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THE ESCAPE-INFRINGEMENT EFFECT OF BLOCKING PATENTS ON INNOVATION AND ECONOMIC GROWTH

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This study develops a Schumpeterian growth model to analyze the effects of different patent instruments on innovation. We first analyze patent breadth, which captures the traditional *positive* effect of patent rights on innovation. Then, we consider a profit-division rule between entrants and incumbents. Given the division of profit, increasing the share of profit assigned to incumbents reduces entrants' incentives for innovation. This aspect of blocking patents captures the recently proposed *negative* effect of patent rights on innovation. Finally, blocking patents generate a *nonmonotonic* effect on innovation when the step size of innovation is endogenous because of a novel escape-infringement effect. Calibrating the model to aggregate data, we find that a marginal increase in the blocking effect of patent protection is likely to enhance economic growth.

Keywords: Economic Growth, Innovation, Intellectual Property Rights

1. INTRODUCTION

The traditional understanding is that secure patent rights enhance the private return to R&D investment. According to this argument, stronger patent rights should increase innovation and economic growth. However, many economists, such as Jaffe and Lerner (2004), Bessen and Meurer (2008) and Boldrin and Levine (2008),

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have recently raised doubts against this traditional viewpoint on patent protection. According to this recent argument, stronger patent rights reduce innovation by increasing the power of existing patentholders, who use their enhanced power to extract surplus from subsequent innovators rather than providing more innovation. In this note, we develop a Schumpeterian growth model to analyze the effects of different patent instruments on innovation and economic growth. The first patent instrument that we analyze is patent breadth, which captures the traditional *positive* effect of patent rights on innovation. Then we consider a profit-division rule between entrants and incumbents. Given the division of profit, increasing the share of profit assigned to incumbents reduces entrants' incentives for innovation, and this aspect of blocking patents captures the recently proposed *negative* effect of patent rights on innovation. Finally, we show that blocking patents generate a *nonmonotonic* effect on innovation when the step size of innovation is endogenous because of an escape-infringement effect that is often neglected in the patent literature.

Intuitively, in the presence of blocking patents, entrants would develop more substantial innovations in order to avoid infringing the patents of incumbents. Therefore, although blocking patents generate a negative effect by reducing the arrival rate of innovation, they also generate a positive effect by increasing the step size of innovation. Combining these positive and negative effects of blocking patents gives rise to an inverted-U relationship between patent rights and innovation that has been documented in recent empirical studies, such as Qian (2007) and Lerner (2009). We also calibrate the model to aggregate data in order to quantify the effect of blocking patents. We find that a marginal increase in the blocking effect of patent protection is likely to enhance economic growth in a calibrated R&D-based growth model.

This study relates to the microeconomic literature on optimal patent design. In this literature, the seminal study is Nordhaus (1969), who shows that the optimal patent length should balance the social benefit of innovation and the social cost of monopolistic distortion. Scotchmer (2004) provides a comprehensive review on the subsequent developments in this patent-design literature. In this literature, an interesting and important policy lever is forward patent protection, which gives rise to the division of profit between sequential innovators; see Green and Scotchmer (1995) for an early study. Our study differs from studies in this literature by analyzing the effects of patent instruments on innovation and economic growth in a quantitative dynamic general-equilibrium (DGE) framework.

As for the macroeconomic literature on patent policy, Judd (1985) provides the seminal DGE analysis on patent length, and he finds that an infinite patent length maximizes innovation. Subsequent studies find that strengthening patent rights via different patent instruments does not necessarily increase innovation and may even stifle it. Examples of these studies include Horowitz and Lai (1996) and Chen and Iyigun (2011) on patent length,[1] O'Donoghue and Zweimuller (2004) on forward patent protection and patentability requirement, Cozzi and Spinesi (2006) on intellectual appropriability, Horii and Iwaisako (2007), Furukawa (2007, 2010) and Akiyama and Furukawa (2009) on patent protection against imitation, and Chu (2009) on blocking patents. Our study complements these growth-theoretic studies by analyzing a novel channel through the escape-infringement effect that gives rise to a nonmonotonic effect of patent rights on innovation and economic growth. Furthermore, we contrast the effects of blocking patents under an exogenous step size versus an endogenous step size of innovation and show that the same patent instrument can have drastically different effects on innovation when the underlying innovation process changes slightly.

The rest of this note is organized as follows. Section 2 presents the model. Section 3 defines the equilibrium and characterizes the equilibrium allocation. Section 4 analyzes the effects of patent instruments on innovation and economic growth. The final section concludes.

