Blocking Patents, Rent Protection and Economic Growth*

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Abstract

We develop a Schumpeterian growth model to analyze the interaction between patent policy and firms' internal strategies to capture value from innovations. We consider two dimensions of patent policy: backward protection against imitation and forward protection, also known as blocking patents, against subsequent innovation that builds on a patented technology. Incumbent patent holders endogenously invest resources to protect their monopoly rents by impeding market entry of innovative competitors. We show that patent policy impacts economic growth through its influence on both the ex ante R&D incentives of potential innovators and the post-innovation rent protection incentives of incumbent firms. Most importantly, our analysis formalizes a novel growth-promoting role of forward protection; by guaranteeing previous innovators a share of future innovators' profits, forward protection reduces the incentive to actively obstruct follow-on innovations. We identify conditions under which the selective use of forward protection can stimulate economic growth through this mechanism.

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1 Introduction

Over the last two decades, a stream of research in endogenous growth theory has emphasized that aspects of the US patent system may be detrimental to innovation and economic growth. Of particular concern is the expansion of patent rights beyond their traditional role of protecting against imitation to encompass rights over the use of a patented technology in subsequent innovations. Several studies have analyzed the potential *blocking-patent* effect of this form of protection in the context of cumulative innovation (O'donoghue and Zweimüller, 2004; Chu, 2009; Chu *et al.*, 2012; Yang, 2018; Klein, 2022). In these models, overlapping patent rights between subsequent innovations require each new innovator to obtain licenses from existing patent holders. Incumbent firms use these rights to extract rents from new entrants, reducing the ex ante R&D incentives of potential innovators, and suppressing economic growth.

A potential shortcoming of this endogenous growth literature is that it does not consider firms' private efforts to supplement the legal protection provided by patents. However, empirical evidence indicates that patent holders invest substantial resources to protect the value of their intellectual property and maintain their advantageous market position. This includes deliberate efforts to mask inventions to make reverse engineering more difficult (Taylor, 1993; Akiyama and Furukawa, 2009; Ghosh and Ishikawa, 2018), imposing costs on potential competitors through aggressive threats of patent litigation based on dubious infringement claims (Lanjouw and Lerner, 2001; Bessen and Meurer, 2013; Chien, 2014; Appel *et al.*, 2019), and political lobbying for favorable market regulations (Bessen, 2016; Huneeus and Kim, 2021; Akcigit *et al.*, 2023). Indeed, a separate line of endogenous growth literature has identified such efforts, collectively referred to as *rent-protecting activities* (RPAs), as a significant barrier to market entry, innovation and economic growth (Dinopoulos and Syropoulos, 2007; Şener, 2008; Grieben and Şener, 2009; Davis and Şener, 2012; Klein, 2020; Dinopoulos *et al.*, 2023a).

In this paper, we develop a Schumpeterian growth model to evaluate how firms' endogenous efforts to safeguard their monopoly rents influence the economic implications of patent policy. Our starting point is the theoretical framework proposed by Dinopoulos and Syropoulos (2007). In this setting, economic growth is driven by innovation in the form of discrete product quality improvements that advance a fixed set of industries along a quality ladder. Innovation is cumulative in the sense that each new quality improvement builds on its industry's previous iteration. Competitive R&D firms hire labor to participate in stochastic R&D races and increase their chances of discovering the next quality improvement. Each new innovator immediately obtains a patent and leverages its quality advantage to displace the incumbent innovator from the market. Incumbents proactively hire specialized labor (e.g. lawyers and lobbyists) to conduct RPAs and raise the cost of competitor innovation in order to defend their dominant market position. Thus, the innovation process is characterized by stochastic contests in which R&D firms invest resources to break into the market and incumbent firms invest resources to stymie these efforts.

We introduce two dimensions of patent policy into this framework: *backward protection* against potential imitation and *forward protection* against subsequent innovation that displaces the incumbent's monopoly position. Backward protection prevents competitors from introducing sufficiently similar imitative products. This determines the patent holder's ability to charge a price above marginal cost and its corresponding monopoly profits. We model forward protection in keeping with the endogenous growth literature that has emphasized the blocking effect of patents. Specifically, forward protection takes the form of a profit-division rule that specifies the share of profits that each new innovator must pay the industry's current incumbent through a mandatory licensing agreement.[1]

We show that patent policy impacts economic growth through two distinct channels: its effect on the ex ante R&D incentives of potential innovators and its effect on the post-innovation RPAs investment of existing patent holders. In the case of backward protection, the model captures the traditional motivation for strengthening protection; stronger backward protection promotes R&D investment by increasing the monopolistic profits of successful innovators. However, the model reveals a countervailing effect that operates through each innovator's incentive to invest in RPAs. When backward protection is strengthened, innovators respond to the greater value of their monopoly position by increasing their demand for RPAs in an effort to deter competitor innovation and entry. Although we find that this RPAs effect only partially counteracts the growth-promoting effect of stronger protection, the associated increase in RPAs represents a cost of the policy that is absent from previous analyses.

In the case of forward protection however, we show that patent holders' endogenous RPAs investment response can *reverse* the traditional finding that stronger protection reduces growth. Exactly as in existing literature, strengthening forward protection creates a blocking effect by increasing each new innovator's licensing burden and decreasing ex ante R&D incentives. However, by guaranteeing current incumbents a larger share of the next innovator's profits, forward protection reduces the incentive to impede subsequent innovation through RPAs investment. This reduction in RPAs expenditure creates a novel growth-promoting effect from stronger forward protection. We show that the relative magnitude of these competing effects depends on the rate of innovation in the initial equilibrium and the effectiveness of RPAs in increasing innovation difficulty. For a given effectiveness of RPAs, we demonstrate that the growth impact of strengthening forward protection is characterized by a threshold rate of innovation; if the status-quo rate of innovation is higher (lower) than the threshold value, then stronger forward protection increases (decreases) economic growth. This is because a greater initial demand for

[1] Similar forms of these two dimensions of patent protection from imitative products and subsequent innovations are sometimes referred to as lagging versus leading breadth and horizontal versus vertical protection. We use the backward and forward protection terminology throughout the paper. We describe how these dimensions of patent protection correspond to US patent law and related literature in Section 1.1. In Dinopoulos and Syropoulos (2007), incumbent innovators do not face the risk of product imitation and receive no compensation when subsequent innovation occurs. Although they do not consider patent protection explicitly in their model, this can be thought of as a special case of the policy framework examined in the present paper in which patents provide complete backward protection but do not provide forward protection.

RPAs implies a greater the reduction in RPAs expenditure when forward protection is strengthened. Since demand for RPAs is high when competitor innovation is rapid and when RPAs offer current incumbents an effective means to obstruct follow-on innovation, strengthening forward protection is most likely to stimulate innovation under these conditions.

To the extent that the effectiveness of RPAs varies, our analysis suggests that forward patent protection may well have heterogenous implications for innovation across industries. Indeed, this is consistent available empirical evidence on the impact of patent protection on follow-on innovation. For example, Watzinger *et al.* (2020) examines a historical case study of the 1956 antitrust ruling against Bell Labs, which made Bell's 7,820 patents freely available to competitors. They find that this removal of patent protection increased subsequent innovation in several technology areas but not in the telecommunications sector, where Bell was able to successfully engage in alternative "exclusionary behavior ... to make entry expensive or impossible." Galasso and Schankerman (2015) examine the causal impact of patent invalidations and find similar variation across industries, concluding that "patent rights block downstream innovation in computers, electronics, and medical instruments, but not in drugs, chemicals, or mechanical technologies." Finally, Sampat and Williams (2019) find that patent rights for human genes do not reduce follow-on innovation and argue that this is specifically because firms' non-patent methods are particularly effective at preventing subsequent innovations in this narrow category. Our analysis formalizes this mechanism in a general equilibrium context and helps to identify market conditions under which the targeted use of forward patent protection may promote economic growth.

1.1 Patent Law, Rent Protection and Related Literature

US patent law grants a patent holder the legal right to sue for infringement whenever another entity makes unauthorized use of a product, process or technology that falls within the claims of the patent. If this entity is found in court to have infringed a patent, they must cease the infringing activity and pay the patent holder damages. In practice, the legal question of what constitutes patent infringement is subject to judicial discretion and is shaped by several common law doctrines. Here, we briefly describe how we capture important aspects of this jurisprudence through two distinct dimensions of patent protection in our model.[2]

The doctrines of disclosure and enablement address the validity of patent claims and instances of "literal infringement" of these claims. According to these doctrines, patent claims must contain information that is 1) not in the prior art and 2) sufficient for a "person skilled in the art" to use the claimed invention without undue experimentation. Any product or process that "falls squarely within the boundaries" of a valid patent claim constitutes literal infringement (Merges and Nelson, 1990). Following O'Donoghue (1998), we interpret these doctrines as determining

[2]For a more detailed discussion of patent law and its representation in economic models, see Merges and Nelson (1990), Merges (1994), Lemley (1997) and O'Donoghue (1998).

the strength of patent protection against imitative products that do not incorporate further innovation. Specifically, we model backward patent protection in terms of the range of inferior quality products that are not considered prior art, and thus fall under the valid claims of a patent.

In the absence of literal infringement, the doctrine of equivalents holds that a new product still infringes an existing patent if it may be considered essentially equivalent. This implies that patents offer a degree of protection against subsequent innovations that perform the same function, even if they improve the product beyond the existing patent's claims (Lemley, 1997). If an innovator's improvement is found to infringe an existing patent, even if the improvement is itself patented, the new innovator must obtain a license to practice its improvement. It is in this sense that patents can be used to block the practice of new innovations. On the other hand, legal precedent recognizes the danger in findings of infringement "so far beyond the literal language of claims that patents would take on unlimited power" (Merges and Nelson, 1990). As a counterbalance, the doctrine of reverse equivalents holds that even if a subsequent innovation falls within the claims of an existing patent, it is protected from infringement if it constitutes a major advance that is "so far changed in principle" from the original invention. Thus, the doctrine of reverse equivalents explicitly allows for innovators that substantially improve an existing technology to escape infringement and blocking patents.

In practice, the cost of litigation and the uncertainty resulting from the potential application of these two doctrines in a particular infringement suit creates an incentive for both parties to reach a licensing agreement. Indeed, Merges and Nelson (1990) justifies the doctrine of reverse equivalents specifically as a way to prevent "bargaining breakdown" when a patent holder can otherwise fully block outside improvements. Lemley (1997) similarly argues that these doctrines "may encourage efficient licensing transactions in situations where they otherwise would not occur."[3] To capture the outcome of this bargaining process in a simple way, we model forward patent protection in terms of an exogenous profit division rule between subsequent innovators. Forward protection reflects the strength of blocking patents by determining the share of a subsequent innovator's profits that an incumbent patent holder extracts through licensing.

In fact, we follow an extensive endogenous growth literature that has modeled forward protection in terms of a profit division rule between subsequent innovators. A series of papers have highlighted the growth-reducing effect of this type of forward protection through its negative impact on R&D incentives in the context of cumulative innovation (O'donoghue and Zweimüller, 2004; Chu, 2009; Yang, 2018; Klein, 2022; Suzuki and Kishimoto, 2023). Additional contributions to the literature have also identified potential mechanisms through which forward protection may stimulate innovation. For example, forward protection may promote growth if it incentivizes basic versus applied research (Chu and Furukawa, 2013; Cozzi and Galli, 2014), directs R&D efforts towards new types of products (Chu *et al.*, 2012), or leads researchers to attempt

[3] When parties cannot reach a voluntary resolution, courts "usually approve arrangements that remove blocking patents so that firms can bring technologies to market" in the form of compulsory licensing agreements (Scotchmer, 2004). See Merges (1994) for further discussion of compulsory licensing of blocking patents.

larger innovations in order to escape patent infringement (Chu and Pan, 2013). In each case, these analyses focus on the effect of patent policy through ex ante R&D incentives. We advance this literature by highlighting a novel growth-promoting role of forward patent protection that operates through the post-innovation RPAs incentives of market incumbents.

