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Abstract

In this note, we analyze the effects of intellectual property rights on the volatility of economic growth. Our analysis is motivated by the observation that the strengthening of patent protection and the increase in R&D in the US coincide with a reduction in growth volatility beginning in the mid 1980's. To analyze this phenomenon, we develop an R&D-based growth model with aggregate uncertainty in the innovation process and apply the model to ask whether increasing patent strength and R&D can lead to a significant reduction in growth volatility. We find a small but non-negligible effect that explains no less than 10% of the observed reduction in growth volatility in the US.

Keywords**:** Economic growth; Intellectual property rights; Growth volatility

JEL classification**:** O33, O34, E32

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Abstract

In this note, we analyze the effects of intellectual property rights on the volatility of economic growth. Our analysis is motivated by the observation that the strengthening of patent protection and the increase in R&D in the US coincide with a reduction in growth volatility beginning in the mid 1980's. To analyze this phenomenon, we develop an R&D-based growth model with aggregate uncertainty in the innovation process and apply the model to ask whether increasing patent strength and R&D can lead to a significant reduction in growth volatility. We find a small but non-negligible effect that explains no less than 10% of the observed reduction in growth volatility in the US.

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1. Introduction

In the early 1980's, the strength of patent rights gradually increased in the US. For example, the Ginarte-Park index of patent rights increased from 3.83 in 1975 to 4.88 in 1995.[1] After this patent reform, private R&D expenditure as a percentage of gross domestic product (GDP) in the US increased from 1.2% in 1980 to an average of 2.5% in recent time. Cross-country empirical studies, such as Varsakelis (2001), Kanwar and Evenson (2003) and Park (2005), employ the Ginarte-Park index to examine the effects of patent strength on R&D and innovation, and they generally find a positive and significant effect.[2] As for the effects of technical progress on the volatility of economic growth, empirical studies, such as Tang (2002) and Tang *et al.* (2008), generally find a negative effect; in other words, technical progress reduces growth volatility.

In this note, we analyze the effects of patent policy on the volatility of economic growth through technical progress. Our analysis is motivated by the observation that the strengthening of patent rights and the increase in R&D in the US coincide with a reduction in growth volatility beginning in the mid 1980's. To explore this issue, we develop an R&D-based growth model with aggregate uncertainty in the innovation process and apply the model to ask whether the strengthening of patent rights and the increase in R&D in the US can lead to a quantitatively significant reduction in growth volatility.

[*Insert Figure 1 about here*]

Figure 1 presents the US time series of growth volatility measured by the coefficient of variation of annual growth in real GDP per capita and shows a well-known pattern that volatility

[1] The Ginarte-Park index is on a scale of 0 to 5, and a larger number indicates stronger patent rights. See Ginarte and Park (1997) and Park (2008a) for a detailed discussion on the construction of this patent index.
[2] See for example Park (2008b) for a survey of this empirical literature.

of economic growth in the US fell overtime until the recent crisis.[3] Specifically, the coefficient of variation decreased from 1.4 in the mid 1980's to 0.78 in 2007. In the numerical analysis, we calibrate the R&D-based growth model to quantify the fraction of this volatility reduction that can be explained by the increase in R&D and the strengthening of patent protection in the US. In summary, we find a small but non-negligible effect that explains no less than 10% of the observed reduction in growth volatility in the US.

Our study relates to the theoretical literature on growth and volatility. Greenwood and Jovanovic (1990) and Acemoglu and Zilibotti (1997) analyze the effect of financial development on volatility and find that financial development can reduce aggregate volatility through financial diversification across firms. Koren and Tenreyro (2007a,b) consider technological diversification instead of financial diversification and show that technological progress improves diversification by increasing the number of input varieties that are subject to imperfectly correlated shocks. Leung *et al.* (2006) show that rent-seeking behaviors can also give rise to a negative effect of technical progress on growth volatility. Taking the negative growth-volatility relationship as a basic premise that is supported by empirical evidence,[4] our study relates to this literature by showing that patent policy can be a useful policy instrument for reducing growth volatility.

