Patent Duration, Innovative Performance, and Technology Diffusion

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Abstract

This paper argues how institutional reform of patent rights affects growth performance in both developed and developing countries. We develop a simple two-country model in which one country is a technological leader and the other a follower that adopts technology through licensing. We show that strengthening protection of patent rights is not necessarily a situation that leads to promoting economic growth in both developed and developing countries. Furthermore, stronger patent protection does not always foster technology transfer from developed to developing countries.

Keywords : patent duration, product innovation, cross-border technology diffusion

1 Introduction

The Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPs) went into effect January 1, 1995, as part of the establishment of the World Trade Organization (WTO). It essentially requires many WTO members to strengthen protection of their intellectual property rights. [1] For example, Ginarte and Park (1997), Park (2001), and Park and Wagh (2002) present empirical evidence that many countries have recently strengthened their protection of intellectual property rights. Under such conditions, the relationship between institutional reform in patent system and macroeconomic performance is an important issue for policy-makers and economists. Therefore, this paper aims to examine how does change in patent duration affect growth performance in countries and international technology diffusion.

In related published research, increasing attention has recently been given to the effects of patent protection in the context of economic growth theory. [2] Earlier studies can be roughly classified into two types. The first emphasizes the duration of the patent (for example, Segerstrom, Anant, and Dinopoulos

[1] Under the agreement, developed countries were required to meet TRIPs requirements by 1996. Developing countries were given until 2000 and least-developed countries until 2006 (later extended to 2016 for pharmaceutical patents).

[2] The first study to address the issue of patent protection using an economic growth model was by Judd (1985). However, Judd (1985) did not describe the process by which innovation occurs as a result of research and development (R&D). See, for example, Romer (1990), Grossman and Helpman (1991), Aghion and Howitt (1992), and others for details of economic growth models with endogenous innovation.

1990; Iwaisako and Futagami 2003; Kwan and Lai 2003). The second focuses on the technical range of patent protection, or patent breadth (for example, Li 2001, Goh and Olivier 2002; O'Donoghue and Zweimüller 2004). [3]

Among the first type of models, Segerstrom, Anant, and Dinopoulos (1991) found that if the wage gap separating workers with high and standard abilities is sufficiently small, then strengthening patent protection stimulates R&D investment by firms, within a model of economic growth with improvements in product quality. Iwaisako and Futagami (2003) point out that the patent duration that maximizes social welfare is a finite. Using U.S. data, Kwan and Lai (2003) show that, in general, protection of intellectual property rights falls below the optimum level. Among the second type of models, Li (2001) uses a quality ladder model to show that a government can achieve the socially optimal R&D intensity by expanding patent breadth and increasing earnings from R&D without providing R&D subsidies when the incentive for firms to invest in R&D is extremely low. Goh and Olivier (2002) construct a model in which both intermediate and final goods expand. They find that strengthening patent protection in the intermediate goods sector promotes economic growth, while strengthening protection in the final goods sector tends to cause economic growth to stagnate. Using a quality ladder model, O'Donoghue and Zweimüller (2004) confirm that the more innovative an industry is, the higher the optimal level of patent protection.

Earlier studies provide various interesting results. However, we think that there is still room for improvement in this line of research, on several counts. For instance, the existence of a cost to maintain a patent is not considered in the related early research. As is known, for a patentee to assert patent rights, a prescribed patent fee payment to the Patent Office is obligatory in an actual patent system. In consideration of this reality, it would be important to construct an economic growth model that includes a cost to maintain the patent and to develop discussion based on that point of view. Further, as pointed out by Yang and Maskus (2001), not much effort has been made in respect of licensing research compared with other modes of international technology transfer, although the importance of licensing has risen rapidly in recent years.[4] For the relationship between patent protection and technology trade by international licensing, it would be important to obtain meaningful qualitative findings.

For the reasons above, we develop an economic growth model with the cost of maintaining a patent right. We then analyze the effects of patent protection on innovation, economic growth, and international technology diffusion through licensing. The proposed model consists of a technological leader country and a follower country. Innovation through R&D activities occurs only in the technological leader country; the follower country introduces the technology by licensing it from the developed country. According to the Organization for Economic Co-operation and Development (OECD 2003), in 1999, 97.6 percent of all patent applications to the European Patent Office and 95.5 percent of all applications to the U.S. Patent and Trademark Office were from OECD countries. Therefore we can interpret that the technological leader is representative of all

[3]The description of the patent claim describes the technical range of patent protection for inventions.

[4]In general, research on international technology transfer in the context of economic growth models has emphasized roles such as foreign direct investment, reverse engineering, and licensing.

OECD countries and the follower is representative of all non-OECD countries, as suggested by Coe, Helpman, and Hoffmaister (1997). We obtain analytical results as follows: In a developed country, if the values of the parameters that reflect the labor force, license fee, and productivity in the basic goods sector are large and the manufacturing cost of intermediate goods and the patent fee are small, then strengthening patent protection may promote innovation and economic growth. On the other hand, in a developing country, if the values of the parameters for the labor force, and productivity in the basic goods sector are large and the cost of manufacturing intermediate goods and the license fee are small, the rate of technology import and economic growth rate may rise as a result of strengthened patent protection. That is, strengthening protection of patent rights is not necessarily a situation that leads to the promotion of product innovation and cross-border technology diffusion.

The rest of this paper is organized as follows. Section 2 constructs a basic model and examines the determinants of economic growth in a steady-state equilibrium. Section 3 analyzes the effects of patent protection on macroeconomic performance in countries. Finally, Section 4 summarizes the main results and concludes.