Following Dinopoulos and Syropoulos (2007), RPAs broadly refer to incumbent firms' multifaceted efforts to protect their market position by deterring competitor innovation and entry. Empirical evidence shows that the use of RPAs is pervasive. For example, US firms report spending approximately $4 billion annually on political lobbying. The bulk of this lobbying is attributable to large firms advocating for highly specific legislation favorable to their individual business interests (Huneeus and Kim, 2021; Blanga-Gubbay *et al.*, 2023). Indeed, Bessen (2016) finds that the rise in corporate profits in the US since 2000 is closely linked to political rent seeking and associated regulatory changes. Similarly, Akcigit *et al.* (2023) examine political connections among Italian firms and show that market leaders exhibit the most political connections and enjoy higher survival probabilities than their competitors, despite being less innovative.

In addition, firms devote considerable resources to masking technology used in their products and impeding technological diffusion to competitors. This includes employing legal teams to obfuscate technical information disclosed in patent applications and strategically designing products with built-in barriers to reverse engineering.[4] In fact, survey evidence indicates that firms consider complexity of product design among the most important means to protect innovations from competitors (Arundel, 2001; Hall *et al.*, 2014).[5] Finally, firms may use strategic threats of patent litigation specifically to impose costs on competitors. For instance, Morton and Shapiro (2014) and Hovenkamp and Cotter (2016) document the rise of "diagonally integrated" non-practicing entities (NPEs) in which large firms acquire patents covering technology that they do not intend to use in their own products, but that they, or a third party, assert against potential competitors. Even though such infringement claims by NPEs rarely result in litigation, they are associated with significant operational impacts in targeted firms including reduced employment, investment and innovation (Chien, 2014; Appel *et al.*, 2019).

Our analysis contributes to the literature pioneered by Dinopoulos and Syropoulos (2007), who first identified RPAs as a structural barrier to innovation in the context of an R&D-based endogenous growth model. Subsequent contributions have extended this literature in several directions including work that analyzes the implications of RPAs in the context of international trade and North-South product-cycles (Grieben and Şener, 2009; Dinopoulos *et al.*, 2023b), the difficulty of both innovation and imitation (Şener, 2008; Davis and Şener, 2012), and the patenting

[4]As Boldrin and Levine (2013) note, "the extent of practical 'disclosure' in modern patents is as negligible as the skills of patent attorneys can make it."

[5]Examples of deliberate efforts to prevent reverse engineering include specialized casing for sensitive components that makes nondestructive disassembly almost impossible, introducing decoy circuitry into electronics, and the use of encryption or other software "locks" (Samuelson and Scotchmer, 2002; Curtis *et al.*, 2011). Several studies have identified this form of strategic investment as an important barrier to technological diffusion and market entry (Taylor, 1993; Ghosh and Ishikawa, 2018; Henry and Ruiz-Aliseda, 2012, 2016).

behavior of innovators (Klein, 2020). To the best of our knowledge, our study is the first to examine the interaction between patent policy and the RPAs incentives of incumbent firms.

The remainder of this study is organized as follows. We develop our theoretical model in Section 2. Section 3 examines the impact of backward and forward patent protection on economic growth. Section 4 explores welfare implications. In Section 5, we calibrate the model to the US economy and provide a quantitative illustration of our analytical results. Section 6 discusses key modeling assumptions and examines how results may change when they are relaxed. Section 7 concludes.

2 The Model

2.1 Households

The economy is populated by a unit continuum of identical households that each begin with a single member at $t = 0$ and grow at an exogenous rate $n > 0$. The population of the economy at time t equals the size of each household, given by $N(t) = e^{nt}$. Each household maximizes lifetime utility according to

$$U \equiv \int_0^\infty e^{-(\rho-n)t} \ln(u(t))dt, \tag{1}$$

where $\rho > n$ is the subjective discount rate. Instantaneous per capita utility at time t is defined as

$$\ln(u(t)) \equiv \int_0^1 \ln \left[\sum_q \lambda^q Z(q, \epsilon, t) \right] d\epsilon, \tag{2}$$

where $\lambda > 1$ denotes the constant step size of quality improvements and $Z(q, \epsilon, t)$ denotes the quantity consumed of a product that has experienced q quality improvements in industry $\epsilon \in [0, 1]$ as of time t. Each industry is structurally identical.

Households maximize (1) at time t by allocating per capita consumption expenditure $c(t)$ given prices. Since quality-adjusted products within each industry are perfect substitutes, households purchase only the product with the lowest quality-adjusted price and optimally spread expenditure evenly across each industry. Simplifying notation, the demand for the good with the lowest quality-adjusted price in a typical industry is given by

$$Z(t) = \frac{c(t)N(t)}{p(t)}, \tag{3}$$

where $p(t)$ is the price of the good. Given (3), maximizing (1) subject to the standard intertemporal budget yields

$$\frac{\dot{c}(t)}{c(t)} = r(t) - \rho, \tag{4}$$

where $r(t)$ is the instantaneous market interest rate. In the steady state, $r(t) = \rho$ such that per capita consumption expenditure c is constant.

2.2 Innovation and Appropriation

In each industry, the most recent successful innovator becomes the industry's quality leader and obtains a patent that provides an imperfect legal right to exclude competing firms from the use of its innovation. As discussed in Section 1.1, we model two dimensions of patent protection. Backward protection determines the degree to which a patent holder can prevent competing firms from introducing sufficiently similar imitative products. In particular, we define backward protection as a single parameter, $\theta \in [1, \lambda]$, which specifies the maximum quality lead that an innovator can effectively maintain over its competitors. As we will see, this implies that backward protection determines a quality leader's ability to charge a price above marginal cost and their corresponding flow profits. Forward protection governs a patent holder's rights over future quality improvements that build on the patented innovation. Forward protection takes the form of a licensing agreement between an industry's incumbent patent holder and the subsequent innovator who will become the industry's new quality leader. We consider a profit-division rule $s \in [0, 1]$, which denotes the share of flow profits that each new innovator must pay to the industry's incumbent patent holder to license its technology.

Overall patent protection, as defined by the (θ, s) pair, is exogenously determined by patent policy. However, quality leaders may further defend their incumbent position through endogenous private investment in *rent-protection activities* (RPAs). More specifically, competitors within each industry participate in stochastic R&D races to innovate the next quality improvement and supplant the incumbent leader. The arrival of innovations in each industry is governed by a memoryless Poisson process with intensity I. A competitor firm j that employs $L_{I,j}(t)$ units of labor in R&D innovates a new quality improvement and enters the market with instantaneous probability $I_j(t)dt$, where dt is an infinitesimal interval of time and $I_j(t) = L_{I,j}(t)/D(t)$. The difficulty of innovation, $D(t)$, depends on the amount of labor that the industry's incumbent employs in RPAs, $L_x(t)$, according to

$$D(t) \equiv \gamma[\delta L_x(t) + (1 - \delta)N(t)]. \tag{5}$$

Here, $\gamma > 0$ affects the overall difficulty of innovation and $0 \leq \delta \leq 1$ determines the effectiveness of RPAs in increasing innovation difficulty relative to exogenous factors. In the special case of $\delta = 0$, our specification of $D(t)$ is equivalent to the commonly used "permanent effects on growth" formulation in which RPAs have no effect and innovation difficulty is simply proportional to population size. If $\delta = 1$, our specification is equivalent to the original Dinopoulos and Syropoulos (2007) framework in which $D(t)$ is proportional to incumbent RPAs.[6] Our model

[6] Both cases remove the counterfactual scale-effects present in first generation endogenous growth models since innovation difficulty grows with the scale of the economy in equilibrium. Our model retains this scale-effects free property. For a discussion of the micro-foundations of the permanent effects on growth model, see Dinopoulos

offers a generalization of Dinopoulos and Syropoulos (2007) that allows for RPAs to influence innovation difficulty in combination with other factors. We emphasize that even though we refer to $D(t)$ as innovation difficulty, it can be interpreted to encompass all costs associated with both innovation and market entry. Similarly, an incumbent's use of RPAs captures the incumbent's combined efforts to raise the cost of this competitor entry as detailed in Section 1.1.[7]

The aggregate, industry-wide rate of innovation is obtained by summing over competitors

$$I(t) = \sum_j I_j(t) = \frac{L_I(t)}{D(t)}, \tag{6}$$

where $L_I(t) \equiv \sum_j L_{I,j}(t)$ is aggregate R&D employment in a typical industry.[8]

2.3 Labor and Production

Each household member is endowed with one unit of labor, which is supplied inelastically. Labor is used for three separate tasks in each industry: R&D, RPAs, and manufacturing final goods. As in Dinopoulos and Syropoulos (2007), labor is partitioned into two categories: non-specialized labor that is employed in either manufacturing or R&D and specialized labor that is used in RPAs.[9] A constant proportion $\alpha > 0$ of labor $N(t)$ is specialized, whereas the remaining $1 - \alpha$ proportion are non-specialized workers. Both types of labor grow at the population growth rate of n.

One unit of labor produces one unit of the final good in each industry. Thus, each quality leader's marginal cost of production equals the non-specialized wage, which is chosen to be the *numeraire*. Leaders compete in prices with a competitive fringe of firms that may imitate the current state-of-the-art quality. Given the backward protection provided by a patent, each leader is able to maintain a $\theta \in [1, \lambda]$ quality lead over these competitors. Therefore, as in Li (2001) and Goh and Olivier (2002), patent holders can drive imitative competitors out of the market by engaging in limit pricing such that $p(t) = \theta$. Competitors can do no better than break even and exit the market. Flow profits, gross of expenditure in RPAs, of each incumbent are

$$\pi(t) = \left(\frac{\theta - 1}{\theta}\right) c(t) N(t), \tag{7}$$

and Şener (2007). See also Dinopoulos and Segerstrom (1999) for a discussion of this case versus semi-endogenous specifications in which policy changes have only "temporary effects on growth."

[7] We do not allow for RPAs to directly influence patent protection. In Section S.4 of our supplementary material, we consider an extension to the model in which incumbents also use RPAs to defend their existing patent against invalidation claims by competitors. Since owners of invalidated patents are stripped of all legal rights, effective patent protection becomes endogenous. We show that our main results continue to hold in this setting.

[8] As is common, the presence of constant returns to scale in competitor R&D implies that the number of competitors conducting R&D in each industry is indeterminate. However, the industry-wide innovation rate is well defined in terms of total R&D employment within the industry as in (6).

[9] We discuss the implications of this assumption in Section 6.1.

where $\theta - 1$ is the profit margin and $c(t)N(t)/\theta$ is the total quantity sold. Exploiting symmetry across industries, the total employment in production is

$$L_z(t) = \frac{c(t)N(t)}{\theta}. \tag{8}$$

2.4 Stock Market Valuations and Optimal RPAs

Let $V_1(t)$ denote the value of winning an R&D race, successfully innovating a quality improvement and entering the market as the new quality leader. Free entry into R&D implies that in every industry with positive research expenditure, the expected return to R&D must equal its cost. Thus, in a symmetric equilibrium with $I(\epsilon, t) = I(t) > 0$, each competitor j hires R&D labor such that $L_{I,j}(t) = I_j(t)V_1(t)$.[10] Using (6), this is equivalent to

$$V_1(t) = D(t), \tag{9}$$

where $D(t)$ is given by (5).

