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Abstract

This paper shows in an endogenous growth model without scale effects that the relationship between intellectual property protection and innovation can be invreted U-shaped, consistent with recent evidence. The inverted-U relationship emerges from an interaction between learning-driven and R&D-driven technological advances.

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Keywords: Growth; intellecual property rights; innovation; learning by doing; scale effect

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1 Introduction

The relationship between intellectual property protection and innovation at the firm level or aggregate level has been a central issue in the growth literature: see Park (2008) for a review. Recently, Qian (2007) and Lerner (2009) reported novel empirical evidence that enhancing intellectual property rights (IPR) protection reduces innovation activities when IPR protection is already strong. This suggests that the relationship between IPR protection and innovation is shaped like an *inverted U*. Although this fact may be explained using existing models,[1] many of the earlier models exhibit the well-known scale effect: more R&D labor should induce more total factor productivity growth.[2] The existence of this relationship in real economic data has been effectively refuted by the enormously influential papers of Jones (1995a; 1995b).

This paper develops an endogenous growth model without scale effects that also explains the inverted-U relationship between IPR protection and innovation. I demonstrate that innovation and learning, two engines of growth, interact with each other to generate the inverted-U relationship and eliminate the scale effect. Put simply, although stronger IPR protection directly increases the incentive to innovate, it also discourages innovation in the long run by suppressing the process of "learning by doing." The rate of innovation, which is independent of labor size, is therefore a unimodal function of IPR strength. This fact has an immediate policy implication: both very strong and very weak IPR policies decrease innovation, so a moderate approach is preferable.

2 The Model

I consider a dynamic general equilibrium model with two engines of growth: innovation and learning. There is a single final good (numeraire), which includes

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[1] See Cadot and Lippman (1995), Horowitz and Lai (1996), O'Donoghue and Zweimuller (2004), Furukawa (2007), Horii and Iwaisako (2007), and Akiyama and Furukawa (2009). Chu (2009) provides a quantitative analysis.

[2] The model by Horowitz and Lai (1997) does not *explicitly* exhibit the scale effect, since it is a partial equilibrium model. But, it will have the scale effect if genral equilibrium is considered in their model. O'Donoghue and Zweimuller (2004) also presented a scale-free version of their model, but did not formally demonstrate an inverted-U relationship between IPR and innovation in this context.

both consumption and capital goods. Competitive firms produce Y_t units of the final good by hiring L workers and using a variety N_t of differentiated intermediate goods. All firms use the identical production function:

$$Y_t = (S_t L)^{1-\alpha} \int_0^{N_t} x_t(j)^\alpha, \;\; \alpha \in (0,1), \tag{1}$$

where S_t is the per capita level of skill for each worker to use intermediate goods and $x_t(j)$ is the amount of jth intermediate good. The *effective* labor supply H_t is per capita skill level S_t times population of workers L: $H_t = S_t L$. I refer to H_t as "human capital."

2.1 Technological Progress: R&D and Learning by Doing

The economy grows endogenously due to two forms of technological progress. The first growth engine is R&D. An R&D firm innovates a new differentiated intermediate good by investing b units of the final good, earning a monopolistic rent π_t.[3] This rent continues for several dates until the firm's idea is imitated, at which point a perfect copy can be supplied by competitive firms. Define $R_t = \int_0^t r(t)dt$, where $r(t)$ represents the interest rate at date t. The value of an innovation is:

$$V_t = \int_t^\infty e^{-(R_\tau - R_t) - \phi^{-1}\tau} \pi_\tau dt, \tag{2}$$

where ϕ^{-1} represents the hazard rate of imitation. This implies $\dot{N}_t^C = \phi^{-1}(N_t - N_t^C)$, where N_t^C is the number of imitated intermediate goods. I interpret the inverse of the imitation rate, ϕ, as *the strength of IPR protection.*[4]

Learning by doing is the second engine of growth. When workers use a larger amount of intermediate goods, they improve their skill at using intermediate goods. This paper offers a dynamic formulation of learning by doing.[5] Accordingly, cumulative human capital $H_t(= S_t L)$ is defined as a weighted sum of the

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[3] See Romer (1990) and Rivera-Batiz and Romer (1991) for variety-expanding R&D. See Grossman and Helpman (1991) and Aghion and Howitt (1992, 1998) for quality-improving R&D.