This study also relates to the literature on patent policy and economic growth. In this literature, one branch of studies analyzes the effects of patent length on growth,[5] whereas another branch analyzes the growth effects of other patent levers, such as patent breadth, patentability

[3] The coefficient of variation is the ratio of the standard deviation to the mean. This scale-invariant index is an appropriate measure for growth volatility because it is not affected by changes in the average growth rate overtime.
[4] See for example Ramey and Ramey (1995), Aghion and Banerjee (2005), Tang (2002) and Tang *et al.* (2008).
[5] See for example Judd (1985), Horowitz and Lai (1996), Iwaisako and Futagami (2003), Futagami and Iwaisako (2007), Chu (2010a), Chen and Iyigun (2011) and Fung *et al.* (2012).

requirement, intellectual appropriability, protection against imitation, and blocking patents.[6] Our paper complements these studies by providing a novel growth-theoretic analysis on the effects of patent policy on the volatility of economic growth.

The rest of this note is organized as follows. Section 2 describes the model. Section 3 defines the equilibrium. Section 4 analyzes the effects of patent policy on growth volatility. The final section concludes with a discussion of the model.

2. The model

To provide a theoretical analysis on patent protection and growth volatility, we consider the quality-ladder growth model in Grossman and Helpman (1991). Specifically, we incorporate into the model mainly two features (a) patent breadth as in Li (2001) and (b) aggregate uncertainty in the innovation process. Given that the quality-ladder model has been well-studied, the familiar components of the model will be briefly described to conserve space while the new features will be described in more details below.

We consider a discrete-time model. At the beginning of each period, the accumulated level of aggregate technology is determined by R&D in previous periods. Given this level of aggregate technology for production, households supply labor while production firms and R&D entrepreneurs hire workers. At this stage, the R&D entrepreneurs hire workers based on their expected productivity for innovation. After final goods are produced, households consume the output. Finally, R&D productivity is realized, and the inventions created in this period contribute to the level of aggregate technology in the next period.

[6] See for example Cozzi (2001), Li (2001), Kwan and Lai (2003), O'Donoghue and Zweimuller (2004), Cozzi and Spinesi (2006), Horii and Iwaisako (2007), Furukawa (2007, 2010), Chu (2009, 2010b, 2011), Chu and Furukawa (2011), Chu and Pan (2012), Chu and Peng (2011), Iwaisako and Futagami (2012), Sorek (2011) and Spinesi (2011).

2.1. Households

There is a unit continuum of identical households, who have a life-time utility function given by

$$(1) \qquad U_0 = E_0\left[\sum_{t=0}^{\infty} \frac{\ln c_t}{(1+\rho)^t}\right],$$

where $\rho > 0$ is the discount rate and c_t is consumption at time *t*. Each household maximizes (1) subject to a sequence of budget constraints given by $a_{t+1} = (1+r_t)a_t + w_t - c_t$, where a_t is a state-contingent asset owned by households and r_t is the rate of return. Each household inelastically supplies one unit of labor to earn a wage income w_t. The familiar Euler equation is

$$(2) \qquad \frac{1}{c_t} = \frac{1}{1+\rho} E_t\left[\frac{1+r_{t+1}}{c_{t+1}}\right].$$

We use $\Omega_{t+1} \equiv c_t / [c_{t+1}(1+\rho)]$ to denote the stochastic discount factor.

2.2. Final goods

Final goods y_t for consumption are produced by a standard Cobb-Douglas aggregator over a unit continuum of differentiated intermediates goods $x_t(i)$ for $i \in [0,1]$ given by

$$(3) \qquad y_t = \exp\left(\int_0^1 \ln x_t(i) di\right).$$

This sector is perfectly competitive, and the producers take the output and input prices as given. The familiar conditional demand function is $x_t(i) = y_t / p_t(i)$, where $p_t(i)$ is the price of $x_t(i)$.