2 The Model

2.1 The Basic Goods Sector

Consider a two-country model that consists of a developed and a developing country. The developed country is a technological leader, the developing country a follower. It is assumed that final goods produced in the two countries are identical and tradable across borders. Here we call the technological leader country 1, and the follower country 2. Product innovation through R&D activities occurs only in country 1. The producers of intermediate goods in country 2 access manufacturing knowledge through licensing agreements with country 1. Inventors in country 1 license their technology only to firms in country 2. We also assume that there is no global capital market. In the following discussion, the variables and parameters associated with country i ($i = 1, 2$) are shown with subscript i; the symbol t represents a time variable.

Following Barro and Sala-i-Martin (1992), we call the homogeneous goods industry in each country the basic goods sector. In each country, this sector consists of a large number of price-taking firms. These firms engage in productive activities using labor and differentiated nondurable intermediate goods; they have a common production technology, with constant returns to scale in inputs. The intermediate goods available at time t in country i are numbered by real numbers on a closed interval $[0, N_i(t)]$. Therefore, $N_i(t)$ can be interpreted as the variety of intermediate goods obtainable in country i at time t. All firms in the basic goods sector are assumed to assemble available intermediate goods and to produce a single composite as an input for basic goods production. For simplicity, we assume that $N_2(t) < N_1(t)$ for all $t \in [0, \infty)$. This assumption rules out the possibility that the initial technological follower becomes a leader. The model thus does not deal with the case of leapfrogging.

For country i, we aggregate firms to the industry level and express the aggregate production function in the industry as follows:

$$Y_i(t) = A_i L_i(t)^{1-\alpha} M_i(t)^{\alpha}, \tag{1}$$

where $Y_i(t)$ is output of basic goods in country i at time t; $L_i(t)$ is labor input (person-hours) in country i at time t; and $M_i(t)$ is a composite of available intermediate goods in country i at time t. For parameters A_i and α, we assume that $A_i > 0$ and $0 < \alpha < 1$. The productivity parameter A_i can be interpreted as an index that reflects the level of human capital, government's industrial policies, the rule of law, and other institutional features. [5] The output elasticity with respect to labor is $1-\alpha$; while the output elasticity with respect to a composite of intermediate goods is α.

Suppose that the amount of a composite good assembled from intermediate goods is determined by

$$M_i(t) = \left[\int_0^{N_i(t)} X_{ij}(t)^{\alpha} dj\right]^{\frac{1}{\alpha}}, \tag{2}$$

where $X_{ij}(t)$ represents the output of an intermediate good of j type in country i at time t. A form of product innovation is captured as the expansion of the variety of differentiated intermediate goods.

We regard a basic good as a numeraire and normalize its price as one. The wage rate in country i and the price of j type's intermediate good in country i can then be expressed as $w_i(t)$ and $P_{ij}(t)$, respectively. Let Π_i be the sector's profit in country i. Then, we obtain

$$\Pi_i = A_i {L_i}^{1-\alpha} \int_0^{N_i} {X_{ij}}^{\alpha} dj - \int_0^{N_i} P_{ij} X_{ij} dj - w_i L_i.$$

As a result of profit-maximizing behavior, in equilibrium, labor demand is given by

$$L_i(t) = \frac{(1-\alpha) Y_i(t)}{w_i(t)}, \tag{3}$$

and demand for j type's of an intermediate good is given by

$$X_{ij}(t) = L_i(t) \left[\frac{\alpha A_i}{P_{ij}(t)}\right]^{\frac{1}{1-\alpha}}. \tag{4}$$

2.2 Intermediate Goods Sector

As in Barro and Sala-i-Martin (2004, ch.6), we consider the case in which the producer of a patented intermediate good is also its product's inventor. Here we set the following assumptions: In country 1, the firms that enter the R&D business procure necessary resources by issuing stock. The government grants a patent when a firm invents a new product as a result of R&D activity. In

[5] Hall and Jones (1999) call such institutional factors social infrastructure. Using cross-country data, they show the crucial role social infrastructure plays in explaining economic performance.

country 1 and 2, the patent duration has a finite value T. When an inventor is granted a patent, the inventor immediately enters into a licensing agreement, obtaining a constant license fee of ΩT (in terms of basic goods) as a lump sum from a firm in country 2. We discuss below the case of a incomplete exclusive license under which the licensor can execute the patent as well. The assignment of a patent or sublicense is not considered.

Patentees must pay a patent fee (in terms of basic goods) to the government. Let z be the holding term of a patent and F the level of the patent fee in relation to its term. To make the analysis simpler, we assume that F is directly proportional to z; that is, for a constant $\lambda > 0$, $F = \lambda z$. We postulate that all patentees retain the patent rights until the patent expires and that the patent fee is paid as a lump sum when the patent is granted. [6] The patent fee is used only for lump-sum transfers to households in country 1. Therefore, the fee paid as a lump sum becomes $\lambda T^2/2$, shown in the shaded area of figure 1.

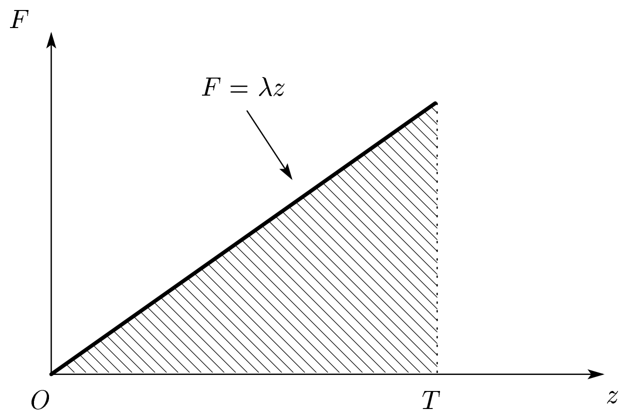

Figure 1 The relation between the holding term of patent right and the patent fee level

Following Barro and Sala-i-Martin (2004, ch.6), the intermediate goods producer's decision-making problem can be considered in two stages. The first stage is related to the R&D business entry decision; the second stage is a profit-maximization problem when a new intermediate good is invented.