[4] This definition captures patent breadth; see Helpman (1993), Eaton and Kortum (1999), and Kwan and Lai (2002). Futagami and Iwaisako (2007) cover the patent length approach. Broadly, my approach applies Yano's (2008, 2009) market quality theory to a dynamic analysis of IPR.

[5] My dynamic approach follows that of Furukawa (2007), in turn akin to Arrow's (1962) original formation. See Romer (1986) for a static setting with learning by doing.

investment in intermediate goods up to date t:

$$H_t = \hat{\theta} \int_{-\infty}^{t} e^{-\theta(t-\tau)} \left(\frac{X_\tau}{N_\tau} \right)^{\psi} d\tau, \quad \psi > 0,\ \hat{\theta} > 0. \tag{3}$$

Here $X_\tau = \int_0^{N_\tau} x_\tau(j)dj$ is the aggregate use of intermediate goods, and θ is the depreciation rate for human capital.[6] Equation (3) captures the idea that on average, when more intermediate goods are used in final production (larger $\frac{X_\tau}{N_\tau}$), the learning effect for workers (captured by H_t) is larger. I assume decreasing returns to scale, $\psi < 1$, to eliminate the scale effect.

2.2 Dynamic Equilibrium

The representative consumer inelastically supplies L units of labor and maximizes $U = \int_0^\infty e^{-\rho t} \ln C_t dt$, $\rho > 0$. The model can be closed by free entry to R&D, $V_t \leq b$, and market clearing, $Y_t = C_t + X_t + b\dot{N}_t$.

In a balanced growth path (BGP), N_t, N_t^C, H_t, Y_t, and C_t all grow at the same rate g^*. This g^* stands for the growth rate of innovation. Denote by n^* the BGP values of the fraction of competitive sectors, $n_t \equiv \frac{N_t^C}{N_t}$, and by H_t the BGP value of H_t. Define $\hat{\phi} \equiv (b^{-1}\alpha^{\frac{1+\alpha-\alpha\psi}{(1-\alpha)(1-\psi)}}(1-\alpha) - \rho)^{-1}$. The following theorem characterizes the dynamic equilibrium. Proofs and details appear in Furukawa (2010).

Theorem 1 *If and only if $\phi > \hat{\phi} > 0$, the BGP uniquely exists. It is saddle-path stable, and characterized by three stationarity conditions. Innovation-consumption market stationarity, $\frac{\dot{N}}{N} = \frac{\dot{C}}{C}$, yields*

$$H^* = b\alpha^{-\frac{1+\alpha}{1-\alpha}}(1-\alpha)^{-1}\left(g^* + \phi^{-1} + \rho\right); \tag{4}$$

human capital accumulation stationarity, $\frac{\dot{H}}{H} = 0$, yields

$$H^* = \alpha^{\frac{1}{1-\alpha}\frac{\psi}{1-\psi}} \left((1 - \alpha^{\frac{1}{1-\alpha}})n^* + \alpha^{\frac{1}{1-\alpha}} \right)^{\frac{\psi}{1-\psi}}; \tag{5}$$

and innovation-imitation stationarity, $\frac{\dot{N}}{N} = \frac{\dot{N}^C}{N^C}$, yields

$$n^* = \frac{1}{\phi g^* + 1}. \tag{6}$$

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[6] Without any loss of generality (see Furukawa, 2010), I can normalize such that $\hat{\theta} = \theta$.

Theorem 1 reveals that the model is a "fully" endogenous growth model without scale effects.[7] Long-run economic growth has economic determinants such as the policies and technologies that affect innovation and learning (in this context the parameters ϕ, b, or ψ). However, the BGP conditions (4)–(6) do *not* depend on the population L.