2.3. Intermediate goods

There is a continuum of industries indexed by $i \in [0,1]$ producing the differentiated intermediate goods. In each industry *i*, there is a temporary leader who holds a patent on the latest technology in the industry and dominates the market until the arrival of the next innovation. The production function for the leader in industry i is

(4) $$x_t(i) = z^{n_t(i)} l_{x,t}(i).$$

$l_{x,t}(i)$ is the number of workers in industry i. $z > 1$ is the exogenous step size of a productivity improvement. $n_t(i)$ is the number of productivity improvements that have occurred in industry i as of time t. Given $z^{n_t(i)}$, the marginal cost of production for the leader in industry i is $w_t / z^{n_t(i)}$.

As is standard in the literature, the current and former industry leaders engage in Bertrand competition,[7] and the equilibrium pricing strategy for the current industry leader is a constant markup over the marginal cost given by

(5) $$p_t(i) = \mu(z,b) w_t / z^{n_t(i)},$$

where $\mu(z,b) = z^b$ for $b \in (0,1)$ that is the level of patent breadth.[8] In Grossman and Helpman (1991), there is complete patent breadth against imitation such that $b = 1$. Li (2001) generalizes the policy environment to allow for incomplete patent breadth $b \in (0,1)$ against imitation. Due to incomplete patent protection, the former industry leader's productivity increases by a factor z^{1-b} (i.e., her productivity becomes $z^{1-b} z^{n_t(i)-1} = z^{n_t(i)-b}$) by imitating the current leader's innovation. Therefore, the limit-pricing markup for the current industry leader is $z^b \in (1, z)$. For the rest of this study, we denote patent protection as $\mu \equiv \mu(z,b)$ and consider changes in μ coming from changes in patent breadth b only. A larger patent breadth increases μ and monopolistic profit.

[7] See Cozzi (2007) for an interesting discussion on the Arrow replacement effect.

[8] The level of patent breadth b can also be interpreted as the fraction of an invention that is protected by its patent. In reality, when an inventor applies for a patent to protect her invention, she makes a number of patent claims to be reviewed by a patent examiner. If the patent claims are too narrow or too specific, imitators may be able to imitate around them to avoid patent infringement.

2.4. R&D

There is a unit continuum of R&D entrepreneurs indexed by $j \in [0,1]$. In each period *t*, they hire workers to create inventions to be implemented at time $t+1$. Entrepreneur *j*'s probability of successfully creating an invention is given by $\lambda_t(j) = \overline{\varphi}_t l_{r,t}(j)$, where $\overline{\varphi}_t$ denotes aggregate R&D productivity that is stochastic. To capture aggregate uncertainty in the innovation process in a tractable way, we assume that $\overline{\varphi}_t$ follows a Bernoulli distribution. With probability $p \in (0,1)$, a good state happens at time *t* such that $\overline{\varphi}_t = \varphi_{g,t}$. With probability $1-p$, a bad state happens such that $\overline{\varphi}_t = \varphi_{b,t} < \varphi_{g,t}$.

To capture the volatility-reducing effect of technical progress, we follow Leung *et al.* (2006) to assume that

(6) $$\varphi_{g,t} = G(l_{r,t})\varphi,$$

(7) $$\varphi_{b,t} = B(l_{r,t})\varphi,$$

where $l_{r,t} \equiv \int l_{r,t}(j)dj$ is aggregate R&D labor, and the parameter φ captures R&D productivity. The spillover functions $G(.)$ and $B(.)$ in the good and bad states have the following properties: (a) $G'(.), B'(.) > 0$, (b) $G''(.), B''(.) \le 0$, and finally (c) $G(l_{r,t}) > B(l_{r,t})$ for any value of $l_{r,t} \in (0,1)$. The formulation in (6) and (7) introduces a positive R&D spillover effect into the model. The presence of positive R&D spillovers across firms is supported by empirical studies such as Jaffe (1986), Bernstein and Nadiri (1988, 1989) and Los and Verspagen (2000).[9] For example, Jaffe (1986) estimates the elasticity of patents with respect to other firms' R&D to be about 1.1 for an