Forward patent protection implies that the most recent innovation within each industry potentially infringes on the patent covering the previous quality iteration. The profit-division rule $s \in [0, 1]$ determines the terms of a licensing agreement between a new entrant and an incumbent for transferring production rights between the two sequential innovators. Specifically, when an entrant develops a new quality improvement, they must pay the incumbent patent holder an $s\pi(t)$ share of profits from the new innovation as a licensing fee in order to enter the market.

Let $V_2(t)$ denote the value of a firm holding patent rights over the second most recent innovation in a typical industry. As is standard, we express $V_2(t)$ through a no-arbitrage condition that equates the expected return from stock in this firm to the risk-free market rate, $r(t)$. Over an infinitesimal interval of time dt, the second most recent innovator receives a flow of licensing payments, $s\pi(t)dt$. With probability $I(t)dt$, a new innovation arrives and displaces the licensee, resulting in a capital loss of $V_2(t)$. With probability $(1 - I(t)dt)$, the licensee is not displaced and its stock appreciates by $[\partial V_2(t)/\partial t]dt = \dot{V}_2(t)dt$. This yields the following no-arbitrage condition,

$$r(t)V_2(t)dt = s\pi(t)dt - I(t)V_2(t)dt + (1 - I(t)dt)\dot{V}_2(t)dt. \tag{10}$$

Dividing both sides of this equation by dt and taking limits as $dt \to 0$ yields,

$$V_2(t) = \frac{s\pi(t)}{r(t) + I(t) - \frac{\dot{V}_2(t)}{V_2(t)}}. \tag{11}$$

Similarly, the no-arbitrage condition corresponding to the value of holding the most recent

[10] Following the literature standard, we focus on a symmetric equilibrium. See, for example, Cozzi *et al.* (2007).

innovation in a typical industry, $V_1(t)$, is given by

$$r(t)V_1(t)dt = (1-s)\pi(t)dt - w_x(t)L_x(t)dt - I(t)[V_1(t) - V_2(t)]dt + (1 - I(t)dt)\dot{V}_1(t)dt, \quad (12)$$

where $w_x(t) > 0$ is the relative wage rate of specialized RPAs labor. Note that the right hand side of (12) captures a new quality leader's flow profits net of licensing fees and expenditure on RPAs. Additionally, competitor innovation does not fully eliminate a new leader's value since its patent entitles it to licensing fees from the new entrant. Thus, the change in stock value associated with the arrival of a subsequent innovation is $[V_1(t) - V_2(t)]$. Dividing both sides of the no-arbitrage condition by dt and taking limits as $dt \to 0$ yields,

$$V_1(t) = \frac{(1-s)\pi(t) - w_x(t)L_x(t) + I(t)V_2(t)}{r(t) + I(t) - \frac{\dot{V}_1(t)}{V_1(t)}}. \quad (13)$$

Equation (13) expresses $V_1(t)$ in terms of the discounted value of net profits and the future value of licensing revenue. As is typical in Schumpeterian growth models, the discount factor in the denominator depends on the equilibrium rate that quality leaders are replaced, $I(t)$. Similarly, the presence of a $I(t)V_2(t)$ term in the numerator of (13) is typical of models that incorporate forward patent protection and blocking patents.

Each quality leader chooses $L_x(t)$ to maximize its value. This is equivalent to maximizing its expected stock return given by the right hand side of equation (12). It is convenient to express the resulting demand for RPAs labor in terms of the *elasticity of innovation with respect to RPAs*, denoted $\eta_x(t)$. That is, we define

$$\eta_x(t) \equiv \left| \frac{\partial I(t)}{\partial L_x(t)} \frac{L_x(t)}{I(t)} \right| = \frac{\delta L_x(t)}{\delta L_x(t) + (1-\delta)N(t)}, \quad (14)$$

where the final expression follows from the definition of $D(t)$ and $I(t)$ in equations (5) and (6). Note that $0 \le \eta_x(t) \le 1$ and that $\eta_x(t)$ corresponds directly to the effectiveness of RPAs in deterring competitor innovation. Using (14), the first order condition associated with the optimal demand for RPAs labor can be written

$$L_x(t) = \frac{I(t)\eta_x(t)[V_1(t) - V_2(t)]}{w_x(t)}. \quad (15)$$

Equation (15) expresses the demand for specialized RPAs labor in terms of a quality leader's marginal cost and benefit from engaging in RPAs. The marginal cost of hiring labor for RPAs is directly given by $w_x(t)$. The marginal benefit is the value associated with delaying displacement from a quality leadership position by increasing the difficulty of competitor innovation. This benefit depends on the capital loss associated with a transition to the second most recent innovator in an industry $[V_1(t) - V_2(t)]$, the rate at which this transition occurs via subsequent innovation $I(t)$, and the effectiveness of RPAs in deterring innovation $\eta_x(t)$.[11]

2.5 Equilibrium

We now solve the model for a steady-state equilibrium in which $I(t)$, $w_x(t)$, and $c(t)$ are constant, $L_x(t)$, $\pi(t)$, $V_1(t)$, and $V_2(t)$ grow at the rate of population growth n, the free-entry condition of (9) holds, quality leaders choose $L_x(t)$ to maximize their value, and the (partitioned) markets for non-specialized and specialized labor clear. Since specialized labor is used only for RPAs, the supply of RPAs labor is a fixed proportion of the total labor force, $\alpha N(t)$. In equilibrium, the wage rate $w_x(t) > 0$ adjusts such that this supply equals the demand for RPAs labor (15) and the market clears with $L_x(t) = \alpha N(t)$. Since non-specialized labor is used for both R&D and production, non-specialized labor market clearing requires that

$$(1-\alpha)N(t) = L_z(t) + L_I(t) = \frac{c(t)N(t)}{\theta} + L_I(t). \tag{16}$$

As in Dinopoulos and Syropoulos (2007), the following proposition shows that the aggregate economy jumps to a uniquely stable balanced growth path (BGP) along which all variables grow at a constant (possibly zero) rate.

Proposition 1. *Holding θ and s constant, the aggregate economy jumps to a unique and stable balanced growth path.*

Proof. See Appendix A. □

Given the stability of the model, we henceforth drop the time index for all variables that are constant in equilibrium.

Imposing specialized labor market clearing, $L_x(t) = \alpha N(t)$, in (14) allows us to express the elasticity of innovation with respect to RPAs as a constant function of parameters

$$\eta_x(\alpha, \delta) = \frac{\delta\alpha}{\delta\alpha + 1 - \delta}. \tag{17}$$

We will often suppress the parameter arguments of $\eta(\alpha, \delta)$ for brevity when there is no risk of confusion. Similarly, we can express innovation difficulty using (5) as

$$D(t) = N(t)d(\alpha, \delta, \gamma), \qquad \text{where} \qquad d(\alpha, \delta, \gamma) \equiv \gamma[\delta\alpha + 1 - \delta]. \tag{18}$$

Since free entry (9) requires that $V_1(t) = D(t)$, we have that $\dot{V}_1(t)/V_1(t) = n$. Using this result, the fact that (4) implies $r = \rho$ in equilibrium, and the optimal demand for RPAs (15), we can rewrite the no-arbitrage condition for a quality leader from (13) as

[11] Note that $V_1(t) > V_2(t)$ is required so that there is positive demand for RPAs. To simplify the analysis, we henceforth assume $s \leq 1/2$, which ensures that quality leaders retain more profits than they pay out through licensing fees and is a sufficient condition for $V_1(t) > V_2(t)$.

$$V_1(t) = \frac{(1-s)\pi(t) + [1+\eta_x(\alpha,\delta)]IV_2(t)}{\rho - n + [1+\eta_x(\alpha,\delta)]I}. \tag{19}$$

Equation (19) illustrates how each quality leader's use of RPAs influences the equilibrium value of developing a new quality innovation. Compared to the no-arbitrage condition that did not incorporate optimal RPAs expenditure (13), note that the replacement rate is now scaled by a $[1+\eta_x]$ term in the discount factor of (19). This reflects the fact that optimal expenditure on RPAs increases in $I\eta_x V_1(t)$, as in (15). Even though the supply of specialized RPAs labor is a fixed proportion of the population, the relative wage of specialized labor w_x adjusts so that the labor market always clears. Thus, by increasing demand for RPAs, any increase in I or $V_1(t)$ translates to a greater cost of RPAs usage. Similarly, since demand for RPAs decreases in $I\eta_x V_2(t)$, the future value of becoming the second most recent innovator enters as $[1+\eta_x]IV_2(t)$ and reflects each incumbent's cost savings on RPAs when w_x falls so that the market clears.

We now establish the equilibrium by deriving two equilibrium conditions in two endogenous variables I and c. Given equation (19) and $\dot{V}_1(t)/V_1(t) = n$, we have that $\dot{V}_2(t)/V_2(t) = n$. Thus, we can rewrite the previous leader's no-arbitrage condition (11) as

$$V_2(t) = \frac{s\pi(t)}{\rho - n + I}. \tag{20}$$

Using our expressions for $V_1(t)$ and $V_2(t)$ from (19) and (20), flow profits from (7) and innovation difficulty from (18), we can rewrite the free-entry condition (9) (henceforth *FE condition*) in terms of $\{I, c\}$ such that,

$$\underbrace{d(\alpha,\delta,\gamma)}_{D(t)/N(t)} = \underbrace{\frac{c}{\theta}\left(\frac{\theta-1}{\rho-n+[1+\eta_x(\alpha,\delta)]I}\right)\left(\frac{s[\eta_x(\alpha,\delta)I-(\rho-n)]}{\rho-n+I}+1\right)}_{V_1(t)/N(t)}. \tag{21}$$

Equation (21) provides an upward sloping relation between I and c. As is typical in endogenous growth models, a greater level of consumption expenditure c implies that developing an innovation is more profitable, which stimulates R&D investment and increases innovation.

Our second equilibrium condition comes from the non-specialized labor market clearing condition (henceforth *LMC condition*). Using (6) and (18), we have $L_I(t) = D(t)I = N(t)d(\alpha,\delta,\gamma)I$. Thus, equation (16) becomes

$$1-\alpha = \frac{c}{\theta} + d(\alpha,\delta,\gamma)I, \tag{22}$$

which is a downward sloping relation between I and c. This reflects the typical resource allocation trade-off between non-specialized labor in manufacturing versus R&D. As illustrated in Figure 1, panel (b), the intersection of (21) and (22) determines the unique equilibrium values of I and c.

