Patent Policy and Economic Growth: A Survey

Chu, Angus C.

University of Macau

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Angus C. Chu

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Abstract

This survey provides a selective review of the literature on patent policy, innovation and economic growth. The patent system is a useful policy tool for stimulating innovation given its importance on technological progress and economic growth. However, the patent system is a multi-dimensional system, which features multiple patent policy instruments. In this survey, we review some of the commonly discussed patent policy instruments, such as patent length, patent breadth and blocking patents, and also use a canonical Schumpeterian growth model to demonstrate their different effects on innovation and the macroeconomy.

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Chu: anguscсc@gmail.com. Department of Economics, University of Macau, Macau, China.

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To summarise, Romer showed that unregulated markets will produce technological change, but tend to underprovide R&D and the new goods created by it. Addressing this under-provision requires well-designed government interventions, such as R&D subsidies and patent regulation. His analysis says that such policies are vital to long-run growth, not just within a country but globally. It also provides guidelines for policy design: patent laws should strike the right balance between the motivation to create new ideas, by giving some monopoly rights to developers, and the ability of others to use them, by limiting these rights in time and space. Royal Swedish Academy of Sciences (2018)

1 Introduction

In this survey, we provide a selective review of the literature on patent policy, innovation and economic growth. The seminal work of Solow (1956) shows an important result that in the long run, economic growth is driven by technological progress, which in turn is driven by R&D and innovation. However, R&D features externalities, which cause the market equilibrium level of R&D investment to deviate from its socially optimal level. Jones and Williams (1998, 2000) show that the market economy tends to exhibit a significant degree of R&D underinvestment.

As a result of this market failure, government intervention is required to stimulate R&D in the economy. An important policy tool of the government is the patent system. However, the patent system is a multi-dimensional policy system, which features multiple patent policy instruments. In this survey, we review some of the commonly discussed patent policy instruments, such as patent length, patent breadth and blocking patents, in the literature on patent policy and innovation-driven growth, which is based on the literature on optimal patent design and the literature on innovation-driven growth.

In the literature on optimal patent design, the seminal study by Nordhaus (1969) explores optimal patent length. Subsequent studies, such as Gilbert and Shapiro (1990), Klemperer (1990) and O'Donoghue (1998), consider other patent policy instruments.[1] Studies in this literature focus on partial equilibrium models, whereas more recent studies adopt a macroeconomic approach and analyze patent policy in dynamic general equilibrium models of economic growth and innovation.

In the literature on innovation and economic growth, the seminal study by Romer (1990) develops the first R&D-based growth model in which innovation comes from new product development. Then, Aghion and Howitt (1992) develop the Schumpeterian growth model in which innovation comes from quality improvement; see also Grossman and Helpman (1991) and Segerstrom *et al.* (1990) for other early studies.[2] In this

[1] See Scotchmer (2004) for a textbook treatment of this literature.
[2] See Aghion *et al.* (2014) for a survey on Schumpeterian growth theory.

survey, we use a canonical Schumpeterian growth model to demonstrate the theoretical effects of various patent policy instruments and review related studies in the literature.

The patent policy instruments that we review in this survey include patent length, patent breadth and blocking patents. Patent length refers to the statutory term of patent, which is 20 years in most countries. Patent breadth refers to the scope or broadness of patent protection, which is determined by how broadly patent claims are interpreted by patent judges when patents are enforced in courts. Blocking patents refer to patents infringing prior patents, whose patentholders then extract surplus from the subsequent innovators. In summary, results from the literature indicate that extending patent length beyond 20 years is ineffective in stimulating R&D whereas increasing patent breadth may have a positive effect on innovation and economic growth but may also worsen income inequality. Finally, blocking patents are detrimental to innovation and economic growth.

The rest of this survey is organized as follows. Section 2 explores the effects of patent policy instruments on innovation. Section 3 considers how patent policy affects inequality. Section 4 provides a brief discussion of the empirical literature. Section 5 concludes.

2 Patent policy and innovation

In this section, we explore the different effects of various patent policy instruments. Section 2.1 considers patent length. Section 2.2 analyzes patent breadth in a Schumpeterian growth model. Section 2.3 extends the model to allow for blocking patents. Section 2.4 discusses other patent policy instruments.