[9] On the one hand, the R&D-based growth literature usually assumes a negative intratemporal R&D spillover across firms to capture the patent-race and duplication effects; see, for example, Kortum (1993) and Jones (1995). On the other hand, motivated by the empirical evidence cited here, theoretical studies on R&D cooperation have long considered positive spillovers in partial-equilibrium models. Early studies in this literature include D'Aspremont and Jacquemin (1988) and Kamien *et al.* (1992). See Chen and Chu (2010) for a general-equilibrium analysis of positive R&D spillovers in a quality-ladder growth model without aggregate uncertainty in the innovation process.

average R&D firm. To preview of our result, we will show that if and only if the spillover effect in the bad state is stronger than in the good state, then increasing R&D would reduce the volatility of economic growth. Because R&D also stimulates technical progress, this scenario is consistent with the empirical evidence for a negative growth-volatility relationship discussed in the introduction.

Let $v_t(i)$ denote the market value of the invention owned by the leader in industry i at time t (before the realization of R&D productivity). Due to the Cobb-Douglas specification in (3), the amount of flow profit is the same across industries (i.e. $\pi_{x,t}(i) = \pi_{x,t}$ for $i \in [0,1]$). As a result, $v_t(i) = v_t$ for $i \in [0,1]$ in a symmetric equilibrium that features an equal arrival rate of innovation across industries.[10] The no-arbitrage condition for v_t is

(8) $$v_t = \pi_{x,t} + E_t[(1-\lambda_t)\Omega_{t+1}v_{t+1}].$$

Equation (8) states that the asset value v_t is equal to the sum of the flow profit captured by this asset at time t and the expected present value of the asset at time $t+1$. λ_t is the probability (after the realization of R&D productivity at time t) that the next innovation occurs and takes away the market at time $t+1$.

Given the above setup, the expected productivity of R&D labor is

(9) $$\varphi_t^e \equiv E_t[\overline{\varphi}_t] = \varphi[pG(l_{r,t}) + (1-p)B(l_{r,t})].$$

The expected arrival rate of innovation for entrepreneur j is

(10) $$\lambda_t^e(j) \equiv E_t[\lambda_t(j)] = \varphi_t^e l_{r,t}(j).$$

The expected profit for R&D entrepreneur j is

[10] 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 in the quality-ladder growth model.

(11) $$\pi^{e}_{r,t}(j) = E_t[\Omega_{t+1} v_{t+1} \overline{\varphi}_t] l_{r,t}(j) - w_t l_{r,t}(j) .$$

The free-entry condition in the R&D sector leads to zero expected profit such that

(12) $$E_t[\Omega_{t+1} v_{t+1} \overline{\varphi}_t] = w_t .$$

This condition determines the allocation of labor between production and R&D.

3. Decentralized equilibrium

This section defines the equilibrium. The equilibrium is a sequence of prices $\{w_t, r_t, p_t(i)\}_{t=0}^{\infty}$ and a sequence of allocations $\{c_t, y_t, x_t(i), l_{x,t}(i), l_{r,t}(j)\}_{t=0}^{\infty}$. Also, in each period,

a. households choose $\{c_t\}$ to maximize (1) subject to the budget constraints taking $\{w_t, r_t\}$ as given;
b. competitive final-goods firms produce $\{y_t\}$ to maximize profit taking $\{p_t(i)\}$ as given;
c. industry leader $i \in [0,1]$ produces $\{x_t(i)\}$ and chooses $\{p_t(i), l_{x,t}(i)\}$ to maximize profit subject to the Bertrand competition taking $\{w_t\}$ as given;
d. entrepreneur $j \in [0,1]$ chooses $\{l_{r,t}(j)\}$ to maximize expected profit taking $\{w_t\}$ as given;
e. the market for final goods clears such that $c_t = y_t$;
f. the labor market clears such that $l_{x,t} + l_{r,t} = 1$.