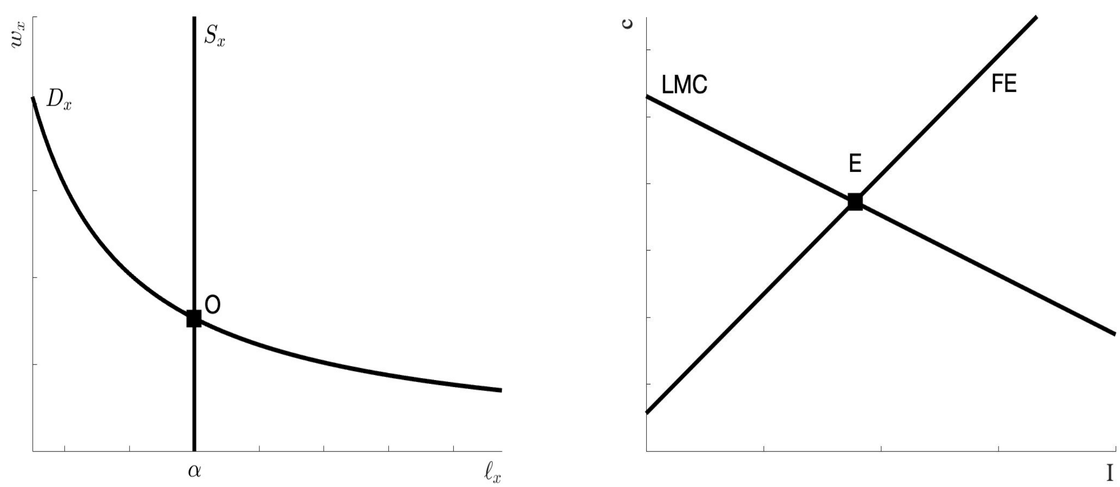
Recall that the FE condition (21) embeds optimal RPAs expenditure into the value of a new innovation. To highlight how the endogenous use of RPAs impacts the implications of patent policy, we also include an illustration of the specialized RPAs labor market in Figure 1, panel (a). Since both the supply and demand for RPAs labor scale proportionally with the economy's population, we graph the wage of specialized labor w_x against the *share* of labor employed in RPAs, denoted $\ell_x \equiv L_x(t)/N(t)$. Together with the supply of a constant share of specialized RPAs labor, labeled S_x, we graph the optimal demand for RPAs in terms of ℓ_x using (15). Specifically, substituting our expressions for $V_1(t)$ and $V_2(t)$ from equations (19) and (20) into (15) yields

$$w_x = \frac{c}{\ell_x \theta}\left(\frac{I\eta_x(\alpha,\delta)(\theta-1)}{\rho-n+[1+\eta_x(\alpha,\delta)]I}\right)\left(1-\frac{s[2(\rho-n)+I]}{\rho-n+I}\right), \tag{23}$$

which is a downward sloping demand function (D_x) between ℓ_x and w_x at any $\{I, c\}$.

Figure 1: Equilibrium

(a) Market for RPAs (b) Equilibrium c, I



Finally, we follow the standard practice in quality-ladder growth models and define economic growth as the growth rate of per capita sub-utility $u(t)$. Per capita sub-utility $u(t)$ in the steady-state equilibrium is given by a deterministic expression such that $\ln u(t) = \ln(c/\theta) + tI\ln\lambda$. Therefore, given that per capita consumption c is constant, the model inherits the usual property that the equilibrium rate of economic growth is proportional to the rate of innovation such that

$$g \equiv \frac{\dot{u}(t)}{u(t)} = I\ln\lambda, \tag{24}$$

where $\ln\lambda > 0$ represents the utility benefit from each innovation.

3 Policy Implications

In this section, we examine how changes to patent policy influence the steady-state equilibrium of the model. As shown in Proposition 1, this model does not exhibit transitional dynamics and immediately shifts to its new steady state. We analyze comparative-statics exercises that represent strengthened backward and forward protection through two policy parameters, θ and s. Our primary focus is to understand how each of these policy tools affects the general-equilibrium relationship between RPAs and economic growth.

3.1 Backward Protection

Strengthening backward protection (increasing θ) directly increases the markup that a quality leader can charge over marginal cost. First, consider how this policy change influences the market for RPAs. By raising each leader's flow profits, incumbents have a greater incentive to invest resources in RPAs to protect their monopoly position. This effect is illustrated in Figure 2, Panel (a) as a rightward shift in the demand for RPAs (equation (23)). As a result, RPAs expenditures increase along with the relative wage of specialized labor at any level of I and c.

On the other hand, the larger flow profits associated with successful innovation increases potential innovators' incentive to invest in R&D. Since the FE condition (equation (21)) includes the cost of optimal RPAs expenditure, it captures the net effect on the value of an innovation as a result of this traditional growth-promoting reward effect against the increased cost of RPAs. Using (21), it is clear that the policy change implies a larger rate of innovation I at any level of consumption expenditure c, and the FE condition shifts rightward in Figure 2, Panel (b). In addition, the increase in prices associated with strengthened backward protection implies that fewer labor resources are used in production at each level of consumption expenditure (see equation (8)). This frees up non-specialized labor available for R&D and shifts the LM curve rightward. Both of these changes imply an increase in the innovation rate and thus economic growth. This comparative statics result for θ is consistent with previous studies such as Li (2001), O'donoghue and Zweimüller (2004), and Yang (2018) and suggests that the increased cost of RPAs only partially counteracts the traditional growth-promoting effect of stronger backward protection. This result is summarized in the following proposition.

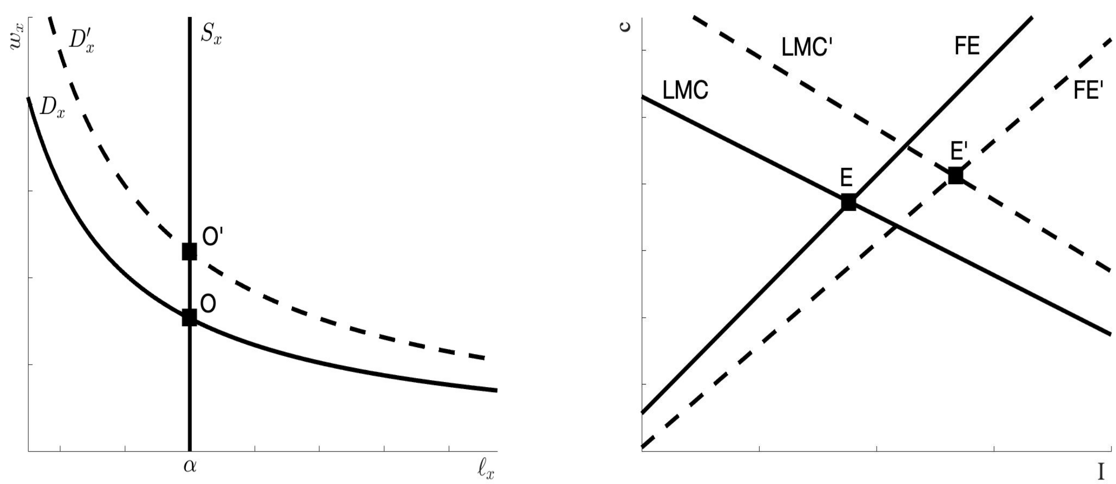
Proposition 2. *Strengthening backward protection increases the equilibrium growth rate. That is, g is strictly increasing in θ.*

3.2 Forward Protection

Strengthening forward protection (increasing s) impacts the free-entry condition through two competing effects on the value of an innovation, which is given by the right hand side of (21). The presence of $-s(\rho - n)$ reflects the established negative *backloading effect* of blocking patents;

Figure 2: Strengthening backward protection ($\theta \uparrow$)

(a) Market for RPAs (b) Equilibrium



a greater profit division s implies larger licensing fees transferred from the current innovator to the previous one. Since licensing fees are paid before licensing revenue is received, this effect reduces the value of each innovation and decreases incentives to invest in R&D. The size of the backloading effect is fixed by the effective discount rate, $\rho - n$. The presence of $s\eta_x I$ reflects a novel and positive *cost-saving effect* of blocking patents that operates through the market for RPAs. A greater profit division s implies a higher value of a firm after it is displaced from its leadership position. As illustrated in Figure 3, Panel (a), this reduces demand for RPAs and the relative wage of specialized labor. The associated decrease in the cost of conducting RPAs increases the value of an innovation and incentives to invest in R&D. Critically, the size of this cost-saving effect depends on the equilibrium rate of innovation, I, and the effectiveness of RPAs in deterring innovation, η_x. This is because higher rates of innovation and RPAs effectiveness both imply greater initial demand for RPAs, and a larger reduction in RPAs expenditure when s increases.

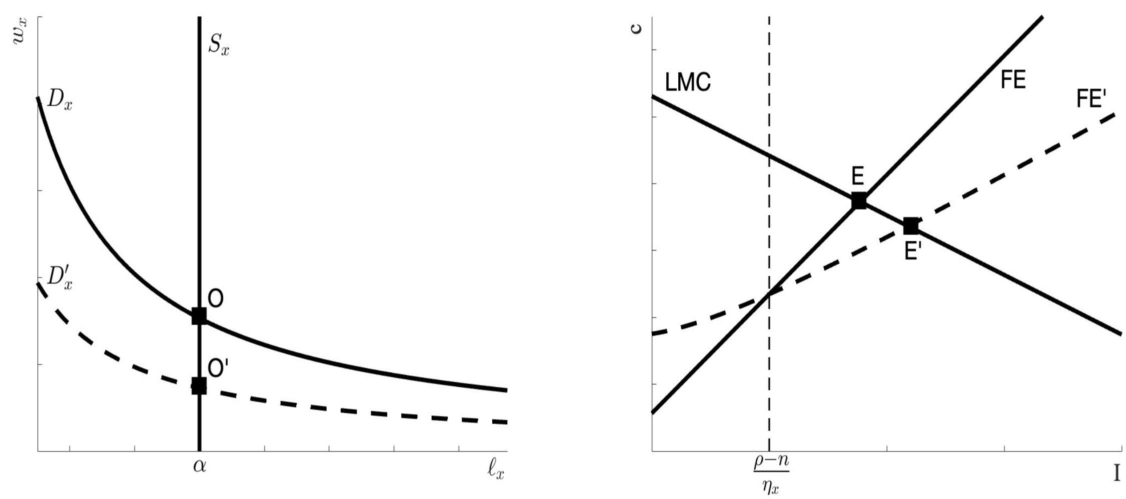
Since the supply of specialized RPAs labor is a fixed proportion of the population, strengthening forward protection does not affect equilibrium employment in RPAs, the difficulty of innovation or the availability of non-specialized labor for R&D and production. Indeed, the policy change has no impact on the labor market clearing condition. Whether strengthening forward protection stimulates or stifles economic growth depends entirely on how the policy influences the return to R&D through the backloading effect and the cost-saving effect. The interplay between these two competing forces creates a *threshold effect* of blocking patents that is determined by the initial equilibrium rate of innovation relative to the discount rate $\rho - n$ and the effectiveness of RPAs η_x. When graphed in (I, c) space, strengthening forward protection causes the

FE condition to rotate around a threshold innovation rate equal to $(\rho - n)/\eta_x$. As illustrated in Figure 3, this implies that when the innovation rate I is smaller (greater) than $(\rho - n)/\eta_x$, a higher s decreases (increases) the innovation rate.[12] This result is summarized in the following proposition.

Figure 3: Strengthening forward protection ($s \uparrow$)

(a) Market for RPAs

(b) Equilibrium



Proposition 3. *Strengthening forward protection increases (decreases) the equilibrium growth rate g if the innovation rate is sufficiently high (low), namely $(\rho - n)/\eta_x(\alpha, \delta) < (>) I$. Equivalently, g increases in s if*

$$\rho - n < \frac{(1-\alpha)(\theta - 1)\eta_x(\alpha, \delta)}{d(\alpha, \delta, \gamma)[\theta + 2\eta_x(\alpha, \delta)]}, \tag{25}$$

and decreases in s otherwise. $\eta_x(\alpha, \delta)$ and $d(\alpha, \delta, \gamma)$ are given by (17) and (18) respectively.

Proof. As argued in the main text, it follows from (21) and (22) that strengthening forward protection is growth enhancing if the innovation rate exceeds a threshold value, $(\rho - n)/\eta_x < I$. We characterize the parameter condition associated with $(\rho - n)/\eta_x < I$ in two steps. First, we compare $(\rho - n)/\eta_x$ to the equilibrium value of the innovation rate I when $s = 0$ ($I|_{s=0}$). Second, we argue that if $(\rho - n)/\eta_x < I|_{s=0}$, then $(\rho - n)/\eta_x < I|_{s>0}$ for all $s \in [0, 0.5]$.