Figure 1 depicts market stationarity (4) as line ι, and human capital accumulation stationarity (5) with (6) as curve η. Line ι is upward sloping, so the *cumulative* human capital encourages innovation as usual. Curve η is downward sloping, meaning that innovation discourages human capital *accumulation*. This relationship can be understood in the following sense. As more goods are innovated (higher g^*), the fraction of monopolistic goods increases (n^* decreases). Increased monopoly typically depresses human capital accumulation, for the reason explained below.

Remark 1 (Monopoly Depresses Human Capital Accumulation) *As the fraction of monopoly goods increases (n^* decreases), the average use of intermediate goods by workers decreases ($\frac{X}{N}$ decreases). This trend occurs because a monopolistic good's supply is smaller than a competitive good's supply, due to monopoly pricing. If the average use of intermediate goods decreases, then workers acquire less skills (learning by doing) and the rate of human capital accumulation decreases. Thus, H^* decreases as n^* decreases: $\frac{\partial H^*}{\partial n^*} > 0$.*

To summarize, Figure 1 shows the interaction between H^* and g^*. *Cumulative* human capital encourages innovation (line ι), while innovation discourages human capital *accumulation* (curve η). In Section 3, I demonstrate that this interaction can generate an inverted-U relationship between IPR and innovation.

3 IPR and Innovation

This section investigates the consequences of tightening IPR protection, represented in this model by increasing ϕ.

An increase in ϕ negatively affects the human capital stock, H^* for the following reason. Stronger IPR protection directly decreases imitation, increasing the

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[7] See Aghion and Howitt (1998), Dinopoulos and Thompson (1998), Peretto (1998), Howitt (1999), and Peretto and Smulders (2002), and Ha and Howitt (2008).

fraction of monopolistic sectors. As shown in Remark 1, increased monopoly discourages human capital accumulation by diminishing the effectiveness of learning by doing, whence the decrease in H^*. The effect of increasing ϕ is therefore a downward shift in curve η of Figure 1.

Stronger IPR protection also increases the expected benefit of innovation, Thus, for a given value of g^*, H^* must decrease as ϕ increases to maintain the benefit at its original level (the cost-benefit balance $V = b$). This is represented by a downward shift of line ι. Then,

Remark 2 *Tightening IPR protection decreases human capital stock;* $\frac{\partial H^*}{\partial \phi} < 0$.

Finally, I will investigate the effect of increasing ϕ on the rate of innovation g^*. Because both line ι and curve η shift downward, the effect on g^* seems to be ambiguous. On the one hand, the downward shift of line ι implies increasing g^* (at fixed H^*). This effect captures the intuition that stronger IPR protection decreases imitation and increases the value of innovation V_t. On the other hand, the downward shift of curve η implies a lower rate of innovation g^*. This negative effect stems from Remark 2: stronger IPR protection decreases the human capital stock H^*, lowering the demand for intermediate goods and the monopolistic profit π. This results in a *decrease* in g^*.

The effect of strengthening IPR protection on innovation therefore depends on whether the positive effect or negative effect dominates. I can formally show that these opposing effects interact to generate an inverted U-shaped relationship between IPR and innovation (see Furukawa, 2010).

Proposition 1 *There is an inverted-U relationship between the strength of IPR protection and the rate of innovation if and only if*

$$b > \alpha^{\frac{2\psi}{(1-\alpha)(1-\psi)}}(1-\alpha)(1-\psi\alpha^{-\frac{1}{1-\alpha}})/\rho\,(1-\psi)\,. \tag{7}$$

Otherwise, the relationship is globally upward sloping.

As shown in Figure 2, Proposition 1 implies that a moderate level of IPR protection, say ϕ^*, maximizes the rate of innovation when the cost of innovation (b) is large enough to satisfy (7). Only when the cost of innovation is small enough to violate (7) does strengthening IPR protection always increase the rate of innovation. Proposition 1 has the following policy implication: *A desirable IPR* *policy varies according to the start-up cost of innovation. When the cost is reasonably high, very strong and very weak IPR policies both suppress innovation; a moderate approach is desirable*.[8]

The inverted-U relationship between IPR and innovation is new to the literature on endogenous growth models *without* scale effects, although it has empirical backing and is common among models *with* scale effects. The novelty of this study is that the inverted-U can also appear in a more conventional, scale-invariant framework.