2. THE MODEL

In this section, we consider a quality-ladder growth model, as in Grossman and Helpman (1991).[2] To consider the division of profit between sequential innovators along the quality ladder, we assume that each entrant (i.e., the most recent innovator) infringes the patent of the incumbent (i.e., the previous innovator). As a result of this patent infringement, the entrant has to transfer a share $s \in [0, 1]$ of his or her profit to the incumbent. However, with sequential innovation, every innovator's patent would eventually be infringed by the next innovation, and he or she can then extract a share s of profit from the next entrant. This formulation of profit division between sequential innovators originates from O'Donoghue and Zweimuller (2004), but our model differs from that of O'Donoghue and Zweimuller (2004) by endogenizing s as a function of the step size of innovation in order to analyze the escape-infringement effect. To make the quality-ladder model more suitable for calibration, we incorporate physical capital accumulation into the model.[3] Given that the Grossman–Helpman model has been well-studied, we will describe the familiar features briefly to conserve space and discuss the new features in details.

2.1. Households

There is a unit continuum of identical households. Their lifetime utility is

$$U = \int_0^\infty e^{-\rho t} \ln C_t dt, \quad (1)$$

where $\rho > 0$ is the discount rate, and C_t is the consumption of final goods at time t. Households maximize (1) subject to

$$\dot{A}_t = r_t A_t + W_t - C_t. \quad (2)$$

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A_t is the value of assets (including capital and patents) owned by households, and r_t is the real rate of return on assets. Households inelastically supply one unit of labor to earn the wage rate W_t. The price of final goods is normalized to unity. From standard dynamic optimization, the Euler equation is

$$\dot{C}_t / C_t = r_t - \rho. \tag{3}$$

2.2. Final goods

The final goods sector is perfectly competitive. Final goods Y_t are produced via a standard Cobb–Douglas aggregator given by

$$Y_t = \exp\left(\int_0^1 \ln X_t(i) di\right), \tag{4}$$

where $X_t(i)$ is intermediate goods $i \in [0, 1]$. Competitive firms producing final goods take as given the output price and input prices $P_t(i)$ for $i \in [0, 1]$. From profit maximization, the conditional demand function for $X_t(i)$ is

$$X_t(i) = Y_t / P_t(i). \tag{5}$$

2.3. Intermediate goods

In the intermediate goods sector, there is a continuum of differentiated intermediate goods $i \in [0, 1]$. Given the technology of the most recent innovator, the production function for intermediate goods i is[4]

$$X_t(i) = Q_t(i)[L_{x,t}(i)]^{1-\alpha}[K_t(i)]^{\alpha}. \tag{6}$$

$Q_t(i)$ is the highest level of technology in industry i at time t, and it is given by $Q_t(i) = \prod_{j=1}^{n_t(i)} z_j(i)$. The integer $n_t(i)$ is the number of innovations that have occurred in industry i as of time t, and $z_j(i) > 1$ is the step size of the jth innovation in industry i. If $z_j(i) = z$ for all $j \in \{1, ..., n_t(i)\}$ and for all $i \in [0, 1]$, then $Q_t(i)$ simplifies to $z^{n_t(i)}$, as in the canonical quality-ladder model. Given that the equilibrium features a symmetric step size z for all $j \in \{1, ..., n_t(i)\}$ and for all $i \in [0, 1]$, we use z to denote $z_j(i)$ for notational simplicity.

$L_{x,t}(i)$ and $K_t(i)$ are respectively the number of production workers and the amount of capital employed in industry i at time t. From cost minimization, the marginal cost of production for the industry leader (i.e., the most recent innovator) in industry i is

$$\mathrm{MC}_t(i) = \frac{1}{Q_t(i)}\left(\frac{W_t}{1-\alpha}\right)^{1-\alpha}\left(\frac{R_t}{\alpha}\right)^{\alpha}, \tag{7}$$

where R_t is the rental price of capital. The standard no-arbitrage condition is $R_t = r_t + \delta$, where δ is the depreciation rate of capital. Given $\mathrm{MC}_t(i)$, the industry leader charges a markup over the marginal cost to maximize profit. In the canonical quality-ladder model, this markup is given by the step size z because of Bertrand competition. Here we consider patent breadth, similarly to Li (2001) and Goh and Olivier (2002), by assuming that the markup $\mu > 1$ is a policy instrument set by the patent authority. Therefore, the monopolistic price is given by

$$P_t(i) = \mu \mathrm{MC}_t(i). \tag{8}$$

As a result, the amount of profit generated in industry i is

$$\pi_t(i) = \left(\frac{\mu - 1}{\mu}\right) P_t(i) X_t(i) = \left(\frac{\mu - 1}{\mu}\right) Y_t, \tag{9}$$

where the second equality of (9) follows from (5). Furthermore, labor income in industry i is

$$W_t L_{x,t}(i) = \left(\frac{1 - \alpha}{\mu}\right) P_t(i) X_t(i) = \left(\frac{1 - \alpha}{\mu}\right) Y_t. \tag{10}$$