Using (21) and (22) with $s = 0$, we have

$$I|_{s=0} = \frac{(1-\alpha)(\theta - 1)}{d(\alpha, \delta, \gamma)[\theta + \eta_x(\alpha, \delta)]} - \frac{\rho - n}{\theta + \eta_x(\alpha, \delta)}. \tag{26}$$

[12] Note that strengthening forward protection does not affect economic growth in the edge case where $I = (\rho - n)/\eta_x$ because the cost-saving and backloading effects exactly offset.

Using (26), the condition $(\rho - n)/\eta_x < I|_{s=0}$ is identical to the parameter condition of (25). Thus, $[\partial I/\partial s]|_{s=0} > 0$ if (25) holds. Next, let (25) hold and consider a marginal increase in s from $s = 0$ to $s' > 0$. Since $[\partial I/\partial s]|_{s=0} > 0$, we have $(\rho - n)/\eta_x < I|_{s=0} < I|_{s=s'}$. This implies that the innovation rate remains greater than the $(\rho - n)/\eta_x$ threshold, and that $[\partial I/\partial s]|_{s=s'} > 0$. Repeating the same procedure for an arbitrary number of sufficiently small increases in s shows that $[\partial I/\partial s] > 0$ for any $s \in [0, 0.5]$ when (25) holds. An identical argument shows that $[\partial I/\partial s] < 0$ for any $s \in [0, 0.5]$ when the inequality in (25) is reversed. □

Proposition 3 shows that increasing the profit-division rule stimulates innovation and economic growth when (i) the effective discount rate $\rho - n$ is low, which implies that the backloading effect is relatively small or (ii) demand for RPAs is high, which implies that the cost-saving effect from reducing RPAs demand is relatively large. This is likely to be the case when RPAs are relatively effective at deterring innovation (η_x) and/or the model's parameters are conducive to a high rate of innovation in equilibrium. This includes strong backward patent protection (θ) according to Proposition 2, a large share of non-specialized labor that can be used in R&D ($1 - \alpha$), and low overall innovation difficulty ($d(\alpha, \delta, \gamma)$).

4 Welfare

In the absence of transitional dynamics as shown in Proposition 1, instantaneous per capita utility is expressed as $\ln u(t) = \int_0^1 \ln[\sum_{q(\epsilon,t)} \lambda^{q(\epsilon,t)}(c/\theta)]d\epsilon$, where we use each incumbent's limit price of $p = \theta$. Substituting this expression into (1), we obtain the following steady-state welfare function

$$(\rho - n)U(I, c) = \left(\frac{\ln \lambda}{\rho - n}\right) I + \ln c - \ln \theta. \tag{27}$$

We consider a social planner who chooses per capita consumption c and the innovation rate I to maximize social welfare in (27), subject to the resource constraint (22). As in Dinopoulos and Syropoulos (2007) and Klein (2020), this implicitly assumes that the social planner cannot control the allocation of resources to RPAs, nor affect the pricing decisions of industry leaders. Thus, the social planner's constraint reflects the traditional trade-off between the resources allocated to the production of final goods and R&D. Optimization results in the following expression that equates the social cost and return of R&D,

$$d(\alpha, \delta, \gamma) = \frac{c}{\theta}\left(\frac{\ln \lambda}{\rho - n}\right). \tag{28}$$

The analogous expression for the market cost and return of R&D is given by the FE condition, (21).

Comparing (21) and (28) illustrates several reasons that the socially optimal and market levels of R&D may differ. The model inherits two effects from the previous RPAs literature. First, the *monopoly-distortion effect* arises because the social planner scales the utility benefit of an innovation by $\ln \lambda$ in (28), while private firms are concerned with the potential monopoly markup rate of $\theta - 1$ in (21). Depending on the relative magnitude of $\ln \lambda$ and $\theta - 1$, this effect implies that equilibrium R&D investment may be either too high or too low. Second, the *intertemporal-spillover effect* is present because the social planner discounts the benefits of each innovation by $\rho - n$, whereas the effective market discount rate of $\rho - n + [1 + \eta_x]I$ incorporates the expected loss due to creative destruction by subsequent innovation, in addition to the cost of deterring innovation through RPAs investment. This effect suggests that equilibrium R&D investment is too low. In addition, the impact of forward protection on market RPAs and R&D incentives creates a novel *blocking-patent effect*, captured by the $s[\eta_x I - (\rho - n)]/(\rho - n + I)$ term in (21). Exactly as in Proposition 3, the direction of this effect depends on whether the cost-saving effect dominates the backloading effect of blocking patents. Specifically, if $(\rho - n)/\eta_x < (>) I$, the blocking-patent effect implies that equilibrium R&D investment is too high (low).

To illustrate how the use of RPAs determines the welfare impact of forward protection through the blocking-patent effect, we compare the socially optimal rate of innovation (I^*) to the equilibrium innovation rate I in the absence of forward protection (i.e. $I|_{s=0}$ given by (26)).[13] Solving the social planner's problem yields

$$I^* = \frac{1 - \alpha}{d(\alpha, \delta, \gamma)} - \frac{\rho - n}{\ln \lambda}. \tag{29}$$

Using (26), we have

$$I^* - I|_{s=0} = \frac{1}{\theta + \eta_x(\alpha, \delta)} \left\{ \frac{(1-\alpha)[\eta_x(\alpha, \delta) + 1]}{d(\alpha, \delta, \gamma)} - (\rho - n) \left[\frac{\theta + \eta_x(\alpha, \delta)}{\ln \lambda} - 1 \right] \right\}. \tag{30}$$

This comparison shows that the equilibrium $I|_{s=0}$ can in principle be less than or greater than the socially optimal I^* depending on parameter values. Observe from equation (30) that, ceteris paribus, $I^* - I|_{s=0}$ increases in the elasticity of innovation with respect to RPAs, η_x. This is because greater effectiveness of RPAs reduces the equilibrium innovation rate when forward protection is absent, but does not directly impact the socially optimal innovation rate. In this way, the equilibrium tends towards an inefficiently low rate of innovation when RPAs are an effective innovation deterrent. Given that our theoretical framework belongs to a class of Schumpeterian models that typically exhibit underinvestment in R&D across a broad range of plausible parameters even in the absence of RPAs, our analysis suggests that the presence of RPAs is likely to further exacerbate this inefficiency.[14] This implies that improving social welfare will tend to

[13] Using (21) and (22), the equilibrium innovation rate I in the general $s > 0$ case can be determined through a second degree equation. Although it is possible to identify the root that corresponds to the unique equilibrium $I > 0$, the resulting expression is complex and does not yield additional insights.

[14] Indeed, when we calibrate the model for numerical analysis in the following section, we uniformly find inefficiently low rates of innovation across all initial equilibria that we consider. See Jones and Williams (2000) for a classic discussion of this common tendency in Schumpeterian models.

require policy changes that increase the equilibrium rate of innovation.

According to Proposition 3, the impact of forward protection on the innovation rate is determined by the relationship between $I|_{s=0}$ and the threshold $(\rho - n)/\eta_x$. Specifically, the parameter condition of (25) shows that forward protection increases innovation when RPAs are sufficiently effective because the associated reduction in RPAs demand generates a greater cost-saving effect. Thus, the presence of positive forward protection both stimulates innovation and enhances welfare when parameters are such that $(\rho - n)/\eta_x < I|_{s=0} < I^*$. We conclude that this case is most likely to occur when η_x is large and firms' private efforts to protect their market position through RPAs effectively impede innovation and entry.

5 Numerical Analysis

In this section, we calibrate the model to aggregate data of the US economy and provide a quantitative illustration of how patent holders' endogenous use of RPAs impacts the traditional implications of patent policy.

5.1 Calibration

The model features six structural parameters $\{\rho, n, \lambda, \alpha, \delta, \gamma\}$ and two patent policy variables $\{\theta, s\}$. Backward patent protection, θ, directly determines each quality leader's markup over marginal cost. We set initial backward protection to $\theta_0 = 1.08$, which implies an 8% markup, to be consistent with empirical estimates.[15] Following Yang (2018) and Klein (2022), we set initial forward protection to $s_0 = 0.15$ so that licensing fees are equal to a 15% share of profits. This is consistent with Chu (2009), who structurally estimates a "backloading discount factor" in the presence of blocking patents that captures the expected fraction of monopolistic profit retained by the innovator. This represents the inverse measure of licensing fees in our context, $1 - s$. Since Chu (2009) calibrates this discount factor to values between $[0.48, 0.85]$, we choose a conservative initial value of $s_0 = 0.15$ that is in line with the lower-bound calibrated value.[16] As is standard, we set the discount factor to $\rho = 0.05$ and set $n = 0.01$ to reflect the 1% long-run average growth rate of the US labor force (Chu and Cozzi, 2018; Chu *et al.*, 2019; Klein, 2022). This implies an effective discount rate of $\rho - n = 0.04$. We set the proportion of specialized RPAs labor to

[15] For example, Basu *et al.* (2006) estimate an average mark-up of 7% for durable manufacturing and Gutiérrez and Philippon (2017) estimate an average 10% markup overall in 2015. See Basu (2019) for a detailed overview of this empirical literature on price markups.

[16] As in Chu (2009), each new innovator must pay licensing fees to the previous innovator in order to enter the market. However, since all firms are risk neutral in our model, we may interpret s_0 as the expected share of profits that new innovators pay in licensing fees given some constant probability that a licensing agreement is required. See Section S.4 of this paper's supplementary material for a framework in which new innovators only pay licensing fees to an endogenous share of incumbents that maintain a valid patent. See also Klein (2022) for a similar setting that differentiates between the size of individual licensing agreements when a new innovation infringes on an existing patent and the probability that such infringement occurs. We thank an anonymous referee for raising this important point.

$\alpha = 0.0075$, or three quarters of a percent, to be consistent with the number of active lawyers and lobbyists in the US, relative to the total labor force.[17]

We calibrate the size of each quality improvement, λ, using the equilibrium relationship between economic growth and the innovation rate from equation (24), $g = I \ln \lambda$. Specifically, we target $g = 2\%$ to reflect long-run growth in the US and set λ such the corresponding innovation rate is consistent with empirical estimates of the average profitable lifespan of patents. For example, Deng (2011) uses data on patent renewals to estimate a median patent lifespan of 12 years in the pharmaceutical industry and 14 years in electronics. Bilir (2014) and Chen and Shao (2020) use data on forward patent citations to estimate patent lifespans that range from about 6 to 11 years across industries. In our model, each patented innovation remains profitable until two subsequent innovations occur. This is because each patent holder earns profits as quality leader and licensing revenue as the second most recent innovator in the industry. Thus, the expected patent lifespan in the model is $2/I$. In our benchmark calibration, we choose an intermediate patent lifespan of 11 years and set $\lambda = 1.1163$ so that the implied innovation rate of $I = 2/11 = 0.1818$ corresponds to a 2% rate of economic growth.

We jointly calibrate our remaining two innovation difficulty parameters, γ and δ, to match our target 2% growth rate and a target for firm expenditure on RPAs. Specifically, with α given, the elasticity of innovation with respect to RPAs, $\eta_x(\alpha, \delta)$, is determined by the importance of RPAs in innovation difficulty, δ. Since η_x strongly influences the demand for RPAs, we calibrate δ such that equilibrium RPAs expenditure as a proportion of firm revenue is consistent with empirical estimates. For example, firm expenditure on legal services averages between 0.5% and 2.7% of revenue across industries and firm size.[18] Average lobbying expenditure is comparatively minor and is concentrated among a small number of large firms. Still, these firms persistently spend tens of millions of dollars annually on lobbying, on the order of 0.1% of revenue (Huneeus and Kim, 2021; Kim and Parenti, 2023). We are not aware of direct estimates of the cost of firms' efforts to mask technology from competitors. However, as discussed in Section 1.1, anecdotal evidence suggests that it too may be substantial. In line with this evidence, we choose a benchmark target of RPAs expenditure equal to 1.5% of firm revenue. We summarize all calibrated parameter values, along with the implied value of $\eta_x(\alpha, \delta)$ in Table 1. As reported in Table 2, we match our growth rate, patent life and RPAs expenditure targets exactly.