2.1 Patent length

We begin our analysis of patent policy by considering patent length, which refers to the statutory term of patent. The seminal study on the analysis of optimal patent length is Nordhaus (1969), who considers a tradeoff between the social cost of monopolistic distortion and the social benefit of innovation in a partial equilibrium model. Subsequent studies by Judd (1985), Iwaisako and Futagami (2003), Futagami and Iwaisako (2007) and Acemoglu and Akcigit (2012) explore optimal patent length in dynamic general equilibrium models of economic growth and innovation.[3] The early study by Judd (1985) finds that an infinite patent length is optimal by eliminating a relative-price distortion, whereas Iwaisako and Futagami (2003) and Futagami and Iwaisako (2007) find that the optimal patent length is finite due to the presence of an additional distortion on the allocation of intermediate goods. Acemoglu and Akcigit (2012)

[3] See also Chou and Shy (1993) who explore a crowding-out effect of patent length on innovation by decreasing the young generation's saving in an overlapping generations model.

provide a quantitative analysis on optimal patent length in a Schumpeterian growth model with step-by-step innovation developed by Aghion *et al.* (2001) and show that the optimal patent length is finite and state-dependent (depending on the technological gaps between industry leaders and their followers).

Although patent length seems to be a natural and relevant patent policy instrument to consider, Pakes (1986) and Schankerman and Pakes (1986) show that most patents are not renewed until the end of the statutory term of 20 years. Therefore, extending the patent length is unlikely to have a significant effect in stimulating R&D. In the rest of this section, we demonstrate the intuition of this finding from Chu (2010a).

Let $v_0(T)$ denote the value of an invention patented at time 0 with a patent length of T years. Let $\pi_t = \pi_0 \exp(g_\pi t)$ denote that the profit flow generated by the patented invention at time t, and g_π is the rate of change in the profit flow π_t. Then, no arbitrage implies that $v_0(T)$ is the present value of π_t from time 0 to time T given by

$$v_0(T) = \int_0^T e^{-rt}\pi_t dt = \int_0^T e^{-(r-g_\pi)t}\pi_0 dt = \frac{1-e^{-(r-g_\pi)T}}{r-g_\pi}\pi_0, \tag{1}$$

where r is the interest rate and also the discount rate of future profits. Then, we can compute the percent change in $v_0(T)$ when the patent length increases from T years to $T+\tau$ years as

$$\Delta v_0 \equiv \frac{v_0(T+\tau) - v_0(T)}{v_0(T)} = \frac{e^{-(r-g_\pi)T} - e^{-(r-g_\pi)(T+\tau)}}{1-e^{-(r-g_\pi)T}}, \tag{2}$$

which shows that Δv_0 crucially depends on the values of g_π and r.

Bessen (2008) estimates that the annual depreciate rate of profit generated by patents is about 14%. Therefore, we consider $g_\pi = -0.14$. Together with an asset return r of 7%, the increase in patent value Δv_0 from extending the patent length from 20 years to 25 years is only 1.0%. However, shortening the patent length from 20 years to 15 years would reduce patent value by 2.8%, which is more significant. Chu (2010a) extends the R&D-based growth model developed by Romer (1990) to allow for finite patent length and calibrates the model to data (including the above estimate of g_π) to show that the effects of extending the patent length beyond 20 years on R&D and economic growth are quantitatively insignificant.

2.2 Patent breath

Given the ineffectiveness of patent length in stimulating R&D, we consider in this section an alternative patent policy instrument known as patent breadth, which refers to the scope or broadness of patent protection. Early studies by Gilbert and Shapiro (1990) and Klemperer (1990) explore the effects of patent breadth in partial equilibrium models. Subsequent studies explore the effects of patent breadth in dynamic general equilibrium models of economic growth and innovation; see Li (2001), Goh and Olivier

(2002) and O'Donoghue and Zweimuller (2004) for early studies, which we will discuss in some details along with recent studies.

We first demonstrate how patent breadth affects the value of patents. For simplicity, we set the patent length T to infinity in order to simplify (1) as

$$v(\mu) = \frac{\pi(\mu)}{r - g_\pi}, \tag{3}$$

where μ captures the level of patent breadth. A larger patent breadth increases the amount of profit π generated by a patent, which in turn increases its value v. Equation (3) implies that the percent change in patent value is determined by the percent change in the amount of profit. Therefore, the key difference between patent length and patent breadth is that patent length affects future profit generated by a patent whereas patent breadth also affects its current profit, which in turn has a more direct effect on the value of patents. In the rest of this section, we use a canonical Schumpeterian growth model to provide a microfoundation for the profit function $\pi(\mu)$ being increasing in patent breadth μ and demonstrate the effects of patent breadth on innovation and economic growth.

2.2.1 A canonical Schumpeterian growth model with patent breadth

The Schumpeterian growth model is developed by Aghion and Howitt (1992). In this model, innovation is driven by the quality improvement of products. Here we present a simple version of the Schumpeterian growth model with patent breadth.