In each industry i, the most recent innovator (i.e., the entrant) infringes the patent of the previous innovator (i.e., the incumbent). As a result of this patent infringement, the most recent innovator pays a licensing fee by transferring a share $s \in [0, 1]$ of his or her profit to the previous innovator. Here we differ from O'Donoghue and Zweimuller (2004) by considering an endogenous profit-division rule given by $s = \beta/z$, where the patent instrument $\beta \in [0, z]$ captures the negative effect of blocking patents. For a given z, a larger β forces the entrant to pay a higher licensing fee to the incumbent and reduces the entrant's incentives for innovation. However, the entrant can reduce the amount of this licensing fee by developing a more substantial innovation through a larger step size z. This setup is reasonable because in reality, the more different an innovation is from previous innovations, the less likely is it to be considered as an infringement. Given a smaller chance of patent infringement, the entrant would have more power to bargain for a lower licensing fee. Because of profit division, the entrant obtains $(1 - s)\pi_t$, whereas the incumbent obtains $s\pi_t$. The most recent innovation and the second most recent innovation are owned by different firms because of the well-known Arrow replacement effect.[5]

2.4. R&D and innovation

Denote the value of the patent on the second most recent innovation in industry i as $V_{2,t}(i)$. Because $\pi_t(i) = \pi_t$ for $i \in [0, 1]$, from (9), $V_{2,t}(i) = V_{2,t}$ in a symmetric equilibrium that features an equal arrival rate of innovation across industries.[6] The familiar no-arbitrage condition for $V_{2,t}$ is

$$r_t V_{2,t} = s\pi_t + \dot{V}_{2,t} - \lambda_t V_{2,t}. \tag{11}$$

Equation (11) equates the interest rate r_t to the asset return per unit of asset. The asset return is given by the sum of (a) the profit $s\pi_t$ received by the patentholder,

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(b) the capital gain $\dot{V}_{2,t}$, and (c) the expected capital loss $\lambda_t V_{2,t}$ because of creative destruction, for which λ_t is the Poisson arrival rate of innovation. As for the value of the patent on the most recent innovation, the no-arbitrage condition for $V_{1,t}$ is

$$r_t V_{1,t} = (1-s)\pi_t + \dot{V}_{1,t} - \lambda_t(V_{1,t} - V_{2,t}). \tag{12}$$

The intuition behind (12) is the same as that behind (11), except for the last term. When the next innovation occurs, the current industry leader becomes the second most recent innovator, and hence, his or her net capital loss is $V_{1,t} - V_{2,t}$.

There is a unit continuum of R&D entrepreneurs indexed by $k \in [0, 1]$, and each entrepreneur hires R&D labor $L_{r,t}(k)$ for innovation. The expected return from R&D is

$$\pi_{r,t}(k) = \lambda_t(k)V_{1,t} - W_t L_{r,t}(k). \tag{13}$$

The arrival rate of innovation for entrepreneur k is

$$\lambda_t(k) = \frac{\varphi L_{r,t}(k)}{z}, \tag{14}$$

where $\varphi > 0$ is a productivity parameter for R&D, and φ/z captures the effect that a larger step size of innovation has a lower chance of success. The zero–expected profit condition for R&D is

$$\frac{\varphi V_{1,t}}{z} = W_t. \tag{15}$$

For the rest of this study, we focus on the balanced growth path. In this case, (11) becomes

$$V_{2,t} = \frac{s\pi_t}{r - g_\pi + \lambda} = \frac{s\pi_t}{\rho + \lambda}, \tag{16}$$

where g_π is the steady-state growth rate of profit, and the second equality of (16) follows from (3).[7] Similarly, (12) becomes

$$V_{1,t} = \frac{(1-s)\pi_t}{\rho + \lambda} + \frac{\lambda V_{2,t}}{\rho + \lambda}. \tag{17}$$

An entrepreneur takes λ and $V_{2,t}$ as given. Given that the step size z is endogenous, he or she chooses z to maximize

$$\frac{\varphi V_{1,t}}{z} = \frac{\varphi}{z}\left[\frac{(1-s)\pi_t}{\rho + \lambda} + \frac{\lambda V_{2,t}}{\rho + \lambda}\right], \tag{18}$$

where $s = \beta/z$.[8] This optimization yields the equilibrium step size given by

$$z^* = \beta\left(\frac{2\rho + \lambda}{\rho + \lambda}\right). \tag{19}$$

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It is useful to note that the equilibrium arrival rate λ^* is also a function of β. To ensure that $z^* > 1$ in equilibrium, we impose the following condition.