5.2 Numerical Results

Table 2 reports results from a benchmark policy experiment of strengthening of both types of patent protection separately. In accordance with Proposition 2, we find that strengthening

[17] In 2022, there were approximately 1.3 million lawyers (American Bar Association, 2022) and 12,500 registered lobbyists in the US (Giorno, 2023). The total labor force was 164.3 million in the US according to the BLS.

[18] These data come from two firm surveys administered by the Corporate Legal Operations Consortium (2019) and the Association of Corporate Counsel (2021). We use these data to help inform plausible bounds on the scale of RPAs spending, but do not intend to suggest that all legal services should be characterized as RPAs.

Table 1: Benchmark calibration summary

Parameter	Description	Value	Source/Target
External			
ρ	Discount factor	0.05	Standard
n	Population growth rate	0.01	US labor force growth, BLS
α	Proportion RPAs Labor	0.0075	Various, see fn. 14
s_0	Initial forward protection	0.15	Chu (2009)
θ_0	Initial backward protection	1.08	Basu (2019), see fn. 13
Internal			
δ	Innovation difficulty, RPAs	0.9888	RPAs exp. / revenue (1.5%)
γ	Innovation difficulty, overall	14.100	Economic growth (2%)
λ	Innovation size	1.1163	Patent lifespan (11 years)
$\eta_x(\alpha, \delta)$	Implied elasticity of I w.r.t. RPAs	0.3984	–

backward patent protection stimulates innovation and economic growth. Specifically, increasing θ from 1.08 to 1.088 increases firm markups by 10% and generates a substantial increase in the economic growth rate of almost a quarter percentage point. The more rapid pace of innovation results in a decrease in the average profitable lifespan of patents of about 1.1 years. The policy change is also welfare improving, which implies R&D underinvestment in the initial market equilibrium as is typical in Schumpeterian growth models. Observe that RPAs expenditure does increase by about 0.17% of firm revenue when backward protection is strengthened. This follows from incumbents' increased demand for RPAs as illustrated in Figure 2 and represents a cost of the policy change specific to the use of RPAs. However, this RPA effect is dominated by the standard growth-enhancing effect of directly increasing monopoly markups and the profits associated with innovation.

We find that strengthening forward patent protection also stimulates innovation, increases economic growth and improves welfare. The guarantee of a larger share of the next innovator's profits reduces each incumbent's demand for RPAs and RPAs expenditure decreases by over 0.3% of firm revenue. This growth-enhancing cost-saving effect dominates the traditional growth-reducing backloading effect from increasing the share of profits that each new innovator must pay out as licensing fees before earning it back as licensing revenue from the next innovator. However, the quantitive impact of the policy change is relatively small. We find that a 100% increase in s, from 0.15 to 0.30, increases growth by only about 0.05 percentage points and decreases the lifespan of patents by 0.27 years. This suggests that the cost savings from reducing RPAs expenditure only just offsets the added cost of associated with larger licensing fees from stronger blocking patents in our benchmark calibration.

However, the relative importance of the cost-saving and backloading effects depends on the scale of RPAs expenditure in the initial equilibrium. This in turn depends on the initial innovation

Table 2: Benchmark: strengthening patent protection

	Benchmark $\theta = 1.08$, $s = 0.15$	Backward protection $\theta = 1.088$, $s = 0.15$	Forward protection $\theta = 1.08$, $s = 0.30$
Growth rate (g%)	2.000	2.225	2.051
Patent life ($2/I$)	11.00	9.888	10.73
RPAs exp. (% revenue)	1.500	1.666	1.184
Consumption (c)	1.020	1.022	1.019
Welfare (U)	11.08	12.35	11.36

rate and the effectiveness of RPAs in deterring innovation. To see this, we first examine the impact of forward protection for across four distinct initial equilibria that are differentiated by the relative effectiveness of, and thus demand for, RPAs. Specifically, we repeat our calibration procedure using alternate target moments based on the lower and upper bound of estimates for RPAs expenditure as a percent of firm revenue, 0.5% and 2.5%. For comparison purposes, we also examine a case where RPAs have no impact on innovation difficulty ($\delta = \eta_x = 0$) and RPAs expenditure is always zero. For each of these alternate cases, we recalibrate both δ and γ to match the associated RPAs target, while holding constant the initial innovation rate so that economic growth remains 2%. We illustrate the impact of forward patent protection in each case in Figure 4. The dotted lines at $s_0 = 0.15$ mark the initial equilibria where RPAs expenditure matches its associated target and the 2% growth rate is common across cases.[19]

When $\eta_x = 0$, RPAs expenditure is zero for any level of forward protection. Since strengthening forward protection does not generate a cost-saving effect in this case, only the backloading effect is present. As in the endogenous growth literature that examines blocking patents in the absence of RPAs, we find that economic growth monotonically decreases in s (O'donoghue and Zweimüller, 2004; Chu, 2009; Yang, 2018; Klein, 2022). In the three cases with $\eta_x > 0$, the cost-saving effect is present since RPAs expenditure decreases in s. However, the relative size of the cost-saving effect depends on the amount of resources that firms devote to RPAs in the initial equilibrium with $s_0 = 0.15$. This is because the a greater initial demand for RPAs implies a greater reduction in RPAs expenditure when forward protection is strengthened. For instance, in the low RPAs effectiveness case where the calibrated value of η_x is 0.109, firms initially spend 0.5% of revenue on RPAs. A change from $s = 0.15$ to $s = 0.30$ results in a reduction in RPAs expenditure of just 0.1% of revenue. This is insufficient to offset the backloading effect, and

[19] As discussed in Section 4, we find that the model produces an inefficiently low equilibrium innovation rate across a wide range of plausible parameter values. In particular, in each case that we examine in this section, the equilibrium innovation rate remains inefficiently low over the entire range of patent policy we consider, $\theta \in [1, \lambda]$ and $s \in [0, 0.5]$. This implies that changes to patent policy improve welfare if and only if they increase innovation. We discuss this tendency of the model and its implications for optimal patent policy further in Section S.2 of our supplementary material.

economic growth still decreases by about 0.03 percentage points. However, in our benchmark case and the high RPAs effectiveness case, the same policy change generates a greater savings of over 0.3% and 0.5% of revenue respectively. This dominates the backloading effect and economic growth increases by 0.05% and 0.17% respectively in these two cases.

Figure 4: Numerical results: RPAs effectiveness and forward protection

(a) RPAs expenditure

(b) Economic growth

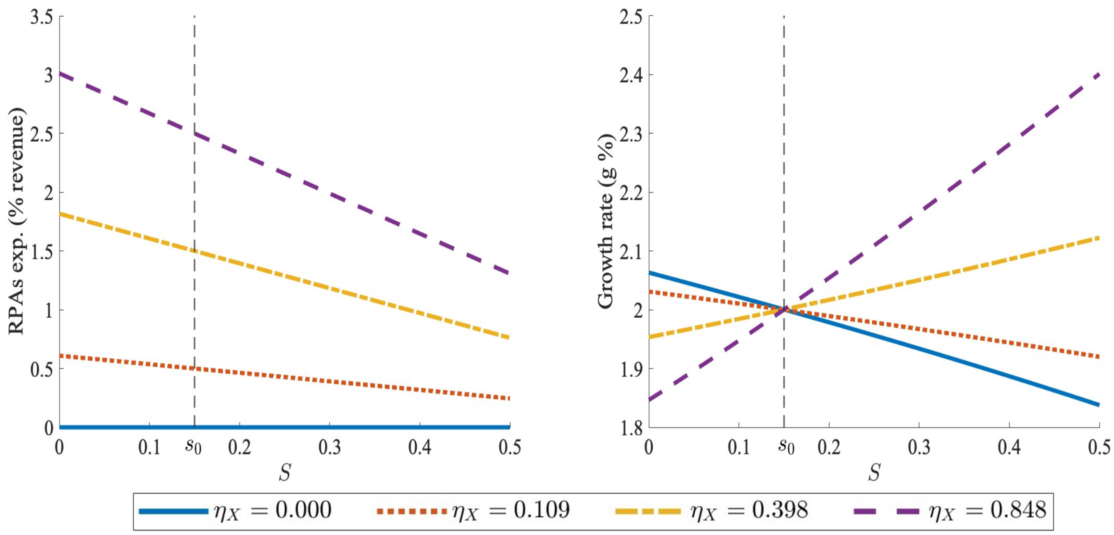


Figure 4 displays the impact of forward protection over the range $s \in [0, 0.5]$ in four cases where RPAs expenditure equals $[0.0\%, 0.5\%, 1.5\%, 2.5\%]$ of revenue respectively in the initial equilibrium with $s = s_0 = 0.15$. The associated parameter values are $\delta = [0.0000, 0.9423, 0.9888, 0.9987]$ and $\gamma = [0.3274, 4.724, 14.10, 24.73]$, which imply that $\eta_x(\alpha, \delta) = [0.00, 0.109, 0.398, 0.848]$. All other parameters remain as reported in Table 1.

Next, we highlight how the initial pace of innovation influences the impact of forward protection through its effect on the use of RPAs. To do this, we consider two additional targets for the profitable lifespan of patents, a high innovation case of 6 years and a low innovation case of 16 years. Since the expected life of a patent is $2/I$ in the model, these targets correspond to $I_0 = 0.333$ and $I_0 = 0.125$ respectively. For each case, we consider the change in economic growth associated with the same strengthening of forward protection from $s_0 = 0.15$ to $s = 0.30$ across distinct values of η_x in increments of 0.05 in a grid from 0 to 1. For each of these 21 values of η_x, we set δ accordingly then calibrate γ to match the targeted initial innovation rate exactly. See Table S.1 in this paper's supplementary material for calibrated δ and γ values. All other parameters remain as reported in Table 1.

We display the results of this policy experiment in Figure 5. The solid red curve corresponds to our benchmark calibration where initial expected patent life is 11 years, and the implied initial innovation rate is $I_0 = 0.1818$. Thus, at the four values of η_x previously considered in Figure 4, this curve directly illustrates our prior results of the growth impact of strengthening forward protection to $s = 0.30$. Note also that the threshold value of η_x for which forward protection becomes growth enhancing is given by where the curve crosses the dotted line at $\Delta g = 0$. As shown in Proposition 3, forward protection increases economic growth when $(\rho - n)/\eta_x < I$. Given our calibrated value of $\rho - n = 0.04$ and $I_0 = 0.1818$, the threshold value of η_x is 0.22 when expected patent life is 11 years.