Consider the situation in which the market structure of intermediate goods that belong to the interval $[0, \widetilde{N_1}(t)]$ is perfectly competitive. The intermediate goods that belong to the interval $(\widetilde{N_1}(t), N_1(t)]$ are produced exclusively by the firm that holds the patent on the goods. It is assumed that all firms can produce one unit of the intermediate good by using ζ_1 units of a basic good and that ζ_1 is constant over time.

We now focus on a firm with a patent on an intermediate good of type $h \in (\widetilde{N_1}(t), N_1(t)]$. Firm h can produce its good exclusively. Representing

[6] The patent fee here refers to the application fee. The model does not consider the examination claim fee, because it assumes that patents are given unconditionally to all new inventions.

$X_{1h}(t)$ as the output of intermediate goods of type h, firm h's profit $\pi_{1h}(t)$ is given by

$$\pi_{1h}(t) = [P_{1h}(t) - \zeta_1]X_{1h}(t). \tag{5}$$

In equilibrium the following equation can be derived from Eq. (4):

$$X_{1h}(t) = L_1(t)\left[\frac{\alpha A_1}{P_{1h}(t)}\right]^{\frac{1}{1-\alpha}}. \tag{6}$$

Note that firm h faces the demand function described in Eq. (6). Hence, Eq. (5) can be rewritten as

$$\pi_{1h}(t) = [P_{1h}(t) - \zeta_1]L_1(t)\left[\frac{\alpha A_1}{P_{1h}(t)}\right]^{\frac{1}{1-\alpha}}. \tag{7}$$

From Eq. (7), as a result of profit-maximizing behavior, the price of the good in equilibrium is set as

$$P_{1h}(t) = \frac{\zeta_1}{\alpha}. \tag{8}$$

Clearly, Eq. (8) indicates that the price becomes a constant over time in equilibrium. It can be seen from Eq. (8) that the price-cost margin ratio is equal to the inverse of the price elasticity of demand; that is, $1-\alpha$. Therefore, the smaller the price elasticity of demand, the greater the price-setting power of the intermediate goods producer becomes. From Eqs. (6) and (8), the amount of production of firm h in equilibrium can be given as follows:

$$X_{1h}(t) = \alpha^{\frac{2}{1-\alpha}} A_1{}^{\frac{1}{1-\alpha}} \zeta_1{}^{-\frac{1}{1-\alpha}} L_1(t). \tag{9}$$

Substituting Eqs. (8) and (9) into Eq. (5) leads to

$$\pi_{1h}(t) = \alpha^{\frac{2}{1-\alpha}} A_1{}^{\frac{1}{1-\alpha}} \left(\frac{1-\alpha}{\alpha}\right) \zeta_1{}^{-\frac{\alpha}{1-\alpha}} L_1(t). \tag{10}$$

Eq. (10) represents the profit of the intermediate goods producer of h type in the subjective equilibrium. This monopolistic profit is paid to stockholders as a dividend.

The inventor (producer) of the good loses the right of monopolistic production when the patent expires, at which point the market for the intermediate good becomes perfectly competitive. Intermediate goods on the interval $[0, \widetilde{N}_1(t)]$ are sold in the perfectly competitive market at time t. Hence, the price of all intermediate goods on $[0, \widetilde{N}_1(t)]$ is equal to the marginal cost ζ_1, and the amount of such goods produced becomes $\alpha^{\frac{1}{1-\alpha}} A_1{}^{\frac{1}{1-\alpha}} \zeta_1{}^{-\frac{1}{1-\alpha}} L_1(t)$.

Because firm h can earn monopolistic profits only for the duration of the patent, the present discounted value of the stream of profits is given by

$$V_{1h}(t) = \int_t^{t+T} e^{-\int_t^{\tau} r_1(\omega)d\omega} \pi_{1h}(\tau)d\tau, \tag{11}$$

where $r_1(\omega)$ denotes the rate of return in country 1 at time ω. [7] It is apparent from Eq. (10) that all firms that invent a new product at time t earn the same monopolistic profit in equilibrium. Consequently, in equilibrium the present discounted value of the stream of profits in Eq. (11) is equal for all firms that invent new products at time t. Thus, hereafter V_{1h} is replaced with V_1. Using Eqs. (10) and (11), we obtain

$$V_1(t) = \alpha^{\frac{2}{1-\alpha}} A_1^{\frac{1}{1-\alpha}} \left(\frac{1-\alpha}{\alpha}\right) \zeta_1^{-\frac{\alpha}{1-\alpha}} \int_t^{t+T} e^{-\int_t^\tau r_1(\omega)d\omega} L_1(\tau)d\tau. \tag{12}$$

We now consider the decision-making problem related to entry into the R&D business. Following Barro and Sala-i-Martin (2004, ch.6), we assume that one unit of new intermediate goods is invented by using a constant η unit (in terms of basic goods) of R&D expenditure. Let $E(t)$ be R&D expenditure at the industry level at time t, and let $N_1(t)$ be the total number of inventions at time t. Then, the law of motion for the total number of invention can be written as

$$\dot{N}_1(t) = \frac{1}{\eta}E(t),$$

where a dot over the variable signifies the time derivative. This equation implies that the more resources allocated to R&D, the more blueprints for new products created. Thus, no uncertainty of invention exists. Expansion in the variety of intermediate goods is interpreted as a form of product innovation; hence, the rate of innovation can be written as $\dot{N}_1(t)/N_1(t)$. Accordingly, a higher rate of innovation implies a higher performance for new product development.