$$\text{Condition B (blocking patents): } \beta\left[\frac{2\rho+\lambda^*(\beta)}{\rho+\lambda^*(\beta)}\right] > 1.$$

In Section 4, we will show that z^* is strictly increasing in β even after the general-equilibrium effect on λ^*, is taken into account, so that there exists a lower-bound value of β above which Condition B holds.[9] Equation (19) yields an important insight that increasing the blocking effect β of patent protection causes the innovators to develop more substantial innovations in order to escape patent infringement. In equilibrium, the profit-division rule under an endogenous step size of innovation becomes

$$s^* = \frac{\beta}{z^*} = \frac{\rho+\lambda}{2\rho+\lambda}. \tag{20}$$

3. DECENTRALIZED EQUILIBRIUM

The equilibrium is a time path of allocations $\{C_t, Y_t, X_t(i), K_t, L_{x,t}, L_{r,t}\}_{t=0}^{\infty}$ and a time path of prices $\{P_t(i), W_t, R_t, r_t, V_{1,t}, V_{2,t}\}_{t=0}^{\infty}$. Also, at each instant of time,

- households maximize utility, taking $\{W_t, r_t\}$ as given;
- competitive final-goods firms produce Y_t and maximize profit, taking $P_t(i)$ as given;
- monopolistic intermediate-goods firms employ $\{L_{x,t}, K_t\}$ to produce $X_t(i)$ and choose $P_t(i)$ to maximize profit, taking $\{W_t, R_t\}$ as given;
- R&D entrepreneurs employ $L_{r,t}$ to maximize expected profit, taking $\{W_t, V_{1,t}\}$ as given;
- the labor market clears in such a way that $L_{x,t} + L_{r,t} = 1$;
- the final-goods market clears in such a way that $Y_t = C_t + I_t$, where I_t is capital investment;
- the capital stock accumulates according to $\dot{K}_t = I_t - \delta K_t$.

3.1. Equilibrium Allocation

To derive the equilibrium allocation, we combine (10) and (15) to obtain

$$\frac{\varphi V_{1,t}}{z^*} = W_t = \left(\frac{1-\alpha}{\mu}\right)\frac{Y_t}{L_x}. \tag{21}$$

Then we substitute (9), (16), and (17) into (21) and rearrange terms to obtain

$$\frac{\varphi}{z^*}\left[(1-s^*) + \left(\frac{\lambda}{\rho+\lambda}\right)s^*\right]\frac{\mu-1}{\rho+\lambda} = \frac{1-\alpha}{L_x}, \tag{22}$$

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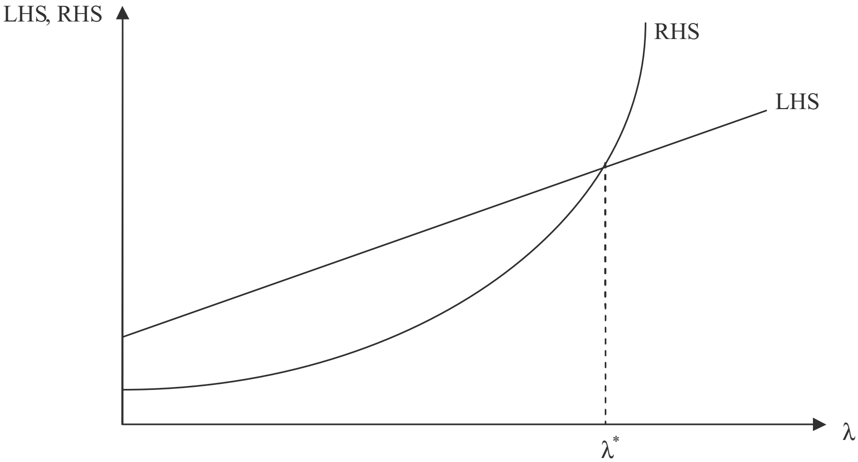

FIGURE 1. Equilibrium arrival rate of innovation.

where z^* and s^* are given by (19) and (20). Using $L_x = 1 - L_r$ and $\lambda = \varphi L_r/z$ from (14), we can reexpress (22) as

$$\varphi(\rho + \lambda) = \beta \left[(1-\alpha)\frac{(2\rho+\lambda)^2}{\mu - 1} + \lambda\,(2\rho + \lambda) \right]. \tag{23}$$

Equation (23) determines the steady-state equilibrium arrival rate λ^* of innovation. Both the left-hand side (LHS) and the right-hand side (RHS) of (23) are increasing in λ. To ensure that the equilibrium λ^* is strictly positive, we impose a lower bound on the R&D-productivity parameter φ, given by

Condition R (R&D productivity): $\varphi > 4\beta(1-\alpha)\rho/(\mu - 1)$.