Following the standard approach in the literature, we consider the equilibrium in which the labor allocation is stationary (i.e., $l_{x,t} = l_x$ and $l_{r,t} = l_r$ for all *t*). Although the labor allocation is stationary, the economy grows along a stochastic growth path (due to aggregate uncertainty in the innovation process) rather than the usual balanced growth path. Using recursive substitution on (8), the value of an invention becomes

(13) $$v_t = \pi_{x,t} + \sum_{h=1}^{\infty} E_t\left[\prod_{k=1}^{h}(1-\lambda_{t+k-1})\Omega_{t+k}\pi_{x,t+h}\right] = \pi_{x,t}\left(1+\sum_{h=1}^{\infty}\left(\frac{1-\lambda^e}{1+\rho}\right)^h\right).$$

The second equality of (13) makes use of the following conditions. The profit share of output is $\pi_{x,t} = c_t(\mu-1)/\mu$, so that $\pi_{x,t+h}/\pi_{x,t} = c_{t+h}/c_t$. Combining this condition with the stochastic discount factor implies $\prod_{k=1}^{h}\Omega_{t+k}\pi_{x,t+h} = \pi_{x,t}/(1+\rho)^h$. As for $E_t\left[\prod_{k=1}^{h}(1-\lambda_{t+k-1})\right]$, it can be shown that it conveniently simplifies to $(1-\lambda^e)^h$, where $\lambda_t^e = \lambda^e = \varphi^e l_r$ for all *t*. Then, (13) simplifies to $v_t = \pi_{x,t}(1+\rho)/(\rho+\lambda^e)$. Combining this condition and the stochastic discount factor yields

(14) $$E_t[\Omega_{t+1}v_{t+1}] = \pi_{x,t}/(\rho+\lambda^e).$$

The production labor share is $w_t l_x = c_t/\mu$. Substituting these conditions into (12) yields

(15) $$(\mu-1)l_x = l_r + \rho/\varphi^e.$$

Lemma 1 presents the condition that determines the equilibrium allocation of R&D labor.

Lemma 1: *The equilibrium allocation of R&D labor is determined by*

(16) $$(\mu-1)(1-l_r) = l_r + \frac{\rho/\varphi}{pG(l_r)+(1-p)B(l_r)}.$$

Proof: Combine (9), (15) and the labor-market clearing condition $l_x + l_r = 1$.□

For the special case in which $G(l_r) = B(l_r) = 1$ for all values of l_r (i.e., no spillovers), (16) simplifies to the equilibrium allocation of R&D labor in the original Grossman-Helpman (1991) model. To ensure that equilibrium R&D labor is non-negative, we impose the following lower bound on the R&D productivity parameter φ.

Condition R (R&D productivity): $\varphi > \dfrac{\rho/(\mu-1)}{pG(0)+(1-p)B(0)}$.

This condition, which implies that the left-hand side (LHS) of (16) is strictly greater than the right-hand side (RHS) of (16) at $l_r = 0$, together with the fact that LHS < RHS at $l_r = 1$ ensures the existence of at least one intersection of LHS and RHS for $l_r \in (0,1)$. LHS is decreasing in l_r while RHS could be either increasing or decreasing in l_r. If RHS is increasing in l_r for $l_r \in (0,1)$, then the solution must be unique. Even if RHS is decreasing in l_r for $l_r \in (0,1)$, Condition R is also sufficient for the solution of $l_r \in (0,1)$ to be unique given that RHS is a convex function in l_r while the LHS is linear; see Figure 2 for an illustration.[11]

[*Insert Figure 2 about here*]

The equilibrium allocation of R&D labor has the usual properties of being increasing in the R&D productivity parameter φ and decreasing in the discount rate ρ. Furthermore, either a higher probability that the good state happens or a larger patent breadth increases R&D labor by improving the incentives for R&D. Lemma 2 summarizes the positive effect of patent breadth on R&D labor.