Consider a firm that invents an arbitrary number of new intermediate goods, $\dot{n}_j(t)$. For such a firm, the total cost of invention is the sum of R&D expenditure and the lump-sum patent fee (that is, $(\eta + \lambda T^2/2)\dot{n}_j(t)$). Total revenue from the invention is the sum of the domestic sales of the intermediate goods and the licensing fees paid by foreign firms (that is, $[V_1(t) + \Omega T]\dot{n}_j(t)$). No incentive exists to undertake R&D if $V_1(t) + \Omega T < \eta + \lambda T^2/2$. Clearly, such a case implies that product innovation will not evolve. Because we are concerned with the equilibrium at which innovation occurs at each point in time, we exclude the case in which $V_1(t) + \Omega T < \eta + \lambda T^2/2$. Where $V_1(t) + \Omega T > \eta + \lambda T^2/2$, the firm will infinitely seek to divert more resources to R&D. Such a situation does not hold in equilibrium, however. Given free entry into the R&D business, the emergence of new products occurs in equilibrium only when $V_1(t) + \Omega T = \eta + \lambda T^2/2$. Therefore, from Eq. (12):

$$\alpha^{\frac{2}{1-\alpha}} A_1^{\frac{1}{1-\alpha}} \left(\frac{1-\alpha}{\alpha}\right) \zeta_1^{-\frac{\alpha}{1-\alpha}} \int_t^{t+T} e^{-\int_t^\tau r_1(\omega)d\omega} L_1(\tau)d\tau + \Omega T = \eta + \frac{\lambda T^2}{2}. \tag{13}$$

We turn now to the profit maximization behavior of the intermediate goods producer in country 2. Here, it is assumed that the cost to the licensee of acquiring the know-how needed to produce the intermediate good is constant. Resources of ν unit in terms of basic goods are necessary to acquire such know-how, and ν is constant over time. We also assume that for all intermediate goods, the term of the license is equal to the duration T of the patent. Therefore,

[7] Note that a gap in the rates of return between country 1 and 2 is possible because international lending is ruled out.

licensees can exclusively produce the product only for a period T. The market structure of goods when the license expires becomes perfectly competitive and the learning cost to produce the goods falls to zero.

Suppose that intermediate goods on the interval $[0, \widetilde{N_2}(t)]$ are produced by a perfectly competitive firm at time t. Intermediate goods on the interval $(\widetilde{N_2}(t), N_2(t)]$ are produced exclusively by licensees. All firms possess manufacturing knowledge of intermediate goods that enables them to produce one unit of intermediate goods using a constant ζ_2 units in terms of basic goods. Consider the firm that receives a license to produce intermediate good of type $l \in (\widetilde{N_2}(t), N_2(t)]$. Hereafter we call this firm l. The profit of firm l is given by

$$\pi_{2l}(t) = [P_{2l}(t) - \zeta_2]X_{2l}(t), \tag{14}$$

where $X_{2l}(t)$ denotes the output of firm l. From Eq. (4) we obtain

$$X_{2l}(t) = L_2(t)\left[\frac{\alpha A_2}{P_{2l}(t)}\right]^{\frac{1}{1-\alpha}}. \tag{15}$$

Because firm l faces the demand function described by Eq. (15), Eq. (14) can be rewritten as

$$\pi_{2l}(t) = [P_{2l}(t) - \zeta_1]L_2(t)\left[\frac{\alpha A_2}{P_{2l}(t)}\right]^{\frac{1}{1-\alpha}}. \tag{16}$$

It can be seen from Eq. (16) that the price at which the profit of firm l is maximized is given by

$$P_{2l}(t) = \frac{\zeta_2}{\alpha}. \tag{17}$$

Substituting Eq. (17) into Eq. (15) yields

$$X_{2l}(t) = \alpha^{\frac{2}{1-\alpha}} A_2{}^{\frac{1}{1-\alpha}} \zeta_2{}^{-\frac{1}{1-\alpha}} L_2(t). \tag{18}$$

Using Eqs. (16), (17), and (18), we can rewrite the profit of firm l as

$$\pi_{2l}(t) = \alpha^{\frac{2}{1-\alpha}} A_2{}^{\frac{1}{1-\alpha}} \left(\frac{1-\alpha}{\alpha}\right) \zeta_2{}^{-\frac{\alpha}{1-\alpha}} L_2(t). \tag{19}$$

The licensee loses the right to produce goods exclusively when the term of the license expires. All who gain access to the market can then produce intermediate goods for which the license term has expired. Thus, the market structure of intermediate goods for which the license term has expired becomes a perfect competition, assuming free entry to the market. Because the intermediate goods at time t that belong to interval $[0, \widetilde{N_2}(t)]$ are produced in a perfectly competitive market, the price of all intermediate goods that belong to its interval equals the marginal cost ζ_2. The aggregate supply of intermediate goods produced by perfectly competitive firms equals $\alpha^{\frac{1}{1-\alpha}} A_2{}^{\frac{1}{1-\alpha}} \zeta_2{}^{-\frac{1}{1-\alpha}} L_2(t)$.