Given Condition R, $\text{LHS}|_{\lambda=0} = \varphi\rho > 4\beta(1-\alpha)\rho^2/(\mu-1) = \text{RHS}|_{\lambda=0}$. Furthermore, LHS is a linear and increasing function in λ whereas RHS is a convex and increasing function in λ. Therefore, RHS crosses LHS exactly once from below, giving rise to a unique equilibrium λ^*; see Figure 1 for an illustration.

Solving the quadratic equation in (23) yields a closed-form solution for λ^*, given by

$$\lambda^* = \Phi + \sqrt{\Phi^2 + \frac{\rho}{\mu - \alpha}\left[\frac{\varphi(\mu - 1)}{\beta} - 4(1-\alpha)\rho\right]}, \tag{24}$$

where $\Phi \equiv [\varphi(\mu-1)/(2\beta) - (\mu + 1 - 2\alpha)\rho]/(\mu - \alpha)$ is a composite parameter.

4. EFFECTS OF PATENTS ON INNOVATION AND GROWTH

In this section, we analyze the effects of the two patent instruments $\{\beta, \mu\}$ on innovation and economic growth. We begin by deriving the steady-state equilibrium growth rates of output and technology. Substituting (6) into (4) yields

$$Y_t = Z_t (L_x)^{1-\alpha} (K_t)^{\alpha}, \tag{25}$$

where the aggregate level of technology is defined as

$$Z_t \equiv \exp\left(\int_0^1 \ln Q_t(i) di\right) = \exp\left(\int_0^1 n_t(i) di \ln z^*\right). \tag{26}$$

The second equality of (26) applies $z_j(i) = z^*$, so that $Q_t(i) = (z^*)^{n_t(i)}$. Applying the law of large numbers, the log of Z_t becomes

$$\ln Z_t = \int_0^t \lambda_\tau d\tau \ln z^*. \tag{27}$$

Therefore, the steady-state equilibrium growth rate of technology is

$$g^* \equiv \frac{\dot{Z}_t}{Z_t} = \lambda^* \ln z^*. \tag{28}$$

On the balanced growth path, Y_t and K_t grow at $g^*/(1-\alpha)$.[10]

The first patent instrument that we analyze is patent breadth μ. An increase in μ shifts down the RHS of (23), causing λ^* to increase. Intuitively, a larger patent breadth enables the industry leader to charge a higher markup, and this greater monopolistic power increases the amount of profits, as well as providing more incentives for R&D and innovation; see also Li (2001) and Chu (2010). This is the traditional positive effect of patent protection emphasized by proponents of intellectual property rights. The higher arrival rate of innovation also increases the equilibrium growth rate g^* if β is sufficiently large. To see this result,

$$\frac{\partial g^*}{\partial \lambda^*} = \ln z^* + \lambda^* \underbrace{\frac{\partial \ln z^*}{\partial \lambda^*}}_{<0} = \ln \beta + \ln\left(\frac{2\rho + \lambda^*}{\rho + \lambda^*}\right) - \frac{\rho\lambda^*}{(2\rho + \lambda^*)(\rho + \lambda^*)}. \tag{29}$$

Then, using log approximation $\ln(1+x) \approx x$, we can show that

$$\ln\left(\frac{2\rho + \lambda^*}{\rho + \lambda^*}\right) \approx \frac{\rho}{\rho + \lambda^*} > \frac{\rho\lambda^*}{(2\rho + \lambda^*)(\rho + \lambda^*)}. \tag{30}$$

Therefore, if $\beta > 1$ (i.e., $\ln \beta > 0$), then $\partial g^*/\partial \lambda^* > 0$.

PROPOSITION 1. *The arrival rate of innovation is increasing in patent breadth* μ. *If* $\beta > 1$, *then economic growth is also increasing in patent breadth* μ.

The second patent instrument that we analyze is the effect of blocking patents, captured by β. However, we first analyze its effect under an *exogenous* step size of innovation. In this case, $z^* = z > 1$ and $s = \beta/z$, where z is a constant.