Figure 5: Numerical results: patent lifespan and forward protection

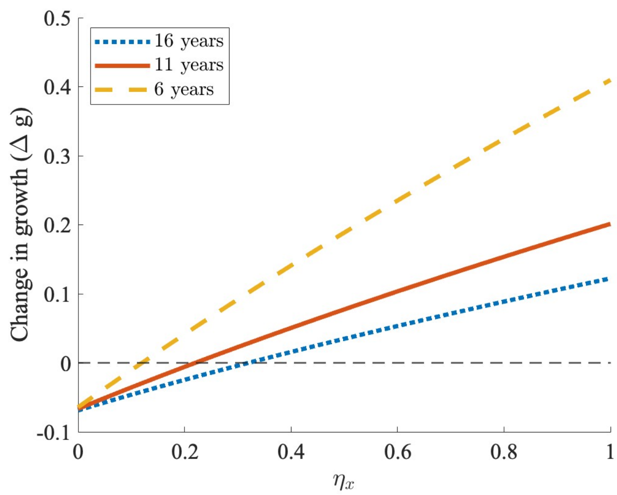


Figure 5 displays the change in economic growth associated with strengthening forward protection from $s_0 = 0.15$ to $s = 0.30$ in three cases where patent lifespan equals 6, 11, and 16 years in the initial equilibrium. We repeat this exercise across values of $\eta_x \in [0, 1]$ in increments of 0.05. For each of the 21 values of η_x, we set δ accordingly then calibrate γ to match the innovation rate associated with each of the three patent lifespans. See Table S.1 for calibrated values. All other parameters remain as reported in Table 1.

We find that shorter patent life, and thus more rapid innovation, both expands the range of η_x for which forward protection is growth enhancing and increases the quantitative impact on the growth rate. That is, no matter the innovation rate, forward protection always decreases economic growth when η_x approaches zero because cost savings from reduced RPAs expenditure are eliminated. However, in the high innovation case where expected patent life is 6 years, forward protection becomes growth enhancing at a relatively low $\eta_x = 0.12$ threshold. When patent life is 16 years, this same threshold is $\eta_x = 0.32$. At any particular value of $\eta_x > 0$, strengthening forward protection yields a larger increase in economic growth when the initial innovation rate is higher. For example, using the previous high RPAs effectiveness value of $\eta_x = 0.848$, we find that strengthening forward protection from $s_0 = 15$ to $s = 0.30$ generates a 0.10, 0.17, and 0.35 percentage point increase in the growth rate when initial expected patent life is 16, 11, and 6 years respectively. We conclude that the quantitative impact of forward protection on economic growth can indeed be substantial when innovation is rapid and RPAs are an effective innovation deterrent.

Overall, these numerical results help to identify conditions under which forward patent protection can be used as an effective policy tool to stimulate innovation and economic growth.

Specifically, we find that forward protection is more likely to facilitate innovation when incumbent firms devote substantial resources to their private efforts to deter competitor innovation. This can occur both as a response to rapid innovation and entry by competitors or in cases where RPAs are particularly effective at impeding competitor innovation. Our analysis suggests that an understanding of whether these conditions are in place and how they may vary across sectors of the economy can facilitate the implementation of effective patent policy.

6 Discussion

In this section, we consider the role of two important assumptions present in our analysis. In Section 6.1, we discuss the partition of the labor force into specialized and non-specialized groups and examine a setting in which labor is instead fully mobile across RPAs, R&D and production. In Section 6.2, we consider the implications of allowing incumbent firms to improve the quality of their own products by investing in R&D.

6.1 Fully Mobile Labor

The baseline model partitions the labor force into a fixed proportion of specialized labor employed only in RPAs and non-specialized labor employed in either manufacturing or R&D. This assumption prevents any crowding-out effects between the resources used for RPAs and those used for R&D. In particular, changes to the demand for RPAs do not directly impact the resources available for, nor the resource cost of, R&D. In this section, we instead suppose that all labor is mobile across these three activities. This implies a single type of labor that earns a common equilibrium wage rate, which is normalized to unity. To keep the analysis concise, we focus on the special case of $\delta = 1$ in (5) so that $D(t) = \gamma L_x(t)$ and the elasticity of innovation with respect to RPAs η_x given by equation (14) is always equal to 1.[20]

The primary effect of mobile labor is that the use of RPAs is no longer fixed by its associated labor supply, but is determined endogenously by the demand for RPAs. Specifically, the supply of RPA labor is now perfectly elastic at $w_x = 1$. After imposing $\eta_x = 1$ and $w_x = 1$, the demand for RPAs remains unchanged from (15), with $L_x(t) = I(t)[V_1(t) - V_2(t)]$. The free-entry condition remains $V_1(t) = D(t)$ as in (9). Since the wage for RPA labor is fixed, the equilibrium innovation rate is completely determined by relative incentives to invest in R&D and RPAs. To see this, first note that the ratio of the free-entry condition (9) and the demand for RPAs yields the following,

$$\underbrace{I(t)[V_1(t) - V_2(t)]}_{RPAs} = \underbrace{\frac{V_1(t)}{\gamma}}_{R\&D} . \tag{31}$$

[20]In Section S.3 of our supplementary material, we show that this version of the model with mobile labor is equivalent to a "lab-equipment" setting in which the input for both RPAs and R&D is a final consumption good, rather than labor.

After imposing $\eta_x = 1$, the expressions for V_1 and V_2 are given by (19) and (20) and remain unchanged from the baseline model. The left hand side of (31) captures each incumbent's incentives to invest in RPAs, and is strictly increasing in I. The right hand side captures R&D incentives in terms of the reward for successful innovation, and is strictly decreasing in I.

Comparative statics policy results follow immediately. Specifically, using our expressions for V_1 and V_2, equation (31) simplifies to

$$\gamma I\{\rho - n + I - s[I + 2(\rho - n)]\} = \rho - n + I + s[I - (\rho - n)]. \quad (32)$$

Note that equation (32) implicitly defines I as a function of parameters and is entirely independent of θ. Thus, strengthening backward protection ($\theta \uparrow$) will no longer have *any* impact on innovation when labor is fully mobile. This is because θ is proportional to both the reward from successful innovation (V_1) and the reward to incumbent firms from preventing subsequent innovation $(V_1(t) - V_2(t))$. As a result, the growth-promoting effect of θ in stimulating R&D is exactly offset by a growth-reducing effect of stimulating RPAs, which increases innovation difficulty.

Next, it follows directly from (32) that strengthening forward protection ($s \uparrow$) is *always* growth enhancing in this setting. As in the baseline model, stronger blocking patents reduce demand for RPAs by decreasing the loss to incumbents when subsequent innovation occurs. This again implies that incumbents reduce expenditure on RPAs, and generates the same threshold effect on R&D incentives as before. That is, blocking patents continue to imply the same growth-reducing backloading effect and growth-enhancing cost-saving effect. However, when labor is mobile, the decrease in the demand for RPAs reduces the actual usage of RPAs. Since the difficulty of innovation is directly related to the use of RPAs, this *RPAs quantity effect* represents an additional growth-enhancing effect of blocking patents. We find that the combined size of the quantity and cost-saving effects always dominate the backloading effect of blocking patents. We summarize these results in the following proposition,

Proposition 4. *In the model with fully mobile labor and* $\delta = \eta_x = 1$*,*

- *Strengthening backward protection has no impact on economic growth.*

- *Strengthening forward protection always increases economic growth.*

These results illustrate that the potential crowding-out effects among the resources used for RPAs and R&D have important implications for the growth impact of patent policy. With a fixed proportion of specialized labor, RPAs labor supply is perfectly inelastic, and the relative wage adjusts in response to policy changes to ensure that the market clears. With fully mobile labor, the RPAs supply curve is perfectly elastic, and all equilibrium adjustment occurs through the quantity of labor used in RPAs. Since this type of adjustment also influences the availability of resources for R&D and production, it amplifies the importance of patent policy's impact on the RPAs investment incentives of incumbent firms. Our stark results in Proposition 4 reflect an extreme example of this effect when labor resources can be reallocated across RPAs and R&D in a frictionless way. Our baseline analysis shows that the reduction in RPAs demand from strengthened forward protection can still be sufficient to stimulate innovation even in the absence of such resource spillovers.

6.2 Incumbent R&D

In the baseline model, all R&D is conducted by potential market entrants and all innovation results in creative destruction. Indeed, our conceptualization of backward patent protection implies that market incumbents have no direct profit incentive to innovate further since their ability to prevent competitor imitation extends only to a fixed distance behind them on the quality ladder as defined by the policy parameter θ. Thus, regardless of the number of quality improvements that they innovate, each incumbent's maximum quality lead over imitative competitors, optimal limit price, and flow profits gross of licensing fees, π, are fixed by θ. Nevertheless, our framework naturally incorporates a particular motivation for incumbent innovation; incumbents may pursue further innovation so that they no longer infringe on the previous innovator's patent and thus, escape licensing fees. This is because each patent grants forward protection that extends to exactly one subsequent λ-sized quality innovation according to the profit-division rule, s. Each patent holder is no longer able to collect licensing fees once a competitor's product has advanced in quality by at least λ^2 over their patented version. This implies that each new λ-sized quality leader has an incentive to innovate exactly one step further to increase their quality lead to λ^2 and avoid infringing on their closest competitor's existing patent. In Section S.5 and Section S.6 of our supplementary material, we characterize the model's equilibrium in this setting and examine the impact of forward patent protection numerically. We focus on summarizing our findings in the main text.[21]

Let $V_1(\lambda, t)$ and $V_1(\lambda^2, t)$ denote the values of incumbent firms that lead their nearest competitors by one and two steps on the quality ladder respectively. Let $I(\lambda, t)$ and $I(\lambda^2, t)$ denote the rate of innovation from new entrants that become one-step leaders and current one-step incumbents that become two-step leaders respectively. We assume the following innovation functions

$$I(\lambda, t) = \frac{L_I(\lambda, t)}{D(t)}, \qquad I(\lambda^2, t) = \left(\frac{L_I(\lambda^2, t)}{\phi N(t)}\right)^{\beta}, \tag{33}$$

where $\phi > 0$ and $0 < \beta < 1$ are parameters specific to incumbent R&D. Note that $\beta < 1$ imposes diminishing returns to incumbent R&D, and is necessary to ensure the existence of

[21]Our analysis is related to Chu and Pan (2013), who also examine how forward protection influences R&D incentives when escaping infringement is possible. In their model, potential market entrants endogenously pursue larger, more costly innovations to "invent around" existing patents. We analyze how this same motivation impacts incumbent behavior through both R&D and RPAs. We discuss our connection to Chu and Pan (2013) further in Section S.5 of our supplementary material.

an equilibrium in which both incumbents and entrants conduct a positive amount of R&D.[22] As before, incumbent firms use RPAs to raise the cost of competitor innovation through $D(t)$. However, one and two-step leaders will optimally employ distinct amounts of specialized RPAs labor since the value of their market position differs.[23] Specifically the demand for RPAs labor for one and two-step leaders are given respectively by,

$$L_x(\lambda, t) = \frac{I(\lambda, t)\eta_x(t)[V_1(\lambda, t) - V_2(t)]}{w_x(t)}, \qquad L_x(\lambda^2, t) = \frac{I(\lambda, t)\eta_x(t)[V_1(\lambda^2, t) - V_2(t)]}{w_x(t)}, \tag{34}$$

where η_x and w_x are constant in equilibrium as before. Since $V_1(\lambda^2, t) > V_1(\lambda, t)$, two-step leaders optimally invest more resources in RPAs to protect their more profitable market position.