If firm l licenses-in at time t, then the present discounted value of the stream of profits, $V_{2l}(t)$, can be written as

$$V_{2l}(t) = \int_t^{t+T} e^{-\int_t^{\tau} r_2(\omega)d\omega} \pi_{2l}(\tau)d\tau, \tag{20}$$

where $r_2(\omega)$ represents the rate of return in country 2 at time ω. Clearly, all firms that licensed-in at time t acquire the same monopolistic profit in equilibrium. Let $V_2(t)$ be the present discounted value of the stream of profits for all licensees. Then, from Eqs. (19) and (20), we obtain

$$V_2(t) = \alpha^{\frac{2}{1-\alpha}} A_2{}^{\frac{1}{1-\alpha}} \Big(\frac{1-\alpha}{\alpha}\Big) \zeta_1{}^{-\frac{\alpha}{1-\alpha}} \int_t^{t+T} e^{-\int_t^\tau r_2(\omega)d\omega} L_2(\tau) d\tau. \tag{21}$$

We next consider whether the firm acquires licenses and enters the intermediate goods industry. The firm must pay ΩT in terms of basic goods to the licensor to obtain the license. It must also incur costs of ν to obtain the know-how needed to manufacture the good. The entry cost for the firm is thus $\Omega T + \nu$. After incurring this cost, the firm reaps profits of $V_2(t)$ through monopolistic production. We focus on the equilibrium that causes the variety of intermediate goods in country 2 to increase at each point in time. From Eq. (21), we obtain the following equilibrium condition:

$$\alpha^{\frac{2}{1-\alpha}} A_2{}^{\frac{1}{1-\alpha}} \Big(\frac{1-\alpha}{\alpha}\Big) \zeta_2{}^{-\frac{\alpha}{1-\alpha}} \int_t^{t+T} e^{-\int_t^\tau r_2(\omega)d\omega} L_2(\tau) d\tau = \Omega T + \nu. \tag{22}$$

2.3 Households

In both countries, all households are infinite lived and are representative agents with perfect foresight. For country i, the total supply of labor is given as $\bar{L}_i$, which is exogenously constant. We assume that households supply labor inelastically and engage in a one time unit of labor at each period. Consequently, $\bar{L}_i$ represents the total number of workers in country i.

Let $c_i(t)$ be per capita consumption and $C_i(t)$ aggregate consumption. It follows that $c_i(t) \equiv C_i(t)/\bar{L}_i$. Households in country i choose consumption paths that maximize the lifetime utility function of the form

$$U_i = \int_0^\infty \left[\frac{c_i(t)^{1-\theta} - 1}{1-\theta}\right] e^{-\rho t}\, dt,$$

where the parameter θ is the reciprocal of the elasticity of intertemporal substitution; the parameter ρ is the rate of time preference; and $(c_i{}^{1-\theta} - 1)/(1-\theta)$ denotes instantaneous utility. It is assumed that $\theta > 0$, $\theta \neq 1$, and $\rho > 0$.

Households in country 1 receive wage, asset income $B_1(t)$ and a lump-sum transfer $G(t)$. In equilibrium $B_1(t) = V_1(t)[N_1(t) - \widetilde{N_1}(t)]$. We define $b_1(t) \equiv B_1(t)/\bar{L}_1$ and $g(t) \equiv G(t)/\bar{L}_1$. Consequently, the household's budget constraint in country 1 can be expressed as

$$\dot{b}_1(t) = w_1(t) + r_1(t)b_1(t) + g(t) - c_1(t).$$

Households in country 2 obtain wage and asset income. We represent total assets as $B_2(t)$. In equilibrium $B_2(t) = V_2(t)[N_2(t) - \widetilde{N_2}(t)]$. We define $b_2(t) \equiv B_2(t)/\bar{L}_2$. Hence, the household budget constraint in country 2 can be expressed as

$$\dot{b}_2(t) = w_2(t) + r_2(t)b_2(t) - c_2(t).$$

Solving the problem that households in each country face, we obtain

$$\frac{\dot{c}_i(t)}{c_i(t)} = \frac{1}{\theta}[r_i(t) - \rho]. \tag{23}$$

Therefore, the sign of household consumption growth in country i is determined by the gap between the interest rate and the rate of time preference. Because we focus on the positive growth rate in equilibrium, we assume that $r_i(t) > \rho$ for all t.

2.4 Growth Rates in a Steady-State Equilibrium

We are concerned with a steady-state equilibrium, defined as a situation in which a general equilibrium holds and all economic variables grow at a constant rate. In the following, we derive the relationships among the economic variables and identify the determinants of the growth rate of each variable that yield a positive growth rate in a steady-state equilibrium.

We first analyze country 1. Recall that intermediate goods on the interval $[0, \widetilde{N}_1(t)]$ are produced by perfectly competitive firms and that the intermediate goods on the interval $(\widetilde{N}_1(t), N_1(t)]$ are produced exclusively by firms that hold the patent rights to those goods. Let γ_{N_i} be the rate of innovation of country i in the steady-state equilibrium. We find that $\widetilde{N}_1(t) = N_1(t-T)$, and the number of the variety of intermediate goods produced by perfectly competitive firms in the steady-state equilibrium equals $\widetilde{N}_1(t) = N_1(t)e^{-\gamma_{N_1}T}$. The number of varieties of intermediate goods produced by monopolistically competitive firms is given by $N_1(t) - \widetilde{N}_1(t) = (1 - e^{-\gamma_{N_1}T})N_1(t)$.