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Furthermore, (22) can be reexpressed as

$$(\mu - 1)\left[\left(1 - \frac{\beta}{z}\right)\rho + \lambda\right] = \frac{(1-\alpha)(\rho+\lambda)^2}{\varphi/z - \lambda}. \qquad \textbf{(31)}$$

It can be shown that Figure 1 also applies to (31). A higher β shifts down the LHS of (31). As a result, λ^* decreases, and this lower arrival rate of innovation also decreases the equilibrium growth rate g^*, because z is assumed to be exogenous in this case. Intuitively, a larger effect of blocking patents forces entrants to transfer a larger share of profit to incumbents, reducing the entrants' incentives for R&D and innovation; see also O'Donoghue and Zweimuller (2004) and Chu (2009). This is the recently emphasized negative effect of patent protection considered by opponents of intellectual property rights.

PROPOSITION 2. *Under an exogenous step size z, the arrival rate of innovation and economic growth are decreasing in the blocking effect β of patents.*

Finally, we analyze blocking patents under an *endogenous* step size of innovation. In this case, z^* and s^* are given by (19) and (20). A higher β induces innovators to choose a larger step size z^* for a given λ, but this larger step size also reduces the equilibrium arrival rate of innovation because of lower R&D productivity φ/z^*. In (23), an increase in β shifts up the RHS, so that β has a negative effect on λ^*, as in the case of exogenous step size. However, with endogenous step size, the larger z^* chosen by innovators also contributes to economic growth. In other words, an increase in β has a negative effect on g^* through λ^* (i.e., the frequency of innovation) as well as a positive effect through z^* (i.e., the size of innovation). To our knowledge, this additional escape-infringement effect of blocking patents has never been analyzed in the patent literature. It is this novel mechanism that gives rise to a nonmonotonic effect of blocking patents on innovation.

Differentiating $g^* = \lambda^* \ln z^*$ with respect to β yields

$$\frac{\partial g^*}{\partial \beta} = \ln z^* \underbrace{\frac{\partial \lambda^*}{\partial \beta}}_{<0} + \lambda^* \frac{\partial \ln z^*}{\partial \beta}, \qquad \textbf{(32)}$$

where

$$\frac{\partial \ln z^*}{\partial \beta} = \frac{1}{\beta} - \frac{\rho}{(\rho+\lambda^*)(2\rho+\lambda^*)}\frac{\partial \lambda^*}{\partial \beta} > 0. \qquad \textbf{(33)}$$

Therefore, the equilibrium step size z^* is strictly increasing in β even after the general-equilibrium effect on λ^* is taken into account. Equations (32) and (33) show that there are both positive and negative effects of blocking patents on economic growth. On one hand, if β is sufficiently large, the negative effect dominates the positive effect, so that $\partial g^*/\partial \beta < 0$. As β approaches its upper bound $\varphi(\mu-1)/[4(1-\alpha)\rho]$, Condition R becomes an equality, and hence, λ^* approaches zero; in this case, the negative effect dominates the positive effect. On the other hand, if β is sufficiently small, the positive effect dominates the negative effect, so that $\partial g^*/\partial\beta > 0$. As β approaches its lower bound, given by Condition B, z^* approaches one, and hence, the positive effect dominates the negative effect in this case. The opposite signs of $\partial g^*/\partial\beta$ at the upper and lower bounds of β imply that g^* must be a nonmonotonic function in β. For the special case of $\rho \to 0$, (23) yields

$$\lim_{\rho\to 0} \lambda^* = \left(\frac{\mu-1}{\mu-\alpha}\right)\frac{\varphi}{\beta}. \qquad \textbf{(34)}$$

Therefore, the equilibrium growth rate becomes

$$\lim_{\rho\to 0} g^* = \left(\frac{\mu-1}{\mu-\alpha}\right)\frac{\varphi\ln\beta}{\beta}. \qquad \textbf{(35)}$$

In this case, g^* is explicitly an inverted-U function in β and reaches a maximum at $\beta = \overline{\beta} \equiv \exp(1)$. We have conducted a large number of numerical simulations for the general case of $\rho > 0$ and found that g^* is always an inverted-U function in β.