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[8] This is in line with Bessen and Maskin' (2009) finding.

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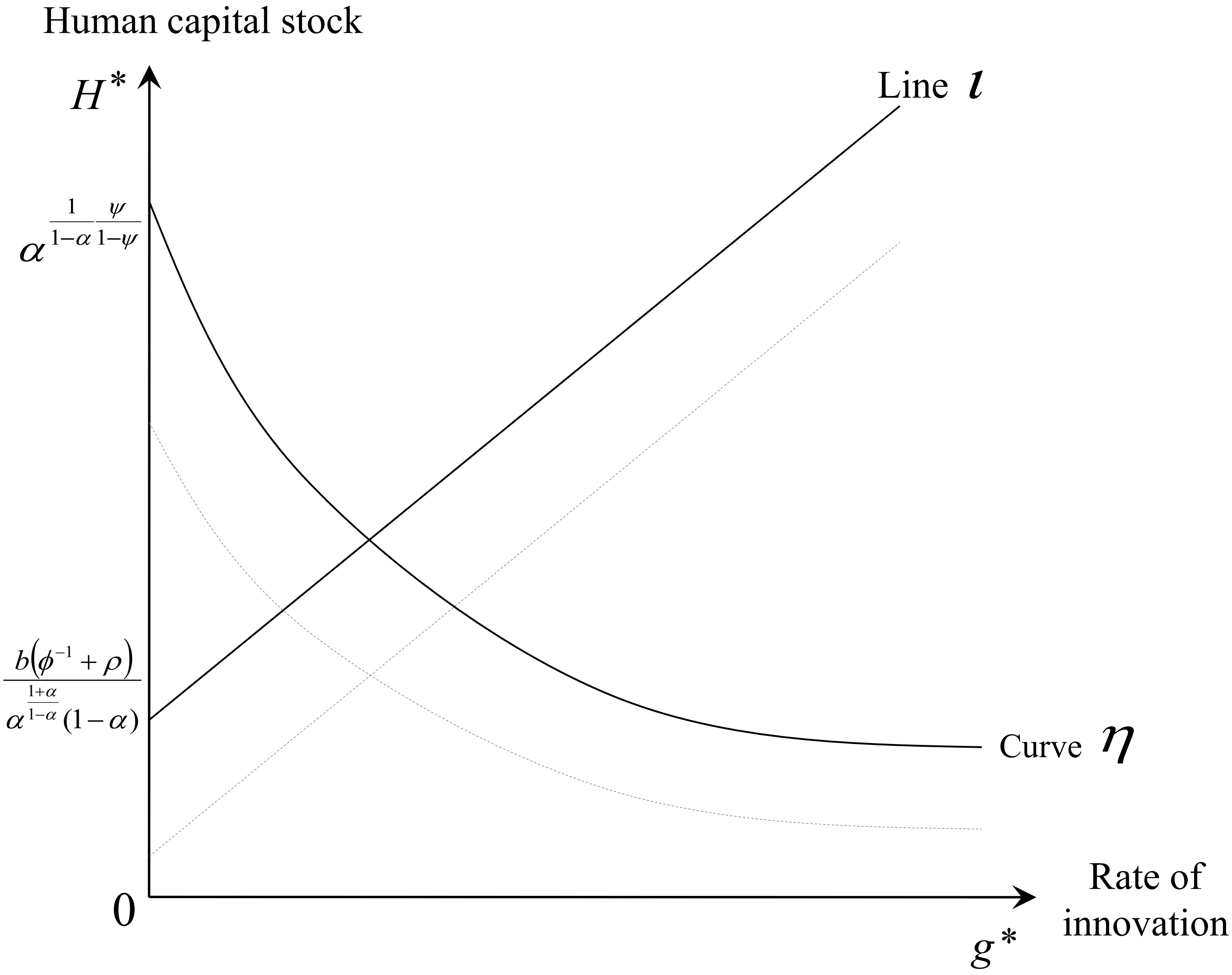