2.2.2 Household

The representative household has the following lifetime utility function:

$$U = \int_0^\infty e^{-\rho t} \ln c_t dt, \tag{4}$$

where the parameter $\rho > 0$ is the subjective discount rate of the household and c_t denotes consumption at time t. The household inelastically supplies L units of labor for production and maximizes utility subject to an asset-accumulation equation:

$$\dot{a}_t = r_t a_t + w_t L - c_t, \tag{5}$$

where a_t is the value of assets (i.e., patented inventions), r_t is the interest rate, and w_t is the wage rate. Dynamic optimization yields the consumption path as

$$\frac{\dot{c}_t}{c_t} = r_t - \rho. \tag{6}$$

2.2.3 Final good

Competitive firms produce final good y_t using a Cobb-Douglas aggregator:

$$y_t = N \exp\left(\frac{1}{N}\int_0^N \ln x_t(i)di\right), \tag{7}$$

where N is the (exogenous) number of differentiated intermediate goods $x_t(i)$ for $i \in [0, N]$.[4] Profit maximization yields the conditional demand function for $x_t(i)$ as

$$p_t(i)x_t(i) = \frac{y_t}{N}, \tag{8}$$

where $p_t(i)$ is the price of $x_t(i)$.

2.2.4 Intermediate goods

There are N monopolistic industries. Each monopolistic industry is dominated by a temporary industry leader (who owns the latest innovation in the industry) until the arrival of the next innovation. The industry leader in industry i produces the differentiated intermediate good $x_t(i)$. The production function of the industry leader in industry $i \in [0, N]$ is

$$x_t(i) = z^{q_t(i)}L_t(i), \tag{9}$$

where the parameter $z > 1$ is the quality step size, $q_t(i)$ is the number of quality improvements that have occurred in industry i as of time t, and $L_t(i)$ is production labor employed in industry i.

Given the productivity level $z^{q_t(i)}$, the marginal cost of the leader in industry i is $w_t/z^{q_t(i)}$. From the Bertrand competition between the current industry leader and the previous industry leader, the profit-maximizing price for the current industry leader is

$$p_t(i) = \mu\frac{w_t}{z^{q_t(i)}}, \tag{10}$$

where the markup $\mu \in (1, z)$ is a patent policy parameter determined by the government. Grossman and Helpman (1991) and Aghion and Howitt (1992) assume that the markup μ is equal to the quality step size z, due to the assumption of complete patent protection on the latest innovation. Here we follow Li (2001) to consider incomplete patent breadth such that $\mu < z$.

The wage payment in industry i is

$$w_tL_t(i) = \frac{1}{\mu}p_t(i)x_t(i) = \frac{1}{\mu}\frac{y_t}{N}, \tag{11}$$

[4] We include N as a parameter to demonstrate some recent results in the literature.

and the monopolistic profit in industry i is

$$\pi_t(i) = p_t(i)x_t(i) - w_t L_t(i) = \frac{\mu - 1}{\mu}\frac{y_t}{N}, \tag{12}$$

which is increasing in the level of patent breadth μ (providing a microfoundation for $\pi(\mu)$ in Section 2.2).

2.2.5 R&D

Equation (12) shows that $\pi_t(i) = \pi_t$. Therefore, the value of inventions is symmetric across industries such that $v_t(i) = v_t$ for $i \in [0, N]$; see Cozzi *et al.* (2007) for a theoretical justification for the symmetric equilibrium. Then, the no-arbitrage condition that determines v_t is

$$r_t = \frac{\pi_t + \dot{v}_t - \lambda_t v_t}{v_t}. \tag{13}$$

Intuitively, the no-arbitrage condition equates the interest rate r_t to the rate of return on v_t given by the sum of monopolistic profit π_t, capital gain $\dot{v}_t$ and expected capital loss $\lambda_t v_t$, where λ_t is the arrival rate of innovation. When the next innovation occurs, the previous technology becomes obsolete; see Cozzi (2007) for a discussion on the Arrow replacement effect.

Competitive entrepreneurs devote R_t units of final good to perform innovation in each industry. We specify the arrival rate of innovation as

$$\lambda_t = \frac{\varphi R_t}{Z_t}, \tag{14}$$

where $\varphi > 0$ is an R&D productivity parameter and Z_t denotes the aggregate level of technology, which captures an increasing-difficulty effect of R&D. The free-entry condition for R&D is

$$\lambda_t v_t = R_t \Leftrightarrow \frac{\varphi v_t}{Z_t} = 1, \tag{15}$$

where the second equality uses (14).

2.2.6 Economic growth

Aggregate technology Z_t is defined as

$$Z_t \equiv \exp\left(\frac{1}{N}\int_0^N q_t(i)di \ln z\right) = \exp\left(\int_0^t \lambda_\omega d\omega \ln z\right), \tag{16}$$

which uses the law of large numbers and equates the average number of quality improvements $\frac{1}{N}\int_0^N q_t(i)di$ that have occurred as of time t to the average number of innovation arrivals $\int_0^t \lambda_\omega d\omega$ up to time t. Differentiating the log of Z_t with respect to time yields the growth rate of technology given by

$$g_t \equiv \frac{\dot{Z}_t}{Z_t} = \lambda_t \ln z. \tag{17}$$

Substituting (9) into (7) yields the aggregate production function given by

$$y_t = N \exp\left(\frac{1}{N}\int_0^N q_t(i)di \ln z + \frac{1}{N}\int_0^N \ln L_t(i)di\right) = Z_t L, \tag{18}$$

where we have used the symmetry condition $L(i) = L/N$. Therefore, the growth rate of final good y_t is also g_t, which is determined by λ_t as in (17).