Using Eqs. (1), (2) and (6) and recalling that the result of the total amount of intermediate goods on $[0, \widetilde{N}_1(t)]$ becomes $\alpha^{\frac{1}{1-\alpha}} A_1{}^{\frac{1}{1-\alpha}} \zeta_1{}^{-\frac{1}{1-\alpha}} L_1(t)$, the aggregate output of basic goods in country 1 is given by

$$Y_1(t) = \alpha^{\frac{\alpha}{1-\alpha}} A_1{}^{\frac{1}{1-\alpha}} \bar{L}_1[e^{-\gamma_{N_1}T} + \alpha^{\frac{\alpha}{1-\alpha}}(1 - e^{-\gamma_{N_1}T})]\zeta_1{}^{-\frac{\alpha}{1-\alpha}} N_1(t). \tag{24}$$

¿From Eq. (24), it is clear that the output of basic goods increases in proportion to the variety of intermediate goods.

If the growth rate of the output of basic goods is given by γ_{Y_i}, then for country 1, $\gamma_{Y_1} = \gamma_{N_1}$. From Eq. (3) and $L_1(t) = \bar{L}_1$, the wage rate of country 1 rises in proportion to the output of basic goods. The wage rate thus increases with increases in the variety of intermediate goods.

The level of aggregate consumption $C_1(t)$ is constrained by

$$C_1(t) = Y_1(t) - \eta\dot{N}_1(t) - \frac{\lambda T^2}{2}\dot{N}_1(t) - \int_0^{N_1(t)} \zeta_1 X_{1j}(t)dj, \tag{25}$$

where $\eta\dot{N}_1(t)$ is a resource related to R&D activity; $\lambda T^2\dot{N}_1(t)/2$ represents a resource of a patent fee (fiscal resource of a lump-sum transfer); and $\int_0^{N_1(t)} \zeta_1 X_{1j}(t)dj$ are the resources required to produce the intermediate goods. In the steady-state equilibrium, we obtain

$$\begin{aligned}\int_0^{N_1(t)} \zeta_1 X_{1j}(t)dj &= \alpha^{\frac{1}{1-\alpha}} A_1{}^{\frac{1}{1-\alpha}} \bar{L}_1[e^{-\gamma_{N_1}T} + \alpha^{\frac{1}{1-\alpha}}(1 - e^{-\gamma_{N_1}T})] \\ &\quad \times\zeta_1{}^{\frac{2-\alpha}{1-\alpha}} N_1(t).\end{aligned} \tag{26}$$

Using Eqs. (25) and (26), we obtain

$$\begin{aligned}\frac{C_1(t)}{N_1(t)} &= \frac{Y_1(t)}{N_1(t)} - \Big(\eta + \frac{\lambda T^2}{2}\Big)\gamma_{N_1} \\ &\quad -\alpha^{\frac{1}{1-\alpha}} A_1{}^{\frac{1}{1-\alpha}} \bar{L}_1[e^{-\gamma_{N_1}T} + \alpha^{\frac{1}{1-\alpha}}(1-e^{-\gamma_{N_1}T})]\zeta_1{}^{\frac{2-\alpha}{1-\alpha}}. \end{aligned} \tag{27}$$

Because $\gamma_{Y_1} = \gamma_{N_1}$ holds, $Y_1(t)/N_1(t)$ on the right-hand side of Eq. (27) becomes a constant. Accordingly, $C_1(t)/Y_1(t)$ on the left-hand side of Eq. (27) must be a constant.

Let γ_{C_i} be the growth rate of consumption in a steady-state equilibrium. Then $\gamma_{C_1} = \gamma_{N_1}$ holds. Let γ_{c_i} be the steady-state growth rate of per worker consumption, and let γ_{y_i} be the growth rate of per worker basic goods in country 1 in a steady-state equilibrium. From the analytical results above, the following relation holds:

$$\gamma_{c_1} = \gamma_{y_1} = \gamma_{N_1} \equiv \gamma_1. \tag{28}$$

As for country 2, intermediate goods on the interval $[0, \widetilde{N_2}(t)]$ are produced by perfectly competitive firms. The intermediate goods on the interval $(\widetilde{N_2}(t), N_2(t)]$ are produced exclusively by firms that hold the licenses to those goods. In a steady-state equilibrium, the total amount of basic goods in country 2 is expressed as follows:

$$Y_2(t) = \alpha^{\frac{\alpha}{1-\alpha}} A_2{}^{\frac{1}{1-\alpha}} \bar{L}_2[e^{-\gamma_{N_2}T} + \alpha^{\frac{\alpha}{1-\alpha}}(1-e^{-\gamma_{N_2}T})]\zeta_2{}^{-\frac{\alpha}{1-\alpha}} N_2(t). \tag{29}$$

From Eq. (29), we find that $\gamma_{Y_2} = \gamma_{N_2}$ holds. Using Eq. (3) and $L_2(t) = \bar{L}_2$, we can confirm that in country 2, the rate of growth of wages is equal to the rate of growth of output of basic goods.

Regarding the resource constraint in country 2, the level of aggregate consumption $C_2(t)$ is constrained by

$$C_2(t) = Y_2(t) - \nu\dot{N}_2(t) - \Omega T\dot{N}_2(t) - \int_0^{N_2(t)} \zeta_2 X_{2j}(t)dj, \tag{30}$$

where $\nu\dot{N}_2(t)$ represents the resources required for country 2 to acquire the know-how needed to manufacture the goods invented in country 1. It should be noted that $\dot{N}_1(t) = \dot{N}_2(t)$. The lump-sum payment required to obtain the license is $\Omega T\dot{N}_2(t)$. The resources used to produce the intermediate goods are given by $\int_0^{N_2(t)} \zeta_2 X_{2j}(t)dj$. In a steady-state equilibrium, the following relation holds.

