemma 2. Thus, similarly to the case we saw in the previous section, the second term is positive if and only if $\delta \in (0, \overline{\delta}(0))$, and there is a value of δ inside that interval that maximizes the flow of innovation in the competitive sectors (which equals the flow of imitation in the long run).

These results imply the existence of a trade-off between these two types of innovation. In particular, imitation (and subsequent R&D in the competitive sectors) vanishes if the flow of leapfrogging is maximized by the most stringent IPRs policy. Figure 4 shows the long-term rate of growth as a function of δ for two different values of $b \in (z^{\min}, a)$. When b is high, that is, when there is only a small difference in the probability of success (or the expected cost of R&D) between the monopolistic and the competitive sectors, the growth rate is maximized at $\delta = 0$. This means that the economy need not rely on imitation to promote growth because the monopoly is not very harmful to R&D activities by outside researchers.[26] Conversely, when the probability of success in R&D in a monopolistic sector, b, is considerably small, the flow of leapfrogging is small even when IPR protection is strongest ($\delta = 0$). In this case, the economy may grow faster with weaker IPR protection, as weaker protection maximizes the flow of imitation. As shown by Figure 4, leapfrogging vanishes at the growth-maximizing value of δ and, therefore, economic growth relies only on imitation and the subsequent innovation in competitive sectors. The following proposition summarizes these results.

Proposition 2. *If the probability of successful leapfrogging is low (with b near $z^{\min}$), the long-term rate of growth is maximized by allowing a certain positive probability of imitation, $\delta \in (0, \overline{\delta}(0))$, so that the flow of imitation is maximized. If the probability of successful leapfrogging is high (with b near a), the long-term rate of growth is maximized by shutting out any imitation, $\delta = 0$, so that the flow of leapfrogging is maximized.*

As stated in the proposition, the authority must choose between imitation and leapfrogging, depending on the degree of difficulty of leapfrogging. The property obtained in the previous section — that is, that the IPRs policy should be an intermediate one — continues to hold when leapfrogging is considerably difficult. The conventional wisdom that imitation is bad for growth applies to the case where leapfrogging is nearly as easy as innovation in the competitive sectors.

However, note that such a dichotomy is possible because the ease of leapfrogging, represented by parameter b, is given independently of the IPR protection. In reality, the policy concerning IPR protection may have some effects on the ease of leapfrogging. Strengthening IPR protection limits the ability of outside researchers to use of state-of-the-art technology in their attempts to create new production methods for higher quality goods. Therefore, strengthening IPR protection reduces the degree of

[26] When $\delta = 0$, the workings of our model are essentially the same as those of the standard quality-ladder endogenous growth models without the possibility of imitation.

ease with which outsiders can leapfrog the incumbents. Hence, if the authority implements the strongest IPR protection to prevent imitation from arising, it inevitably inhibits the innovative activities aiming at leapfrogging the existing monopolists. By incorporating this trade-off into the model in the next section, we show that shutting out all imitation is no longer the growth-maximizing policy even when there is no difference in the technical difficulty of innovation between the monopolistic and competitive sectors.

5 An extension

So far it is assumed that the authority can directly control the probability of imitation, δ. Suppose, instead, that the authority sets the breadth of IPR protection so that it bans the production of imitated goods whenever the method of production of those goods has a certain degree of similarity to the monopoly firm's method of production. By setting a broader IPR protection, the authority can reduce the probability of imitated goods emerging. However, such policies may have a side effect on the possibility of leapfrogging in the monopolistic sectors; the production method of the innovated goods may have some similarity to the incumbent's production method, and, therefore, when protection of the incumbent's IPRs is wide, the production of the innovated goods may be banned.[27] This section presents a simple extension of the model that incorporates this trade-off.

Suppose that, in each monopolistic sector and in each period, a method of imitating the state-of-the-art good is found with a probability of $\delta_0 > \overline{\delta}(0)$, and that the similarity of this method to that involved in producing the good of the incumbent

[27] For simplicity, this section considers the degree of similarity in the technology or production process used to produce goods, without explicitly considering the difference in the quality of outputs. Although it is outside the scope of this paper, some IPRs policies set the breadth of protection in terms of quality (usually called lagging/leading breadth). O'Donoghue and Zweimuller (2004) examined this issue in a quality-ladder model where increments of quality are determined endogenously.

firm is randomly drawn from a certain distribution. Let $\epsilon \geq 0$ denote the difference in the production methods and $F_I(\epsilon)$ be its distribution function.[28] The realization of ϵ is independent across sectors and time. The authority chooses the breadth of IPR protection, $\bar{\epsilon} \in [0, \infty)$, and bans the production of an imitated good whenever $\epsilon \leq \bar{\epsilon}$. Then, the probability that the imitated goods appear in the market is given by:

$$\delta = \delta_0(1 - F_I(\bar{\epsilon})). \tag{26}$$

That is, by choosing an appropriate level of $\bar{\epsilon}$, the authority can indirectly choose any δ within $[0, \delta_0]$.