Using $\dot{c}_t/c_t = g_t$ and (6) in (13), we derive the balanced-growth value of an invention as

$$v_t = \frac{\pi_t}{\rho + \lambda} = \frac{\mu - 1}{\mu}\frac{Z_t}{\rho + \lambda}\frac{L}{N}, \tag{19}$$

which uses (12) and (18). Equation (19) shows that v_t is increasing in level of patent breadth μ. Substituting (19) into (15) yields

$$\lambda^* = \frac{\mu - 1}{\mu}\frac{\varphi L}{N} - \rho, \tag{20}$$

which is the steady-state arrival rate of innovation. Equation (20) shows that the steady-state arrival rate λ^* of innovation is increasing in the level of patent breadth μ. Therefore, the steady-state growth rate $g^* = \lambda^* \ln z$ is also increasing in the level of patent breadth μ. Proposition 1 summarizes this result.

Proposition 1 *Economic growth is increasing in the level of patent breadth.*

This result originates from Li (2001), which is the first study that analyzes patent breadth in the Schumpeterian growth model. Although a larger patent breadth μ increases economic growth g^*, it also requires more R&D investment R_t and crowds out consumption $c_t = y_t - NR_t$. The optimal level of patent breadth can be derived by trading off these two dynamic-general-equilibrium effects,[5] which corresponds to the tradeoff behind optimal patent length analyzed by Nordhaus (1969) in a partial-equilibrium setting. Subsequent studies by Goh and Olivier (2002), Chu (2011) and Saito (2017) explore sector-specific optimal patent breadth in the presence of multiple R&D sectors and analyze which sector-specific characteristics call for a higher level of patent breadth. Iwaisako (2020) performs a quantitative analysis on optimal patent breadth in the semi-endogenous-growth version of the Schumpeterian model in Segerstrom (1998) and Li (2003).

[5] Using the welfare function $U = (\ln c_0 + g^*/\rho)/\rho$, one can derive optimal patent breadth as $\overline{\mu} = \frac{\varphi L}{\rho N}\frac{\ln z}{1 - \ln z}$ given an interior solution; i.e., $\overline{\mu} < z < \exp(1)$. Derivations are available upon request.

2.2.7 Negative effects of patent breadth on innovation

Although early studies tend to find that increasing patent breadth has a positive effect on economic growth and innovation, recent studies discover negative effects of patent breadth via various general-equilibrium channels. For example, Chu, Furukawa and Ji (2016) show that although patent breadth μ increases economic growth in the short run when the number of differentiated products N is fixed, a larger μ reduces economic growth in the long run when N becomes endogenous. Intuitively, a larger patent breadth increases the amount of monopolistic profits and attracts the entry of new products. In this case, we can assume that the number of differentiated products N is an increasing function in μ and modify (20) as

$$\lambda^* = \frac{\mu - 1}{\mu}\frac{\varphi L}{N(\mu)} - \rho. \tag{21}$$

Then, a larger μ has a positive effect on innovation via the profit margin $(\mu - 1)/\mu$ and a negative effect on innovation via a larger number of products $N(\mu)$. This latter effect dilutes the amount of resources for the innovation of each product. Chu, Furukawa and Ji (2016) and Chu, Kou and Wang (2020) show that this negative effect of patent breadth μ dominates its positive effect on the steady-state equilibrium growth rate in the Schumpeterian growth model with both quality improvement and new product development in Peretto (2007, 2015).

In the literature, there are also other general-equilibrium channels through which patent breadth causes negative effects on innovation and economic growth. For example, Chu, Cozzi, Fan, Pan and Zhang (2020) consider an R&D-based growth model with credit constraints and show that the distortionary effect caused by a larger patent breadth could tighten the credit constraints and stifle innovation. They also provide empirical evidence for this theoretical result. Iwaisako and Futagami (2013) develop a growth model with both innovation and capital accumulation to show that patent breadth has a positive effect on innovation but a negative effect on capital accumulation, generating an overall inverted-U effect on economic growth.[6]

2.3 Blocking patents

O'Donoghue and Zweimuller (2004) refer to the modelling of patent breadth in Li (2001) as lagging breadth because it protects the current industry leader from the previous industry leader but not future industry leaders. Therefore, they propose an additional form of patent breadth known as leading breadth, which protects the current industry leader against subsequent innovators. O'Donoghue and Zweimuller (2004) introduce a general formulation of leading patent breadth to the Schumpeterian growth model. Here we provide a simple formulation based on Chu and Pan (2013).