$$\begin{aligned}\int_0^{N_2(t)} X_{2j}(t)dj &= \alpha^{\frac{1}{1-\alpha}} A_2{}^{\frac{1}{1-\alpha}} \bar{L}_2[e^{-\gamma_{N_2}T} + \alpha^{\frac{1}{1-\alpha}}(1-e^{-\gamma_{N_2}T})] \\ &\quad \times\zeta_2{}^{\frac{2-\alpha}{1-\alpha}} N_2(t). \end{aligned} \tag{31}$$

Using Eqs. (30) and (31), we obtain

$$\begin{aligned}\frac{C_2(t)}{N_2(t)} &= \frac{Y_2(t)}{N_2(t)} - (\nu + \Omega T)\gamma_{N_2} \\ &\quad -\alpha^{\frac{1}{1-\alpha}} A_2{}^{\frac{1}{1-\alpha}} L_2[e^{-\gamma_{N_2}T} + \alpha^{\frac{1}{1-\alpha}}(1-e^{-\gamma_{N_2}T})]\zeta_2{}^{\frac{2-\alpha}{1-\alpha}}. \end{aligned} \tag{32}$$

Because $\gamma_{Y_2} = \gamma_{N_2}$, $Y_2(t)/N_2(t)$ on the right-hand side of Eq. (32) becomes a constant. The results imply that $C_2(t)/Y_2(t)$ on the right-hand side also becomes a constant. It follows that $\gamma_{C_2} = \gamma_{N_2}$. Hence, for country 2, the following relation is derived.

$$\gamma_{c_2} = \gamma_{y_2} = \gamma_{N_2} \equiv \gamma_2. \tag{33}$$

3 Effects of Patent Protection

As mentioned above, it is noteworthy there has been a recent globally trend for stronger intellectual property rights. What effect has this trend had on the macro-economy of each country? In the following discussion, we analyze the effects of strengthening patent protection through extension of patent duration on macroeconomic performance in country 1 and 2.

We continuously focus on a steady-state equilibrium. By definition, γ_{c_i} is a constant. From Eq. (23), $r_i(t)$ is a constant as well; hence, we omit the symbol t and write r_i in what follows. From Eq. (13), we obtain

$$\chi_1(1 - e^{-r_1 T}) = \Big(\eta + \frac{\lambda T^2}{2} - \Omega T\Big) r_1, \tag{34}$$

where $\chi_1 \equiv \alpha^{\frac{1+\alpha}{1-\alpha}} A_1{}^{\frac{1}{1-\alpha}} \zeta_1{}^{-\frac{\alpha}{1-\alpha}} \bar{L}_1(1-\alpha)$. Let $\widehat{\gamma}_i$ be a steady-state growth rate at $r_i = \widehat{r}_i$ in country i. Figure 2 shows that r_1 in Eq. (34) is determined uniquely by the value $\widehat{r}_1$ for the intersection of $\chi_1(1 - e^{-r_1 T})$ and $(\eta + \lambda T^2/2 - \Omega T) r_1$.

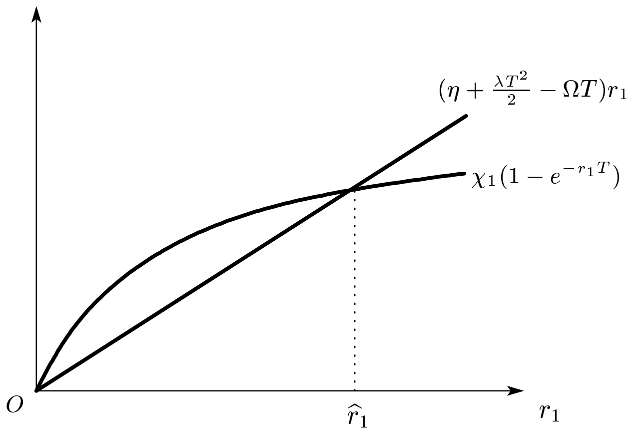

Figure 2 Steady-state equilibrium in country 1

Using Eqs. (23) and (28), we obtain

$$\widehat{\gamma}_1 = \frac{1}{\theta}(\widehat{r}_1 - \rho). \tag{35}$$

It should be noted that $\widehat{r}_1$ depends on the patent duration, T. Differentiating Eq. (35) with respect to T yields

$$\frac{\partial \widehat{\gamma}_1}{\partial T} = \frac{\widehat{r}_1(\chi_1 e^{-\widehat{r}_1 T} + \Omega - \lambda T)}{\theta\left(\eta + \frac{\lambda T^2}{2} - \Omega T - \chi_1 T e^{-\widehat{r}_1 T}\right)}. \tag{36}$$

Here we focus attention on Figure 2. It is found that the slope of the tangent to $\chi_1(1 - e^{-r_1 T})$ curve at $\widehat{r}_1$ is $\chi_1 T e^{-\widehat{r}_1} T$. On the other hand, the slope of the $(\eta + \lambda T^2/2 - \Omega T)r_1$ line is $\eta + \lambda T^2/2 - \Omega T$. As is apparent from Figure 2, the following relationship holds at $\widehat{r}_1$.

$$\eta + \frac{\lambda T^2}{2} - \Omega T > \chi_1 T e^{-\widehat{r}_1} T.$$

Hence, the sign in parentheses in the denominator in Eq. (36) becomes positive for all $T > 0$. Therefore, the sign of $\partial\widehat{\gamma}_1/\partial T$ is determined according to the sign in parentheses of the numerator in Eq. (36). The result suggests that if χ_1 and Ω are relatively large and λ is relatively small, then the rate of innovation and the rate of economic growth in country 1 may be promoted by strengthening patent protection, meaning the extension of patent duration, for a given value of $T > 0$. Intuitively, we can interpret the implications of the model as follows: Other things being equal, as a result of an extension in patent duration, an increase in the patent fee reduces the firm's incentive to undertake R&D. However the extension in patent duration also raises the innovator's revenue by increasing the license fee. When the increase in such revenues is greater than the increase in the cost to maintain the patent, the strengthening of patent protection will induce greater R&D activity in a technological leading country. As well, the increase in R&D will promote innovation, technology exports, and economic growth in the long run.