In addition, the choice of $\bar{\epsilon}$ affects the flow of leapfrogging. Suppose that, without any protection of the incumbent firms' technology, the probability of a researcher in a monopolistic sector successfully innovating is $\widehat{a}$, which is the same as the probability of success for a researcher in a competitive sector. The new production technology is partly dependent on the technology of the current incumbent firm and the degree of similarity, ϵ, is randomly chosen from distribution $F_L(\epsilon)$. When IPR protection is introduced, any innovation that has ϵ smaller than $\bar{\epsilon}$ is restricted[29] and, therefore, the probability that one researcher successfully leapfrogs falls to $\widehat{b} = \widehat{a}(1 - F_L(\bar{\epsilon}))$. Recall that, when $\widehat{a}$ and $\widehat{b}$ are very small, they almost coincide with $a \equiv -\ln(1 - \widehat{a})$ and $b \equiv -\ln(1 - \widehat{b})$. Thus, the above relationship can be approximated by:

$$b = a(1 - F_L(\bar{\epsilon})). \tag{27}$$

Equations (26) and (27) imply that stronger IPR protection (a larger $\bar{\epsilon}$) no longer unambiguously facilitates R&D activities in monopolistic sectors. Although it increases the reward for leapfrogging by extending the expected length of monopoly, it also makes leapfrogging more difficult. To see this tradeoff more concretely, let us

[28]Function $F(\cdot)$ satisfies $F(0) = 0$, $\lim_{\epsilon \to \infty} F(\epsilon) = 1$ and $F'(\epsilon) > 0$ for all $\epsilon \in [0, \infty)$.

[29]For simplicity, we rule out the possibility that the incumbent firm licenses the patent of its technology to the successful innovator.

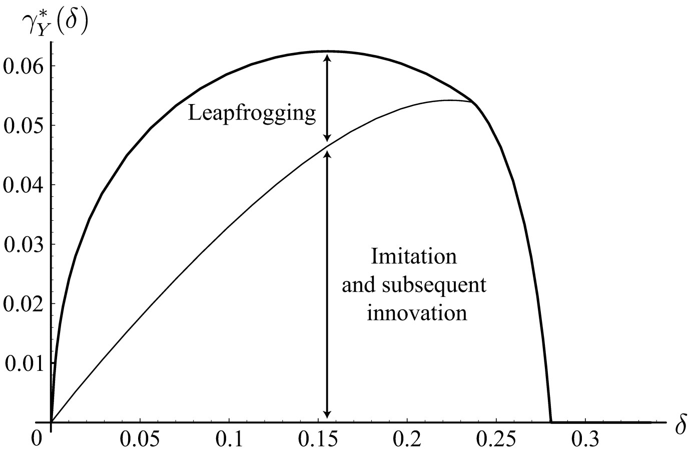

Figure 5: Growth rate on the BGP with a trade-off between δ and b. In this numerical example, we choose $\delta_0 = 0.4$, $\phi_L = 3$, and $\phi_I = 1$. The remaining parameters are the same as in Figure 3.

specify the distribution of ϵ by:

$$F_I(\epsilon) = 1 - \exp(-\epsilon/\phi_I), \;\; F_L(\epsilon) = 1 - \exp(-\epsilon/\phi_L), \tag{28}$$

where $\phi_L > \phi_I > 0$. The realization of ϵ is distributed exponentially and parameter ϕ_L represents the average degree of difference between an innovation and the incumbent monopolist's technology. The value of ϕ_L is assumed to be larger than ϕ_I because the imitation tends to have more similarity to the original good than does the innovation. By substituting (28) for (26) and (27), we obtain:

$$b = a(\delta/\delta_0)^{\phi_I/\phi_L} \equiv B(\delta), \quad \delta \in [0, \delta_0]. \tag{29}$$

Equation (29) shows that b is an increasing and concave function of δ and that $b = 0$ when $\delta = 0$ (this relationship is depicted by the dashed curve in Figure 3).