[6] See also Yang (2021) who explores the welfare effect and optimal design of patent breadth in the framework of Iwaisako and Futagami (2013).

In each industry, the latest industry leader (i.e., the entrant) infringes the patent of the previous industry leader (i.e., the incumbent). Due to this patent infringement, the entrant has to transfer a share $s \in (0, 1)$ of her monopolistic profit to the incumbent. Therefore, the profit share s captures the strength of blocking patents. Due to the division of profit, the entrant obtains $(1 - s)\pi_t$ as her profit at time t, whereas the incumbent obtains $s\pi_t$ as her profit. When the next innovation arrives, the current entrant becomes the incumbent and her profit changes from $(1 - s)\pi_t$ to $s\pi_t$, whereas the current incumbent loses her claim to the profit generated by the next entrant. In other words, we assume that the degree of leading patent breadth covers only the next innovation but not the subsequent ones; see O'Donoghue and Zweimuller (2004) for a more general formulation.

Let $v_{2,t}(i)$ denote the patent value of the second most recent innovation in industry i. Because $s\pi_t(i) = s\pi_t$ for all $i \in [0, N]$, we have $v_{2,t}(i) = v_{2,t}$ in a symmetric equilibrium. The no-arbitrage condition that determines $v_{2,t}$ is

$$r_t = \frac{s\pi_t + \dot{v}_{2,t} - \lambda_t v_{2,t}}{v_{2,t}}, \tag{22}$$

which equates the interest rate r_t to the rate of return on $v_{2,t}$ given by the sum of monopolistic profit $s\pi_t$, capital gain $\dot{v}_{2,t}$ and expected capital loss $\lambda_t v_{2,t}$, where λ_t is the arrival rate of innovation.

Let $v_{1,t}(i)$ denote the patent value of the most recent innovation in industry i. Because $(1 - s)\pi_t(i) = (1 - s)\pi_t$ for all $i \in [0, N]$, we also have $v_{1,t}(i) = v_{1,t}$ in a symmetric equilibrium. The no-arbitrage condition that determines $v_{1,t}$ is

$$r_t = \frac{(1 - s)\pi_t + \dot{v}_{1,t} - \lambda_t(v_{1,t} - v_{2,t})}{v_{1,t}}, \tag{23}$$

which equates the interest rate r_t to the rate of return on $v_{1,t}$ given by the sum of monopolistic profit $(1 - s)\pi_t$, capital gain $\dot{v}_{1,t}$ and expected capital loss $\lambda_t(v_{1,t} - v_{2,t})$, which captures that when the next innovation arrives, the current entrant becomes the incumbent (i.e., losing $v_{1,t}$ while gaining $v_{2,t}$).

The rest of the model is the same as in Section 2.2. Using $\dot{c}_t/c_t = g_t$ and (6) in (22), we derive the balanced-growth value of $v_{2,t}$ as

$$v_{2,t} = \frac{s\pi_t}{\rho + \lambda}. \tag{24}$$

Similarly, using $\dot{c}_t/c_t = g_t$ and (6) in (23), we derive the balanced-growth value of $v_{1,t}$ as

$$v_{1,t} = \frac{(1 - s)\pi_t}{\rho + \lambda} + \frac{\lambda}{\rho + \lambda} v_{2,t} = \frac{\pi_t}{\rho + \lambda}\left(1 - s + s\frac{\lambda}{\rho + \lambda}\right), \tag{25}$$

where the second equality uses (24). The R&D free-entry condition becomes

$$\lambda_t v_{1,t} = R_t \Leftrightarrow \frac{\varphi v_{1,t}}{Z_t} = 1. \tag{26}$$

Substituting (25) into (26) yields the following equilibrium condition:

$$\lambda = \frac{\mu - 1}{\mu} \frac{\varphi L}{N} \left(1 - s + s\frac{\lambda}{\rho + \lambda}\right) - \rho, \tag{27}$$

which also uses (12) and (18). It is useful to note that (27) captures (20) as a special case with $s = 0$ and that $\Omega \equiv 1 - s + s\lambda/(\rho + \lambda) < 1$ due to the discounting ρ of backloaded profit $s\pi_t$, which we refer to as the backloading effect of blocking patents. Here the level of patent breadth μ can be greater than the quality step size z due to the consolidation of market power by the entrant and the incumbent, which in turn could stimulate innovation; see O'Donoghue and Zweimuller (2004) for a discussion.