We now consider the case of country 2. Eq. (22) can be rewritten as

$$\chi_2(1 - e^{-r_2 T}) = (\nu + \Omega T)r_2, \tag{37}$$

where $\chi_2 \equiv \alpha^{\frac{1+\alpha}{1-\alpha}} A_2^{\frac{1}{1-\alpha}} \zeta_2^{-\frac{\alpha}{1-\alpha}} \bar{L}_2(1-\alpha)$. Figure 3 represents the right-hand and left-hand sides of Eq. (37) as functions of r_2.

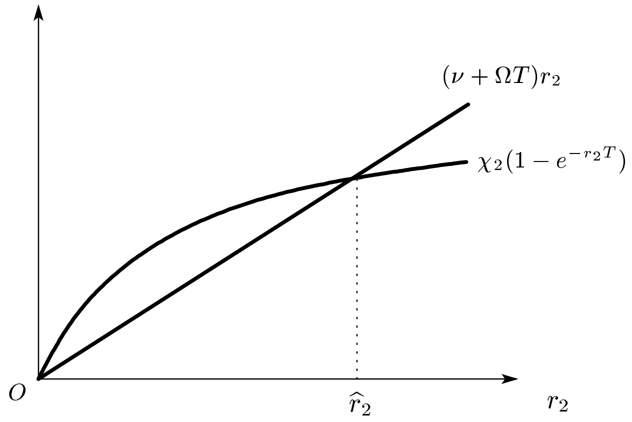

Figure 3 Steady-state equilibrium in country 2

Here $\widehat{r}_2$ denotes the rate of return of steady-state in country 2. From Figure 3, we find that, other things being equal, the smaller ν becomes, the larger $\widehat{r}_2$ grows. Recall that ν is the cost to the firm in country 2 of acquiring the know-how to produce the intermediate goods invented in country 1. It is therefore possible to interpret ν as the absorptive capacity of workers in country 2. [8] When the value of ν is small, absorptive capacity is considered high.

Using Eqs. (23) and (33), we can describe the per worker growth rate in steady-state equilibrium by

$$\widehat{\gamma}_2 = \frac{1}{\theta}(\widehat{r}_2 - \rho). \tag{38}$$

From Eq. (38), we obtain

$$\frac{\partial \widehat{\gamma}_2}{\partial T} = \frac{\widehat{r}_2(\chi_2 e^{-\widehat{r_2}T} - \Omega)}{\theta(\nu + \Omega T - \chi_2 T e^{-\widehat{r_2}T})}. \tag{39}$$

Note that the slope of the tangent to the $\chi_2(1-e^{-r_2 T})$ curve at $\widehat{r}_2$ is $\chi_2 T e^{-\widehat{r_2}} T$. On the other hand, the slope of the $(\nu + \Omega T)r_1$ line is $\nu + \Omega T$. From Figure 3, we can confirm that the following inequality holds.

$$\nu + \Omega T > \chi_2 T e^{-\widehat{r_2}} T.$$

Accordingly, the value in parentheses in the denominator of Eq. (39) is positive for all $T > 0$. The sign in parentheses in the numerator of Eq. (39) is indeterminate. Thus, the sign of $\partial \gamma_2 / \partial T$ depends on the sign in parentheses of the numerator of Eq. (39). For example, for given values of $T > 0$, when χ_2 is large and Ω small, strengthening patent protection may promote technology imports and economic growth in country 2.

Therefore, we can present an interesting interpretation; that is, extending the duration of patent protection seems to have two side (positive or negative) effects on economic growth in both countries. For country 1, if the values of the parameters for the labor force, the license fee, and productivity in basic goods sector are relatively large and the parameters for cost of manufacturing intermediate goods and the patent fee are relatively small, then strengthening patent protection will promote product innovation, technology exports, and economic growth. On the other hand, for country 2, if the values of the parameters for the labor force, and productivity in the basic goods sector are relatively large and the manufacturing cost and the cost of manufacturing intermediate goods and the license fee are relatively small, then technology imports and economic growth rate in country 2 rise as a result of strengthened patent protection.

4 Concluding Remarks

This paper extends discussions in earlier research, including those by Romer (1990), Grossman and Helpman (1991), and Barro and Sala-i-Martin (1992), to examine the relationship between patent protection and macroeconomic performance in the context of a two-country model.

[8] Goto (1993) notes that the high absorptive capacity of workers contributed greatly to Japan's rapid economic development.

The main results can be summarized as follows: The model implies that, for a leading country, when the values of the parameters for the labor force, the license fee, and productivity in the basic goods sector are large and the parameters for cost of manufacturing intermediate goods and the patent fee are small, strengthening patent protection will promote innovation, technology exports, and economic growth in the leading country. On the other hand, for a follower country, when the values of the parameters for the labor force, and institutional factors are large and the cost of manufacturing intermediate goods and the license fee are small, the follower country's technology imports and economic growth rise as a result of strengthened patent protection. Hence, the model suggests that strengthening patent protection is not necessarily growth and technology trade promoting.

Related earlier literature in the context of economic growth models did not take into account the role of the cost to maintain a patent, although it is an important aspect of patent systems. In view of an actual patent system, therefore, we shed light on an aspect of such a cost and derive the suggestive policy implications. However, future research will be needed to elaborate and generalize the issues involved because our discussion was based on some strong assumptions.

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