The difficulty of leapfrogging, b, affects growth through the functions $M(z)$, $\mu^*(z, \delta)$, and $z^*(\delta)$ (see their definitions in equations 7, 21, and 24). Let us be explicit about this dependence and write the functions as $M(z; b)$, $\mu^*(z, \delta; b)$, and $z^*(\delta; b)$. Then, substituting (29) into (25) gives:

$$\begin{aligned}\gamma_Y^*(\delta)/\ln\lambda =& \mu^*(z^*(\delta; B(\delta)), \delta; B(\delta))z^*(\delta; B(\delta))M(z^*(\delta; B(\delta)); B(\delta)) \\ &+ (1 - \mu^*(z^*(\delta; B(\delta)), \delta; B(\delta)))z^*(\delta; B(\delta))N(z^*(\delta; B(\delta)); B(\delta)),\end{aligned} \tag{30}$$

from which the long-term rate of growth is calculated for each level of $\delta \in [0, \delta_0]$. Similarly to (25), the first term of (30) represents the flow of leapfrogging, whereas the second term represents the flow of innovation in the competitive sectors. Suppose that protection is so stringent that imitation never occurs (i.e., $\overline{\epsilon} = \infty$ and, therefore, $\delta = 0$ from equation 26). In this case, the second term is zero because it coincides with the flow of imitation on the BGP. In addition, the first term becomes zero because $M(z; B(0)) = M(z; 0) = 0$. That is, an excessively stringent IPR protection never facilitates growth because it shuts down not only imitation but also leapfrogging, resulting in zero growth. Suppose, conversely, that the IPRs policy is so loose (i.e., the breadth of protection is so narrow) that $\delta \geq \overline{\delta}(0)$. Then, $z^*(\delta; B(\delta)) < b$ from Lemma 2, and, therefore, $M(\cdot) = N(\cdot) = 0$. This means that both terms of (30) are zero.

These properties and the continuity of $\gamma_Y^*(\delta)$ with respect to δ, give the following proposition.

Proposition 3. *When the authority sets the breadth of IPR protection, $\overline{\epsilon}$, the long-term rate of growth is maximized by setting a certain intermediate (not the widest) breadth of protection so that the probability of imitation, implied by (26), is within the interval* $(0, \overline{\delta}(0))$.

Figure 5 presents a numerical example confirming that the long-term rate of economic growth is maximized with imperfect protection of IPRs. Observe from the figure that, in our parameter values, both leapfrogging and imitation coexist under the growth-maximizing level of δ. This implies that the authority does not necessarily need to *choose* between leapfrogging and imitation as in the previous section; rather, the growth-maximizing policy must find an appropriate *mix* of these two engines of growth by manipulating the degree of IPR protection.

6 Conclusion

In a quality-ladder model of endogenous growth, we have examined the extent to which growth is facilitated by stronger IPR protection, which reduces the possibility of imitation. The above analysis has shown that the most stringent IPRs policy does not necessarily facilitate growth, and that, in most cases, the long-term rate of growth is maximized with imperfect protection of IPRs. These results were obtained by incorporating two notable features of R&D into the model: (i) for both informational and legal reasons, R&D is easier in competitive sectors where any firm can produce state-of-the-art-goods than it is in monopolistic sectors where outsiders cannot produce state-of-the-art-goods, and (ii) R&D projects take time to be completed, which creates the risk of duplication of innovation.

Stronger IPR protection reduces the flow of imitation and, eventually, the number of competitive sectors. As a result, researchers are more concentrated in a smaller number of competitive sectors where the probability of success is higher than in monopolistic sectors. However, the narrower are the fields where R&D is carried out intensively, the higher is the risk of duplication of innovation in each field. This makes R&D more inefficient. In an extension of the model, we have shown that stronger protection may reduce the flow of leapfrogging by increasing the possibility that innovations are restricted by the protection of existing IPRs. When protection is initially too stringent, the sum of these two adverse effects tends to exceed the stimulating effect that secure IPRs have on innovation. Given that this is the case, our model predicts that loosening IPR protection will enhance growth in the long run.