Figure 1: Equilibrium of *g* and *H*

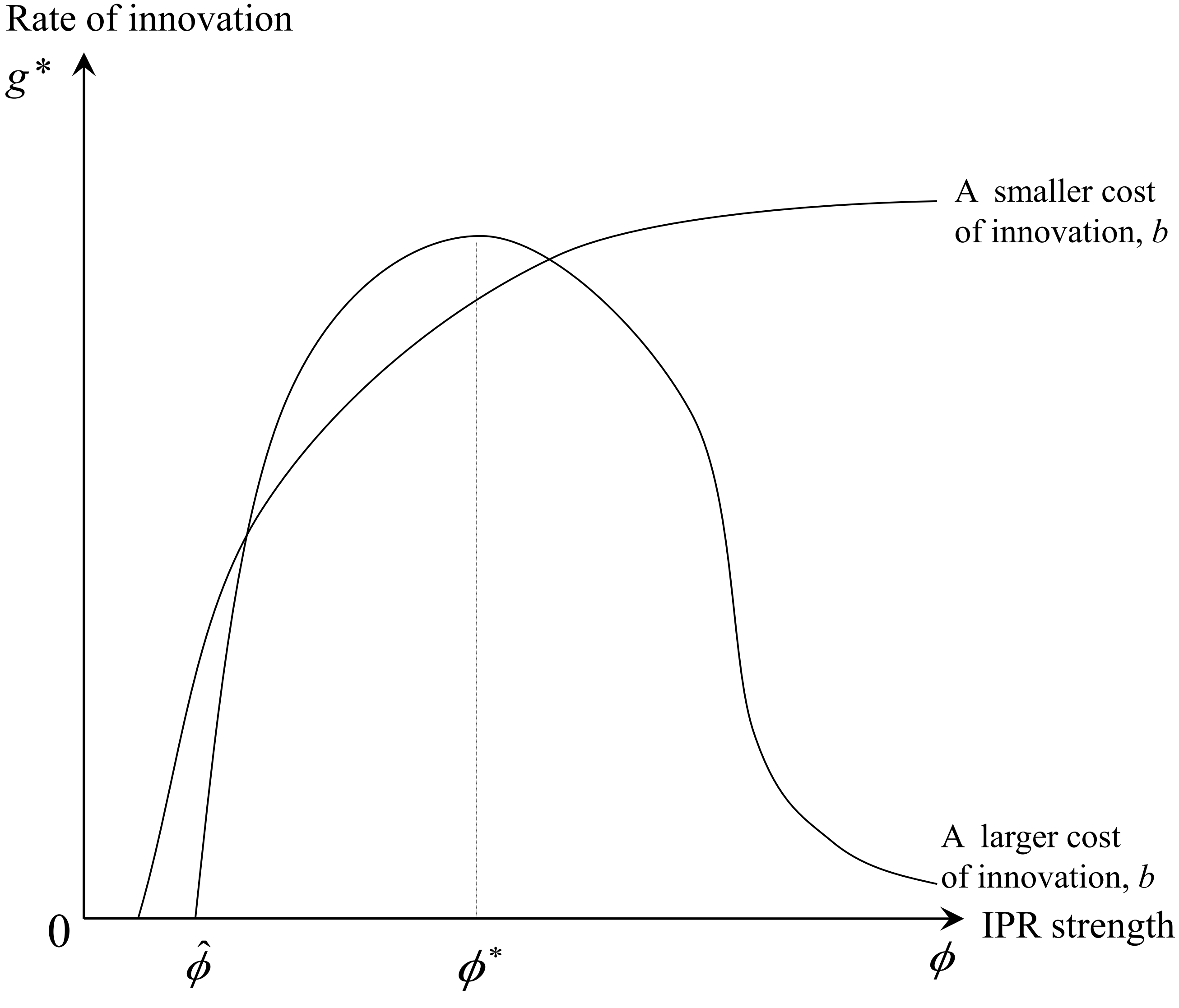

Figure 2: IPR and Innovation