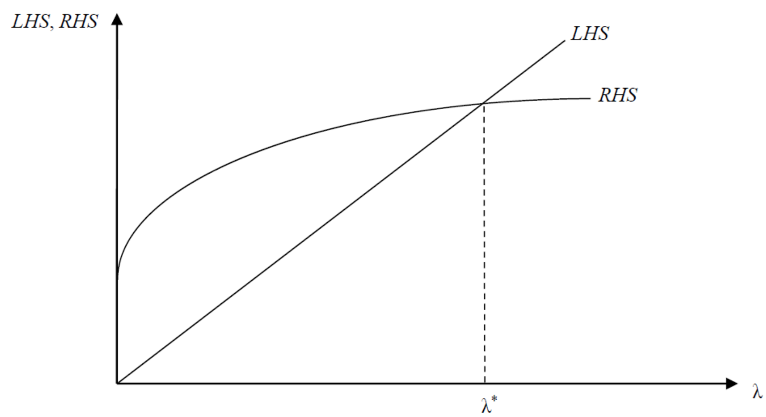

Figure 1: Unique steady-state equilibrium

Figure 1 plots (27) and shows a unique steady-state equilibrium value of λ^*. The profit share s captures the strength of blocking patents. Stronger blocking patents (i.e., a larger s) shift down RHS in Figure 1 and reduce the steady-state arrival rate λ^* of innovation, which in turn leads to a lower steady-state growth rate $g^* = \lambda^* \ln z$. Proposition 2 summarizes this result.

Proposition 2 *Economic growth is decreasing in the strength of blocking patents.*

This result originates from Chu (2009), who provides a quantitative analysis on the effects of blocking patents in the Schumpeterian growth model and shows that reducing the strength of blocking patents causes significant positive effects on R&D, economic growth and social welfare.[7] Subsequent studies consider different extensions of the

[7] The model in Chu (2009) is based on O'Donoghue and Zweimuller (2004). Although the backloading effects of blocking patents are also present in O'Donoghue and Zweimuller (2004), they do not consider blocking patents as a policy instrument that affects the profit-division rule and instead focus on the markup-consolidation effects of leading patent breadth.

Schumpeterian growth model to explore the effects of blocking patents. Chu, Cozzi and Galli (2012) and Niwa (2016) consider a model with both quality improvement and new product development. Chu and Pan (2013) consider an endogenous step size of quality improvements. Cozzi and Galli (2014) consider a model with a two-stage cumulative innovation structure (capturing the basic research stage and the applied development stage). All of these studies find that the overall effects of blocking patents on economic growth become inverted-U under these extensions. Niwa (2018) introduces blocking patents to the model with endogenous survival investment in Furukawa (2013) and shows that blocking patents are likely to stimulate (stifle) innovation at a high (low) level of patent breadth. Yang (2018) also considers the interaction between blocking patents and patent breadth and explores their optimal coordination on social welfare.[8]

2.4 Other patent policy instruments

In addition to patent length, patent breadth and blocking patents, there are also other patent policy instruments that have been explored in the literature. O'Donoghue and Zweimuller (2004) introduce a patentability requirement to the Schumpeterian growth model with an endogenous quality step size.[9] They show that raising the patentability requirement can stimulate innovation by increasing the step size of quality improvement. In contrast, Kiedaisch (2015) shows that in a Schumpeterian growth model with persistent leadership developed by Denicolo (2001), raising the patentability requirement stifles innovation by reducing entrants' pressure on incumbents to innovate in order to preempt entry.

Helpman (1993) models patent protection as a parameter that reduces the exogenous probability of an imitation process. Kwan and Lai (2003) provide a quantitative analysis to simulate the dynamic effects of this patent policy parameter on economic growth and social welfare. Subsequent studies by Furukawa (2007) and Horii and Iwaisako (2007) follow this modelling approach of patent protection against imitation and find an inverted-U effect of patent protection on economic growth. Cozzi (2001) and Cozzi and Spinesi (2006) also consider imitation but at the invention stage and model patent protection as an improvement in intellectual appropriability that reduces the chance of an innovation being stolen by a competitor before the innovator manages to patent the innovation.

[8] See also Chu and Furukawa (2011) and Yang (2013) for an analysis on the optimal coordination of patent breadth and a profit-division rule in research joint ventures.

[9] The idea of a patentability requirement originates from O'Donoghue (1998) in the patent-design literature and captures the minimum quality step size for an invention to be patentable; see also Chen *et al.* (2018) for a recent study that explores how it affects the choice between risky and safe R&D.

3 Patent policy and inequality

In the previous section, we consider a representative household in the economy. Therefore, we could not analyze how patent policy affects income inequality. In this section, we introduce heterogeneous households to the Schumpeterian growth model as in Chu (2010b) and Chu and Cozzi (2018). Then, we use the model to explore the effects of patent policy on income inequality.