PROPOSITION 3. *Under the endogenous step size z^*, the arrival rate of innovation is decreasing in β, but the step size of innovation is increasing in β. Therefore, blocking patents generate a nonmonotonic effect on economic growth.*

4.1. Quantitative Analysis

In this section, we calibrate the model to quantify the blocking effect β of patent protection on innovation and economic growth. There are five structural parameters $\{\rho, \alpha, \mu, \varphi, \beta\}$ that are relevant to this numerical exercise. First, we set the discount rate ρ and the capital-share parameter α to their standard values of 0.04 and 0.3, respectively. Then, we use three empirical moments to calibrate the remaining three parameters. Using (10) and (22), we can express R&D expenditure as a share of GDP as

$$S_r \equiv \frac{WL_r}{Y} = \left(\frac{\mu-1}{\mu}\right)\left[(1-s^*) + \left(\frac{\lambda^*}{\rho+\lambda^*}\right)s^*\right]\frac{\lambda^*}{\rho+\lambda^*}, \qquad \textbf{(36)}$$

where s^* is given by (20). In the United States, S_r is about 0.025. Then, we use (24) to set the arrival rate of innovation to a standard range of values given by $\lambda^* \in \{0.1, 0.2, 0.3\}$. Finally, we use (28) to set the growth rate g^* of total factor productivity (TFP) to a standard value of 0.015 for the U.S. economy. These three empirical moments pin down the values of μ, φ, β, respectively. Table 1 presents the calibrated values of these structural parameters, the equilibrium step size z^*, and the equilibrium profit-division rule s^*. The large values of s^* in Table 1 imply a significant effect of blocking patents, which is consistent with the case studies analyzed in Jaffe and Lerner (2004).

Given these calibrated parameter values, we perform a counterfactual exercise by increasing β to examine whether strengthening the blocking effect of patent

TABLE 1. Calibration

λ^*	β	φ	μ	z^*	s^*
0.10	0.90	3.22	1.05	1.16	0.78
0.20	0.92	6.04	1.04	1.08	0.86
0.30	0.94	8.87	1.03	1.05	0.89

protection would increase or decrease economic growth. The result is reported in Figures 2a–2c.

In Figures 2a–2c, we see that the values of $\beta \in \{0.90, 0.92, 0.94\}$ are all on the upward-sloping side of the inverted U, and this finding is robust to varying the parameter values within a reasonable range. In our sensitivity analysis, we find that β is on the downward-sloping side of the inverted U only when we consider an extremely low arrival rate λ^* of less than 0.05, which implies an expected duration between innovation arrivals of more than 20 years. Although the literature does not provide a precise estimate for λ^*, the expected duration between innovation arrivals should be less than 20 years. Therefore, we conclude that a marginal increase in the blocking effect of patent protection is likely to enhance economic growth in a calibrated R&D-based growth model that features the escape-infringement effect arising from an endogenous step size of innovation. The intuition is as follows. From (28), $\lambda^* = g^*/\ln z^*$; therefore, for a given TFP growth rate g^*, a lower arrival rate λ^* of innovation must be accompanied by a larger step size z^*. For a given L_r,[11] the TFP growth rate $g^* = \varphi L_r(\ln z^*)/z^*$ is an inverted-U function in z^*. Consequently, for a sufficiently large z^*, any further increase in z^*, which is increasing in β, causes the growth rate to fall.

5. CONCLUSION

In this note, we have analyzed the effects of different patent instruments on innovation and economic growth. We find that whether stronger patent rights stimulate or stifle innovation depends on the underlying patent instrument. Whereas patent breadth has a positive effect on innovation, blocking patents generate a negative effect on innovation under an exogenous step size of innovation. However, the effect of blocking patents on innovation and economic growth becomes nonmonotonic once we allow for an endogenous step size of innovation, and this nonmonotonic effect of patent rights on innovation is consistent with the findings of recent empirical studies. Finally, we find that a marginal increase in the blocking effect of patent protection is likely to stimulate economic growth in a calibrated R&D-based growth model.

NOTES

1. Horowitz and Lai (1996) show that extending the term of patent increases the size of innovation but delays the introduction of subsequent innovations. Although our model generates a similar