Lemma 2: *Equilibrium R&D labor is increasing in the level of patent breadth.*

Proof: Differentiating the LHS of (16) shows that $\partial LHS / \partial \mu > 0$. Given Condition R, the unique intersection of LHS and RHS must move to the right regardless of the slope of RHS.□

[11] When Condition R fails to hold, it is possible for multiple equilibria to arise. In this case, one can show that the equilibrium with a larger R&D labor is the stable equilibrium with the same comparative statics as in Lemma 2.

4. Effects of patent breadth on growth volatility

In this section, we analyze the effects of patent breadth and R&D on the volatility of economic growth. First, we derive the expected growth rate. Due to the Cobb-Douglas production function in (3), each industry i employs an equal number of production workers. Then, substituting (4) into (3) yields $y_t = Z_t l_x$, where the level of aggregate technology is defined as

$$Z_t \equiv \exp\left(\int_0^1 n_t(i) di \ln z \right) = \exp\left(\sum_{s=0}^{t-1} \lambda_s \ln z \right). \tag{17}$$

The second equality in (17) uses the law of large numbers implying that the average number of inventions occurred across industries is equal to its expected value. Using the log approximation $\ln(1+x) \approx x$, the growth rate of technology and output at time $t+1$ is approximately equal to

$$g_{t+1} \approx \ln(Z_{t+1}/Z_t) = \lambda_t \ln z = \overline{\varphi}_t l_r \ln z. \tag{18}$$

Therefore, the expected growth rate is

$$E_t[g_{t+1}] = \varphi^e l_r \ln z = (\varphi \ln z)[pG(l_r) + (1-p)B(l_r)] l_r, \tag{19}$$

which is increasing in l_r as in the Li (2001) model without aggregate uncertainty in innovation.

Proposition 1: *A larger patent breadth increases the expected growth rate.*

Proof: From Lemma 2, l_r is increasing in μ. Then, from (19), $E_t[g_{t+1}]$ is increasing in l_r.□

Next, we derive the variance of the equilibrium growth rate given by

$$\mathrm{var}(g_{t+1}) = \mathrm{var}(\overline{\varphi}_t)(l_r \ln z)^2 = (\varphi \ln z)^2 p(1-p)[G(l_r) - B(l_r)]^2 (l_r)^2. \tag{20}$$

The coefficient of variation of the equilibrium growth rate is

$$\sigma_g \equiv \frac{\sqrt{\mathrm{var}(g_{t+1})}}{E_t[g_{t+1}]} = \left(\frac{G(l_r) - B(l_r)}{pG(l_r) + (1-p)B(l_r)} \right) \sqrt{p(1-p)}. \tag{21}$$

Equation (21) implies that an increase in l_r reduces growth volatility if and only if the following condition holds.

Condition V (volatility reduction): $B'(l_r)/B(l_r) > G'(l_r)/G(l_r)$ for any value of $l_r \in (0,1)$.

Given that the expected growth rate is monotonically increasing in l_r, Condition V must hold in order for the model to deliver the empirically observed negative relationship between technical progress and growth volatility. Therefore, we assume that Condition V holds for the rest of our analysis. Under this condition, increasing R&D mitigates the fall in R&D productivity in the bad state sufficiently to decrease the variance of $\overline{\varphi}_t$. Proposition 2 summarizes this finding.

Proposition 2: *If and only if Condition V holds, then a larger patent breadth would reduce the volatility of economic growth.*

Proof: From Lemma 2, l_r is increasing in μ. Then, differentiating σ_g in (21) shows that σ_g is decreasing in l_r if and only if Condition V holds.□

4.1. A quantitative analysis

In this section, we calibrate the model to investigate whether strengthening patent protection and increasing R&D can explain a significant fraction of the observed volatility reduction in the US. To facilitate this numerical analysis, we specify a functional form for $G(l_r) = l_r^{\gamma} + \varepsilon$ and $B(l_r) = l_r^{\beta} + \varepsilon$, where the parameters $\gamma, \beta \in (0,1)$ determine the degree of spillovers in the good and bad states, and ε is a scale parameter. There are eight structural parameters $\{\rho, b, \varphi, z, p, \beta, \gamma, \varepsilon\}$ in the model. First, we set the discount rate ρ to a standard value of 0.03. To calibrate the remaining parameters, we consider the following empirical moments in the US.