There is a unit continuum of households indexed by $h \in [0,1]$. Household h has the following utility function:

$$U(h) = \int_0^\infty e^{-\rho t} \ln c_t(h) dt, \tag{28}$$

where $\rho > 0$ is the discount rate as before and $c_t(h)$ denotes consumption of household h at time t. The household inelastically supplies L units of labor for production and maximizes utility subject to an asset-accumulation equation:

$$\dot{a}_t(h) = r_t a_t(h) + w_t L - c_t(h), \tag{29}$$

where $a_t(h)$ is the value of assets owned by household h. As before, r_t is the interest rate, and w_t is the wage rate. Dynamic optimization yields the consumption path of household h as

$$\frac{\dot{c}_t(h)}{c_t(h)} = r_t - \rho, \tag{30}$$

which shows that all households share the same consumption growth rate (i.e., $\dot{c}_t(h)/c_t(h) = \dot{c}_t/c_t$ for all $h \in [0,1]$).

Given the homothetic preference of all households and the absence of idiosyncratic risk except for the different levels of initial wealth $a_0(h)$, the aggregate economy behaves as in the case of a representative household. Therefore, all the equilibrium allocations in the previous sections apply to the case of heterogeneous households, such that the steady-state arrival rate λ^* of innovation and the steady-state equilibrium growth rate g^* are the same as before.

The level of income received by household h at time t is given by

$$I_t(h) \equiv r_t a_t(h) + w_t L. \tag{31}$$

Aggregating $I_t(h)$ across $h \in [0,1]$ yields the aggregate level of income I_t in the economy. Let $S_{I,t}(h) \equiv I_t(h)/I_t$ denote the share of income received by household h at time t. Then, we have

$$S_{I,t}(h) = \frac{r_t a_t}{r_t a_t + w_t L} S_{a,t}(h) + \frac{w_t L}{r_t a_t + w_t L}, \tag{32}$$

where $S_{a,t}(h) \equiv a_t(h)/a_t$ denotes the share of wealth owned by household h at time t. We measure income inequality by the coefficient variation of income defined as

$$\sigma_{I,t} \equiv \sqrt{\int_0^1 [S_{I,t}(h) - 1]^2 dh} = \frac{r_t a_t}{r_t a_t + w_t L} \sigma_{a,t}, \tag{33}$$

where $\sigma_{a,t} \equiv \sqrt{\int_0^1 [S_{a,t}(h) - 1]^2 dh}$ is the coefficient variation of wealth at time t. Chu, Furukawa, Mallick, Peretto and Wang (2021) show that the Gini coefficient of income is also given by the same expression as $\sigma_{I,t}$ in (33) when $\sigma_{a,t}$ is the Gini coefficient of wealth.

Given a stationary wealth distribution,[10] wealth inequality is determined by the initial wealth distribution that is exogenously given at time 0 (i.e., $\sigma_{a,t} = \sigma_{a,0}$). Income equality $\sigma_{I,t}$ is also determined by the endogenous asset-wage income ratio $r_t a_t/(w_t L)$ because wealth inequality drives income inequality here; see Piketty (2014) for evidence on the importance of wealth inequality on income inequality.

Suppose we focus on the special case without blocking patents (i.e., $s = 0$). Then, the value of households' assets is simply $a_t = v_t N$. From (19), the value of all patented inventions is

$$v_t N = \frac{\mu - 1}{\mu} \frac{Z_t L}{\rho + \lambda}. \tag{34}$$

From (11), the wage income is given by

$$w_t L = \frac{y_t}{\mu} = \frac{Z_t L}{\mu}, \tag{35}$$

which uses $L(i) = L/N$ and (18). The asset-wage income ratio is given by

$$\frac{r_t a_t}{w_t L} = \frac{r_t v_t N}{w_t L} = (\rho + g) \frac{\mu - 1}{\rho + \lambda}. \tag{36}$$

Substituting (36) and (20) into (33) yields the degree of income inequality as

$$\sigma_{I,t} = \left(1 + \frac{w_t L}{r_t a_t}\right)^{-1} \sigma_{a,0} = \left(1 + \frac{1}{\rho + g^*} \frac{\varphi L}{\mu N}\right)^{-1} \sigma_{a,0}, \tag{37}$$

where $\sigma_{a,0} > 0$ is exogenous and $g^* = \lambda^* \ln z$ in which λ^* is determined by (20).

Equation (37) shows that income inequality is increasing in patent breadth μ via the following two channels: an increase in the interest rate $r^* = \rho + \lambda^* \ln z$, and an increase in the asset-wage ratio $a_t/w_t = \mu N/\varphi$. Chu and Cozzi (2018) refer to these two effects as the *interest-rate* effect and the *asset-value* effect of patent breadth on income inequality. Proposition 3 summarizes this result.

Proposition 3 *Income inequality is increasing in the level of patent breadth.*

This result originates from Chu (2010b), which is the first study that explores the effects of patent breadth on income inequality in the Schumpeterian growth model. Chu

[10] It can be shown that the aggregate economy in the Schumpeterian growth model in Section 2 always jumps to the balanced growth path, along which the wealth distribution is stationary.

and Cozzi (2018) extend the analysis to compare the different effects of patent breadth and R&D subsidies on income inequality. Both of these studies find positive effects of patent breadth on income inequality. However, a recent study by Chu, Furukawa, Mallick, Peretto and Wang (2021) shows that although patent breadth μ increases income inequality in the short run when the number of differentiated products N is fixed, a larger μ reduces income inequality in the long run when N becomes endogenous.