Appendix

Proof of Lemma 1

We define $f(\mu,\delta) \equiv -\delta\mu + (1-\mu)G(\psi(\mu,\delta))$. Note that functions $G(\cdot)$ and $\psi(\cdot)$ are continuous from their definitions. This implies that function $f(\mu,\delta)$ is also continuous. In addition, $f(0,\delta) = G(\psi(0,\delta)) \geq 0$ and $f(1,\delta) = -\delta \leq 0$ for any $\delta \in [0,1]$. Therefore, the intermediate value theorem shows that, for every $\delta \in [0,1]$, there exists $\mu^*(\delta) \in [0,1]$ such that $f(\mu^*(\delta),\delta) = 0$. As (18) can be written as $\mu_{t+1} - \mu_t = f(\mu_t,\delta)$, $\mu^*(\delta)$ is a fixed point of this system. As $\mu^*(\delta)$ is assumed to be the unique fixed point, $f(\mu,\delta) > 0$ holds for all $\mu < \mu^*(\delta)$ and $f(\mu,\delta) < 0$ holds for all $\mu > \mu^*(\delta)$, implying that this system is globally stable.

To examine the properties of $\mu^*(\delta)$, consider first the case where $\delta < \overline{\delta}(0)$. Note that, from (16), this implies $\delta < \overline{\delta}(\mu)$ for all $\mu \in [0,1]$. In this case, as we explained in the text, there exists a positive value of n at which (15) holds with equality, and this value of n decreases with δ. This means that $\psi(\mu,\delta) > 0$ and $\psi_\delta(\mu,\delta) < 0$ for all $\mu \in [0,1]$. As $G(m) > 0$ and $G'(m) < 0$ whenever $m > 0$, it turns out that $f(0,\delta) = G(\psi(0,\delta)) > 0$ and $f_\delta(\mu,\delta) = -\mu + (1-\mu)G'(\psi(\mu,\delta))\psi_\delta(\mu,\delta) < 0$ for all $\mu \in [0,1]$. That is, the value of function $f(\cdot)$ at $\mu = 0$ is above the horizontal μ axis, and the whole function $f(\cdot)$ shifts down as δ increases. Therefore, given that $f(\cdot)$ intersects only once with the horizontal μ axis within $\mu \in [0,1]$, these properties imply that the point of intersection is not at $\mu = 0$ (hence, $\mu^*(\delta) > 0$) and that this point moves leftward as δ increases (hence, $\mu^{*\prime}(\delta) < 0$). Second, when $\delta = 0$, $f(\mu,0) = (1-\mu)G(\phi(\mu,0)) > 0$ for all $\mu < 1$, which means that μ_t converges to one. Finally, when $\delta \geq \overline{\delta}(0)$, we explained in the text that $\psi(0,\delta) = 0$. As $G(0) = 0$, this means $f(0,\delta) = G(\psi(0,\delta)) = 0$, implying that $\mu^*(\delta) = 0$. This completes the proof.

Proof of Lemma 2

From (22) and (23), function $Z(z,\delta)$ is continuous and it satisfies the conditions that $\lim_{z\to\underline{z}(\delta)} Z(z,\delta) - z = \infty - \underline{z}(\delta) > 0$ and $\lim_{z\to\infty} Z(z,\delta) - z = 1/(\beta\overline{V}(\delta)L) - \infty < 0$, where $\overline{V}(\delta)$ is defined by (14). Thus, the intermediate value theorem guarantees that for every $\delta \in [0,1]$, there is at least one level of $z^*(\delta) \in (\underline{z}(\delta), \infty)$ such that $Z(z^*(\delta), \delta) - z^*(\delta) = 0$ holds, which is a fixed point of (18). In addition, the assumption that the fixed point is unique means that $Z(z, \delta) - z$ cuts the horizontal z axis from above and does so only once in $z \in [\underline{z}(\delta), \infty)$. Note that $Z_\delta(z, \delta) > 0$ from (21)-(24). Thus, the curve of $Z(z, \delta) - z$ shifts upward as δ increases. This implies that the point of intersection moves rightward as δ increases: i.e., $z^{*\prime}(\delta) > 0$.

Let us examine the condition under which $z^*(\delta)$ is smaller than a. Note that, because $Z(z, \delta) - z$ cuts the horizontal z axis from above and does so only once, the point of intersection (i.e., $z^*(\delta)$) is smaller than a if and only if $Z(a, \delta) - a < 0$. As $Z(a, \delta) = 1/(\beta \overline{V}(\delta) L)$ from (22) and (23), this condition is equivalent to $\delta < 1 - \beta^{-1} + a\pi L \equiv \overline{\delta}(0)$. Thus, $z^*(\delta) < a$ if and only if $\delta < \overline{\delta}(0)$.