We set (a) the R&D share of GDP (i.e., $w_t l_r / y_t$) in 1980 to 0.012, (b) the average innovation arrival rate λ^e to 0.17 based on the empirical estimate in Laitner and Stolyarov (2011),[12] (c) the average productivity growth rate g^e to 0.01, and (d) the variation coefficient σ_g of the growth rate to 1.4. Furthermore, we consider a feasible range of values for $\{\beta,\gamma\}$. Finally, we set ε to 0.05, which is the smallest value under which Condition R holds. In our numerical analysis, we find that raising the value of ε would favor the model in explaining a larger fraction of the observed volatility reduction, so we intentionally choose a small value of ε.

In the US, R&D as a percentage of GDP increases from 1.2% in 1980 to 2.5% in recent time. Holding other calibrated parameter values constant, we increase the level of patent breadth b such that $w_t l_r / y_t$ rises from 0.012 to 0.025. We find that this policy change reduces growth volatility σ_g and explains about 10% to 35% of the observed volatility reduction in Figure 1 (i.e., from 1.4 in the 1980's to 0.78 in 2007). To be conservative, we consider the lower bound of 10% as our benchmark.

Table 1: Calibration results for $\gamma = 0$

β	0.65	0.70	0.75	0.80	0.85	0.90	0.95	1.00
z	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06
φ	65.3	55.6	52.1	50.1	48.7	47.8	47.1	46.6
p	0.12	0.17	0.19	0.21	0.22	0.23	0.24	0.24
b_{1980}	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
b_{2007}	0.46	0.46	0.46	0.47	0.47	0.47	0.47	0.47
fraction	35.1%	27.0%	22.3%	18.8%	16.0%	13.6%	11.7%	10.0%

Table 1 presents our benchmark results for $\gamma = 0$. The last row of Table 1 reports the fraction of the volatility reduction in Figure 1 that can be explained by the increase in R&D in the US. We see that as β decreases, the value of p (that is needed for $\sigma_g = 1.4$) decreases.

[12] It is useful to note that considering a larger innovation-arrival rate of 0.33 as in Acemoglu and Akcigit (2012) would not change our main results.

These smaller values of β and p increase the fraction of the observed volatility reduction that can be explained by the model. For $\beta \leq 0.6$, the model is unable to generate a value of 1.4 for σ_g. In fact, as β approaches zero, σ_g approaches zero.

Table 2: Calibration results for $\gamma = 0.1$			
β	0.90	0.95	1.00
z	1.06	1.06	1.06
φ	93.8	86.9	83.4
p	0.13	0.16	0.17
b_{1980}	0.24	0.24	0.24
b_{2007}	0.46	0.46	0.46
fraction	18.4%	14.3%	11.3%

In Table 2, we examine the robustness of our results by considering a larger value of $\gamma = 0.1$. In this case, we find that the model is able to explain a larger fraction of the observed volatility reduction for a given value of β; however, the model is unable to generate a value of 1.4 for σ_g when $\beta \leq 0.85$. Intuitively, the difference between β and γ must be sufficiently large in order for the model to deliver a significant degree of volatility. As γ rises further, the model is able to explain an even larger fraction of the observed volatility reduction for a given value of β; however, when γ becomes sufficiently large, the model is unable to generate a value of 1.4 for σ_g even when $\beta = 1$.