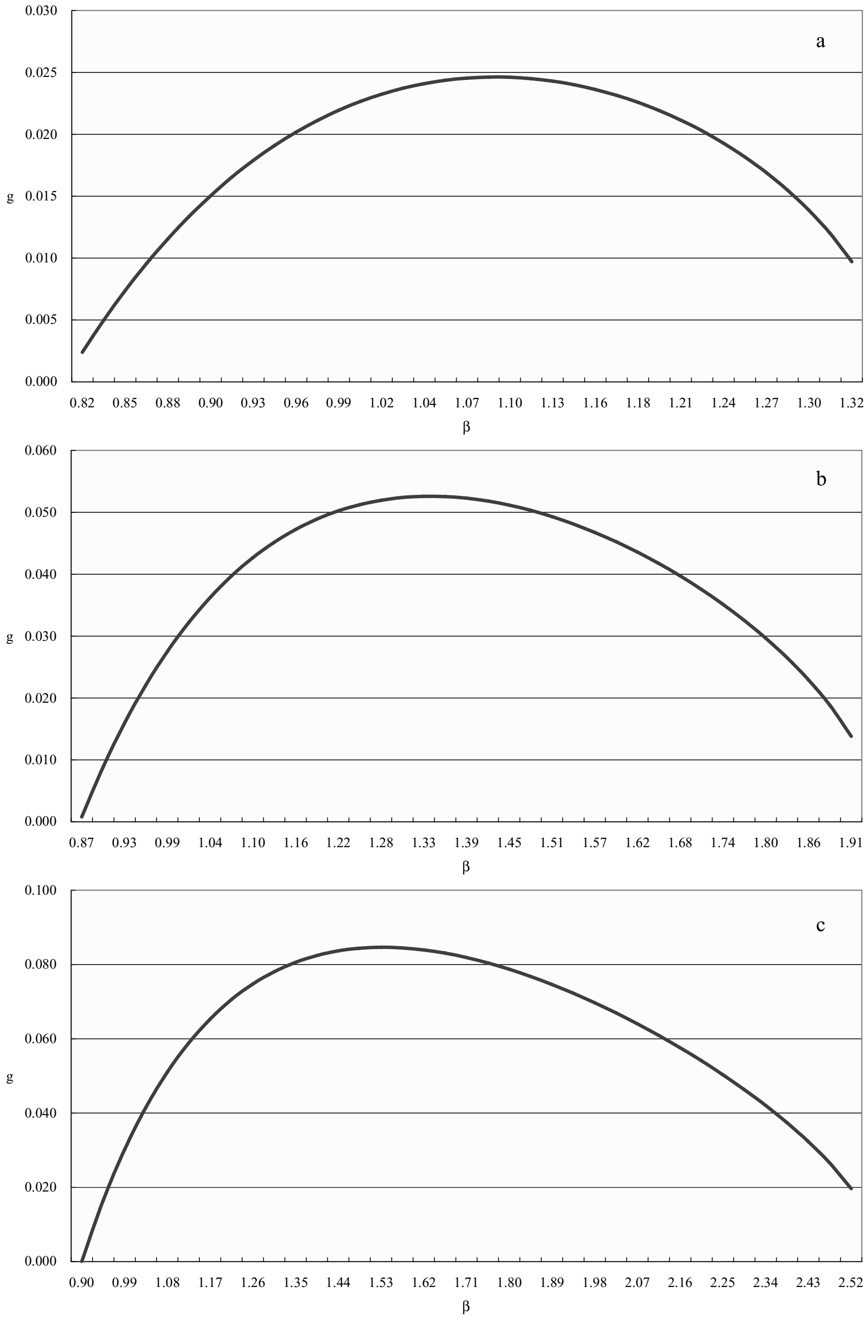

FIGURE 2. Effects of blocking patents on economic growth: (a) $\lambda = 0.1$, (b) $\lambda = 0.2$, (c) $\lambda = 0.3$.

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asymmetric effect of patent rights on the size and frequency of innovation, the underlying mechanism (i.e., overlapping patent rights and the escape-infringement effect) in our model is very different from that of Horowitz and Lai (1996).

2. See also Segerstrom et al. (1990) and Aghion and Howitt (1992) for other pioneering studies on the quality-ladder growth model.

3. For a variety-expanding R&D-based growth model with both physical capital and human capital, see Arnold (2000), Funke and Strulik (2000), and Sequeira (2011).

4. In this study, we focus on the standard Cobb–Douglas production function, which features a unit elasticity of substitution between capital and labor. For a recent study on how a nonunitary elasticity of substitution may affect long-run economic growth, see for example Palivos and Karagiannis (2010).

5. See Cozzi (2007) for an interesting discussion of the Arrow effect.

6. We follow the standard approach in the literature to focus on the symmetric equilibrium. See Cozzi et al. (2007) for a theoretical justification for the symmetric equilibrium as the unique rational-expectations equilibrium in the quality-ladder model.

7. It is useful to note that consumption, output, and profit all grow at the same rate on the balanced growth path.

8. It is useful to note that the s in V_2 is not chosen by the entrepreneur, but by the next innovator.

9. It is useful to note that $\beta > 1$ is not neccesary for Condition B to hold, given $\rho > 0$.

10. See Samaniego (2007) for an interesting discussion of the link between R&D and TFP growth.

11. It is useful to note that equilibrium R&D labor L_r is largely pinned down by the empirical moment $S_r = [(1-\alpha)/\mu][L_r/(1-L_r)]$.

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