Next, let us examine the condition under which $z^*(\delta)$ is smaller than b. Specifically, we want to find a threshold level $\delta^{LF}(b)$ such that $z^*(\delta) < b$ if and only if $\delta < \delta^{LF}(b)$, for a given level of b. Similarly to the above argument, $z^*(\delta) < b$ holds if and only if $Z(b, \delta) - b < 0$. From (23) and (22):

$$Z(b, \delta) = \frac{1}{\beta \overline{V}(\delta) L} \frac{\delta + (1 - \pi) b N(b)}{(1 - N(b)/L)\delta + bN(b)}. \tag{31}$$

When $\delta = 0$, (31) implies that $Z(b, 0) = (1 - \beta)(1 - \pi)/(\beta \pi L) \equiv z^{\min}$. Thus, when $b \leq z^{\min}$, $Z(b, \delta) - b \geq Z(b, 0) - b \geq 0$ holds for all $\delta \in [0,1]$ because $Z(b, \delta)$ is increasing in δ. This means that $z^*(\delta) \geq b$ for all $\delta \in [0,1]$ and, therefore, that $\delta^{LF}(b) = 0$ for $b \leq z^{\min}$.

Now, consider the case of $b > z^{\min}$. Note that in this case $Z(b, 0) - b = z^{\min} - b < 0$. In addition, note that we have shown $Z(a, \overline{\delta}(0)) - a = 0$, which implies $Z(b, \overline{\delta}(0)) - b > 0$ because $b < a$ (recall that $Z(z, \overline{\delta}(0)) - z > 0$ cuts the horizontal z axis from above and does so only once). Thus, from the continuity of $Z(z, \delta) - z$ with respect to δ, the intermediate value theorem guarantees the existence of $\delta^{LF}(b) \in (0, \overline{\delta}(0))$ such that:

$$Z(b, \delta^{LF}(b)) - b = 0. \tag{32}$$

As $Z(b, \delta)$ is strictly increasing in δ, $\delta^{LF}(b)$ is uniquely determined and $Z(b, \delta) - b < 0$

if and only if $\delta < \delta^{LF}(b)$. Thus, $z^*(\delta) < b$ if and only if $\delta < \delta^{LF}(b)$. The following proves that $\delta^{LF}(b)$ is increasing in b for all $b > z^{\min}$. Let us choose arbitrary values of b_1 and b_2 so that $z^{\min} < b_1 < b_2$. From the definition of $\delta^{LF}(b)$ in (32),

$$Z(b_1, \delta^{LF}(b_1); b_1) - b_1 = 0 = Z(b_2, \delta^{LF}(b_2); b_2) - b_2, \tag{33}$$

where we use expression $Z(z, \delta; b)$ to show explicitly the dependence of function $Z(z, \delta)$ on b. As $Z(z, \delta^{LF}(b_1); b_1) - z$ intersects the horizontal z axis from above and does so only once, the first equation of (33) implies that $Z(z, \delta^{LF}(b_1); b_1) - z < 0$ for all $z > b_1$. Thus, from $b_1 < b_2$ and (33):

$$Z(b_2, \delta^{LF}(b_1); b_1) - b_2 < 0 = Z(b_2, \delta^{LF}(b_2); b_2) - b_2. \tag{34}$$

Note from (7) that $M(z) = 0$ whenever $b \leq z$, which means that the value of function $Z(z, \delta; b)$ does not depend on b whenever $b \leq z$. Thus, when $z = b_2$ (which means that $b_1 < b_2 = z$):

$$Z(b_2, \delta^{LF}(b_1); b_1) = Z(b_2, \delta^{LF}(b_1); b_2). \tag{35}$$

From (34) and (35), we obtain $Z(b_2, \delta^{LF}(b_1); b_2) < Z(b_2, \delta^{LF}(b_2); b_2)$. As $Z_\delta(z, \delta; b) > 0$, this implies that $\delta^{LF}(b_1) < \delta^{LF}(b_2)$; i.e., $\delta^{LF}(b)$ is increasing in b.

Finally, we show the continuity of $\delta^{LF}(b)$ and its boundary property. As $Z(b, \delta; b) - b$ is continuous in δ and b, $\delta^{LF}(b)$, as defined by (32), is continuous for all $b \in (z^{\min}, a)$. In addition, it is continuous at $b = z^{\min}$ because $\delta^{LF}(b) \to 0$ as $b \to z^{\min}$ from $Z(z^{\min}, 0) - z^{\min} = 0$ (recall that $\delta^{LF}(b) = 0$ for all $b \leq z^{\min}$). When $b \to a$, $\delta^{LF}(b) \to \overline{\delta}(0)$ because $Z(a, \overline{\delta}(0)) - a = 0$. This completes the proof.

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