5. Conclusion

In this note, we have analyzed the effects of intellectual property rights on technical progress and growth volatility. In summary, strengthening patent protection improves the incentives for R&D and increases technical progress that in turn reduces the volatility of economic growth. Although the model features a reduced-form relationship between technical progress and growth volatility via a positive externality of R&D spillovers, we believe that this simple setup is appropriate for our purpose for two reasons. First, our focus is on the effect of patent policy on growth volatility while taking the negative effect of technical progress on growth volatility as a basic premise that is supported by empirical evidence. Secondly, it is still an on-going debate as to the main channel through which technical progress reduces volatility; therefore, we adopt a reduced-form setup instead of taking a stand on which structural mechanism is empirically the most relevant.

In this study, we have considered a stylized model, so that the numerical results should be viewed as illustrative. In reality, whether or not strengthening patent protection reduces growth volatility significantly depends on two channels: (a) patent policy has a significant and positive effect on technical progress, and (b) technical progress has a significant and negative effect on growth volatility. Existing empirical evidence seems to suggest that both of these channels are often present, especially among high-income countries.[13]

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[13] See for example Park (2008b) and Tang *et al.* (2008).

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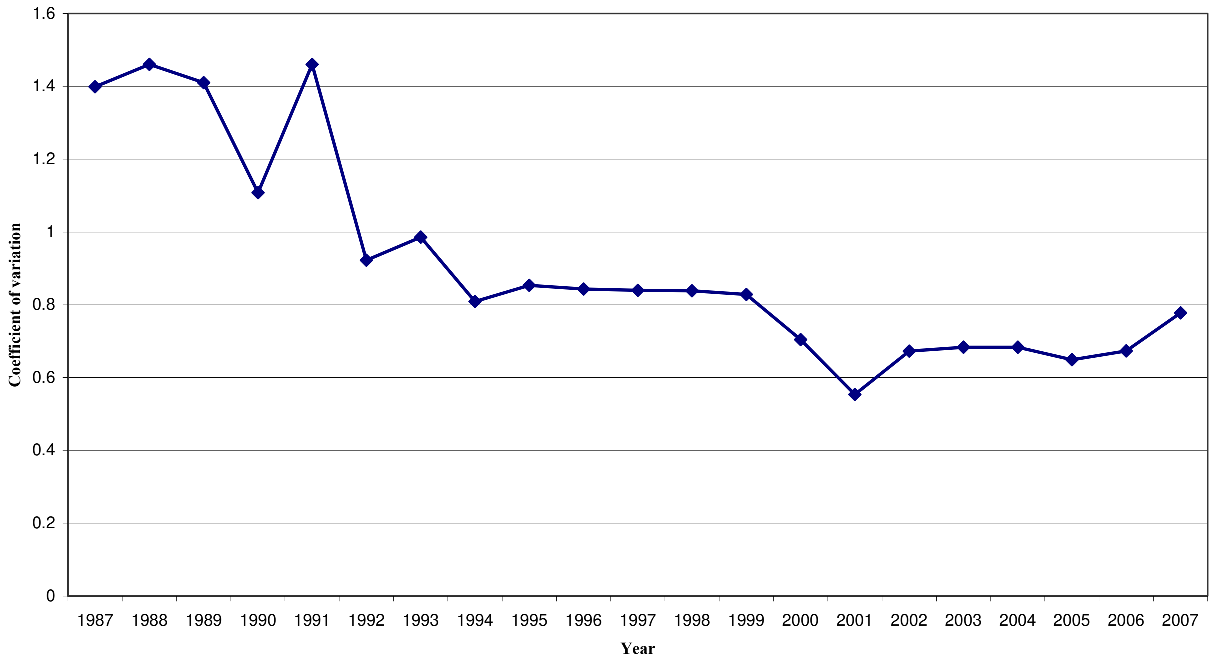
Figure 1: Growth volatility in the US



Footnote: Figure 1 presents the 10-year rolling coefficient of variation of annual growth in real GDP per capita using data from the Penn World Table.

Figure 2: Equilibrium allocation of R&D labor