The intuition of the above result can be explained as follows. A larger patent breadth attracts the entry of new products and increases the number of differentiated products $N(\mu)$, which in turn exerts a negative dilution effect on the arrival rate λ^* of innovation in (21) and the interest rate $r^* = \rho + \lambda^* \ln z$. Chu, Furukawa, Mallick, Peretto and Wang (2021) show that the negative effect of patent breadth μ on income inequality prevails in the long run in the Schumpeterian growth model with both quality improvement and new product development in Peretto (2007). They also provide empirical evidence to support this theoretical result.

Given the assumption of homothetic preferences in Chu, Furukawa, Mallick, Peretto and Wang (2021), the aggregate economy continues to be independent of the income distribution. Kiedaisch (2021) extends the R&D-based growth model in Foellmi and Zweimuller (2006),[11] in which the income distribution affects the aggregate economy due to non-homothetic preferences of heterogeneous households, to explore the effects of patent protection (taking into account its effects via the income distribution) on economic growth. In summary, he finds that the overall effect of patent protection on economic growth is ambiguous and depends on the underlying income distribution.

4 Empirical literature

There is also an empirical literature on patent policy and economic growth. In this literature, empirical studies often employ a country-level measure of patent rights developed by Ginarte and Park (1997). As a result, these studies are often based on cross-country regressions. The Ginarte-Park index includes five categories of patent rights: (a) patent duration, (b) coverage, (c) enforcement mechanisms, (d) restrictions on patent scope, and (e) membership in international treaties. They assign a score from zero to one to each category, and the Ginarte-Park index simply adds up the five scores on a scale from zero to five, in which a larger number implies stronger patent rights. Park (2008a) updates the index, which is now available for 122 countries from 1960 to 2005 with one observation for each 5-year interval.

Many empirical studies use the Ginarte-Park index to evaluate the effects of patent rights on innovation; see Park (2008b) for a survey. Early studies, such as Varsakelis (2001), Kanwar and Evenson (2003) and Chen and Puttitanun (2005), find a positive relationship between patent rights and innovation. However, subsequent studies find that the effects differ across countries. For example, Falvey *et al.* (2006) find

[11] See also Zweimuller (2000).

a positive and significant relationship between patent rights and economic growth in low-income and high-income countries but not in middle-income countries. Considering industry-level data, Hu and Png (2013) also find that stronger patent rights tend to have a positive effect on the growth of patent-intensive industries and that this effect is stronger in higher-income countries. Chu, Cozzi and Galli (2014) find that the relationship between patent rights and economic growth tends to be negative for countries that are far away from the global technology frontier but becomes positive for countries that are close to the global technology frontier. Similarly, Chu, Cozzi, Fan, Pan and Zhang (2020) find that the relationship between patent rights and economic growth tends to be negative for countries that have a low level of financial development but becomes positive for countries that have a high level of financial development.

In summary, the evidence for a positive relationship between patent rights and innovation seems to be stronger for developed countries than for developing countries. Chu, Cozzi and Galli (2014) provide the following theoretical explanation for this empirical finding in a Schumpeterian growth model: developed countries require original innovations to achieve economic growth whereas developing countries can rely on the reverse engineering of foreign technologies. Consequently, stronger patent rights may slow down economic growth in developing countries by hindering the reverse engineering of foreign technologies.

There is also a small number of empirical studies that examine the effects of patent rights on income inequality. Adams (2008) is a notable example and finds that stronger patent rights tend to increase income inequality. Adams (2008) considers static panel regressions, whereas Chu, Furukawa, Mallick, Peretto and Wang (2021) use a panel VAR to examine the dynamic effects of stronger patent rights on income inequality. They find that stronger patent rights increase income inequality in the short run but decrease inequality in the long run.

5 Conclusion

In this survey, we have provided a selective review of the literature on patent policy and innovation-driven growth. In particular, we have explored the multi-dimensional nature of the patent system, which features multiple patent policy instruments such as patent length, patent breadth and blocking patents. We have used a canonical Schumpeterian growth model to demonstrate the different effects of these patent policy instruments on innovation and inequality. Our findings from the literature can be summarized as follows. First, extending patent length beyond the current 20 years is ineffective in stimulating R&D. Second, increasing patent breadth may have a positive effect on innovation but may also worsen income inequality. Third, blocking patents are detrimental to innovation and economic growth. Finally, it is worth noting that this survey focuses on the within-country effects of patent policy on domestic innovation and that there is also a vast literature on the cross-country effects of patent policy on technology transfer.[12]

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