In addition to RPAs, one-step leaders invest resources in R&D in an effort to become a two-step leader and escape licensing payments. The marginal cost of R&D labor is the non-specialized wage of 1 and the marginal benefit is $[\partial I(\lambda^2, t)/\partial L_I(\lambda^2, t)][V_1(\lambda^2, t) - V_1(\lambda, t)]$. Given (33), each one-step leader's demand for R&D labor can be written

$$L_I(\lambda^2, t) = \beta I(\lambda^2, t)[V_1(\lambda^2, t) - V_1(\lambda, t)], \tag{35}$$

which illustrates that the optimal total R&D expenditure for each one-step leader is equal to a share β of the probability weighted expected value of further innovation. In our supplementary material, we express (35) as the following incumbent R&D equilibrium condition,

$$\frac{\phi I(\lambda^2)^{\frac{1-\beta}{\beta}}}{\beta} = \underbrace{\left[\frac{c(\theta - 1)}{\theta}\right]\left(\frac{s}{\rho - n + [1 + \eta_x]I(\lambda) + (1 - \beta)I(\lambda^2)}\right)}_{[V_1(\lambda^2, t) - V_1(\lambda, t)]/N(t)}. \tag{36}$$

Equation (36) represents one of three conditions that characterize the model's equilibrium in terms of three endogenous variables $I(\lambda)$, $I(\lambda^2)$ and c. The left hand side of (36) captures the expected cost of incumbent innovation given diminishing returns to incumbent R&D, and the right hand side captures the associated return. Since one and two-step leaders earn the same gross profit flows π, the expected return to incumbent innovation is proportional to the size of licensing fees associated with forward protection, $s\pi$. In this way, the model is specifically isolating a policy based motivation for incumbent innovation that stems from escaping licensing payments to previous innovators. Not surprisingly, we find that the rate of incumbent innovation

[22]In the presence of RPAs targeted at innovation by entrants, it is natural to assume that incumbents have a cost advantage in conducting R&D. However, if both entrants and incumbents exhibit constant returns to scale to R&D, the model will tend toward an equilibrium in which only one form of innovation is profitable depending on the size of this cost advantage. See Segerstrom and Zolnierek (1999) and Segerstrom (2007) for a discussion of this point.

[23]To allow for the existence of a steady-state equilibrium in which all industries share a common rate of entrant innovation $I(\lambda, t)$, we define $D(t)$ as a stock variable that grows with the use of RPAs and depreciates at a constant rate, $0 < \kappa < 1$, according to $\dot{D}(t) = \gamma[\delta L_x(j, t) + (1 - \delta)N(t)] - \kappa D(t)$, where $j \in \{\lambda, \lambda^2\}$. See Section S.5 of our supplementary material for details.

is monotonically increasing in s.

As in the baseline model, the free-entry condition, $V_1(\lambda, t) = D(t)$, captures the incentives for entrant R&D. In our supplementary material, we show that the free-entry condition can be written,

$$\frac{D(t)}{N(t)} = \underbrace{\left(\frac{c(\theta-1)}{\theta[\rho - n + [1+\eta_x]I(\lambda)]}\right)\left(1 + \frac{s[I(\lambda)\eta_x - (\rho - n) - I(\lambda^2)\Omega]}{\rho - n + I(\lambda) + I(\lambda^2)}\right)}_{V_1(\lambda,t)/N(t)}, \tag{37}$$

where

$$\Omega \equiv \frac{\beta(\rho - n) + [\beta + \eta_x]I(\lambda)}{\rho - n + [1+\eta_x]I(\lambda) + (1-\beta)I(\lambda^2)} > 0.$$

First, observe that both the innovation-enhancing cost-saving effect and innovation-reducing backloading effect of forward protection continue to impact entrant R&D incentives as in the baseline model. These effects appear as the positive $sI(\lambda)\eta_x$ and the negative $s(\rho - n)$ terms in the numerator of the expression in square brackets. Indeed, in the absence of incumbent innovation ($I(\lambda^2) \to 0$), equation (37) collapses to the free-entry condition of the baseline model given by (21). In this case, the interaction between these two effects determines the impact of forward protection on entrant innovation as in Proposition 3.

However, the final $-sI(\lambda^2)\Omega$ term implies that presence of incumbent innovation introduces a new, innovation-reducing effect of forward protection on entrant R&D incentives. This is because part of the value of entrant innovation is the expectation of future licensing revenue from the next competitor that innovates. When competitors escape licensing fees more rapidly through further innovation, the present value of future licensing revenue declines. This negative effect is partially attenuated by each one-step entrant leader's own ability to escape licensing fees through innovation. However, after taking into account R&D expenditure as shown in equation (35), each one-step leader captures only a portion $1 - \beta$ of the expected value of their own subsequent innovation. We refer to this combined effect as the *escape infringement effect*, and conclude that forward protection is less likely to stimulate entrant innovation in the presence of incumbent innovation.

Of course, the rate of economic growth in this setting depends on the rate of both incumbent and entrant innovation. In our supplementary material, we analyze the growth impact of forward protection numerically and find the following two main results. First, it remains possible for strengthened forward protection to stimulate entrant innovation under plausible circumstances. Through the exact same mechanism as in the baseline model, this occurs when the cost-saving effect is large due either to a high effectiveness of RPAs (η_x) or a rapid initial pace of entrant innovation. Since incumbent innovation always increases with stronger forward protection, economic growth necessarily increases in this case. Second, the interaction between incumbent and entrant innovation can generate a non-monotonic, inverted U-shaped relationship between forward patent protection and economic growth. This is because the increase in incumbent innovation associated with stronger forward protection can initially boost growth, *even* in cases where the cost-saving effect is sufficiently small so that entrant innovation decreases in s. Since more rapid incumbent innovation creates a larger negative escape infringement effect on entrant R&D incentives, the decline in entrant innovation can eventually accelerate at higher levels of s to the point where economic growth also begins to fall in s. Overall, these numerical results echo the findings of our primary analysis; strengthening forward protection continues to most effectively stimulate economic growth when firms devote substantial resources to obstructing competitor innovation through RPAs.

7 Conclusion

In this study, we explore the economic implications of patent policy in a Schumpeterian endogenous growth framework in which incumbent patent holders invest resources to impede subsequent entry and protect their monopoly rents. We consider two dimensions of patent policy: backward protection against potential imitation and forward protection, or blocking patents, against subsequent innovation that builds on a patented technology. Our results show that the interaction between patent policy and patent holders' endogenous investment in rent-protecting activities (RPAs) plays a crucial role in the impact of patent protection on economic growth.

In particular, our analysis formalizes a growth-enhancing role of forward protection in a general equilibrium context; by ensuring that previous innovators are entitled to a share of future innovators' profits, forward protection weakens the incentive to actively impede follow-on innovations. Thus, even though the growth-reducing blocking effect of patents that is highlighted by prior literature remains present, the legal protection offered by patents may promote growth by substituting for more costly private alternatives.

We emphasize that our analysis does not suggest that stronger forward patent protection always promotes growth. Rather, it illustrates that the growth impact of patent protection depends on several factors including the pace of innovation and the effectiveness of firms' RPAs in deterring innovation. Additionally, our analysis has focused on the particular form of forward protection that has received the most attention in endogenous growth settings; mandatory licensing agreements between the two innovators of successive generations of the same product. Future work may profitably explore how different aspects of patent protection influence our findings, such as the breadth of protection across multiple generations of technology or protections for technology that are used by firms in multiple industries. This may be particularly fruitful in the context of models that incorporate innovation by incumbents and entrants where policy changes may have nuanced effects on R&D incentives across different types of firms. We believe that further research into the way that patent policy interacts with the internal strategies firms use to defend their market position is an important step towards a more comprehensive understanding of the relationship between patents and economic growth.

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Appendix: Proof of Proposition 1

Define transformed variables $\Psi_1(t) \equiv c(t)N(t)/V_1(t)$ and $\Psi_2(t) \equiv c(t)N(t)/V_2(t)$. First, differentiating $\Psi_2(t)$ with respect to t yields

$$\frac{\dot{\Psi}_2(t)}{\Psi_2(t)} \equiv \frac{\dot{c}(t)}{c(t)} + n - \frac{\dot{V}_2(t)}{V_2(t)} = r(t) - \rho + n - \frac{\dot{V}_2(t)}{V_2(t)}, \tag{A.1}$$

where the second equality follows from (4). Combining (6), (7), (9), and (16), the no-arbitrage condition for $V_2(t)$ in (11) can be expressed as

$$\frac{\dot{V}_2(t)}{V_2(t)} = r(t) - s\left(\frac{\theta-1}{\theta}\right)\Psi_2(t) + \Omega - \frac{\Psi_1(t)}{\theta}, \tag{A.2}$$

where $\Omega \equiv (1-\alpha)/[\gamma(\delta\alpha + 1 - \delta)]$ and the definitions of $\Psi_1(t)$ and $\Psi_2(t)$ are used. Substituting (A.2) into (A.1) yields the law of motion for $\Psi_2(t)$ such that

$$\frac{\dot{\Psi}_2(t)}{\Psi_2(t)} = s\left(\frac{\theta-1}{\theta}\right)\Psi_2(t) + \frac{\Psi_1(t)}{\theta} - \Omega + n - \rho. \tag{A.3}$$

Next, imposing specialized labor market clearing, $L_x(t) = \alpha N(t)$, in (14) yields a constant elasticity of innovation with respect to RPAs such that $\eta_x \equiv \delta\alpha/(\delta\alpha + 1 - \delta)$. Then differentiating $\Psi_1(t)$ with respect to t yields $\dot{\Psi}_1(t)/\dot{\Psi}_1(t) \equiv r(t) - \rho + n - \dot{V}_1(t)/V_1(t)$. Combining this equation for $\dot{\Psi}_1(t)/\dot{\Psi}_1(t)$ along with (6), (7), (9), (13), (15), and (16) yields the law of motion for $\Psi_1(t)$ such that

$$\frac{\dot{\Psi}_1(t)}{\Psi_1(t)} = \left[(1-s)\left(\frac{\theta-1}{\theta}\right) + \frac{1+\eta_x}{\theta}\right]\Psi_1(t) + (1+\eta_x)\Omega\frac{\Psi_1(t)}{\Psi_2(t)} - \left(\frac{1+\eta_x}{\theta}\right)\frac{\Psi_1^2(t)}{\Psi_2(t)} - (1+\eta_x)\Omega + n - \rho, \tag{A.4}$$

where we use the fact that $V_2(t)/V_1(t) = \Psi_1(t)/\Psi_2(t)$.

Linearizing (A.3) and (A.4) around the steady-state equilibrium yields the differential equation system that characterizes the dynamics of this model such that

$$\begin{bmatrix} \dot{\Psi}_1(t) \\ \dot{\Psi}_2(t) \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} \Psi_1(t) - \Psi_1 \\ \Psi_2(t) - \Psi_2 \end{bmatrix}, \tag{A.5}$$

where

$$a_{11} = \eta_x\Omega + s\left(\tfrac{\theta-1}{\theta}\right)\Psi_2(t) + \tfrac{\Psi_1(t)}{\theta} - \left(\tfrac{1+\eta_x}{\theta}\right)\tfrac{\Psi_1^2(t)}{\Psi_2(t)} > 0, \quad a_{12} = -(1+\eta_x)\tfrac{\Psi_1^2(t)}{\Psi_2^2(t)}\left[\Omega - \tfrac{\Psi_1(t)}{\theta}\right] < 0,$$
$$a_{21} = \tfrac{\Psi_2(t)}{\theta} > 0, \quad a_{22} = s\left(\tfrac{\theta-1}{\theta}\right)\Psi_2(t) > 0.$$

Recall that using (6), (9), and (16) implies $I(t) = \Omega - \Psi_1(t)/\theta > 0$. Therefore, one can rewrite $a_{11} = I(t) + [(1+\eta_x)\Psi_1(t)/\theta][1 - \Psi_1(t)/\Psi_2(t)] + s(1-1/\theta)\Psi_2(t)$, which is positive, because we have $\theta > 1$ and $\Psi_2(t) > \Psi_1(t)$ (i.e., $V_2(t) < V_1(t)$ satisfying the condition (15) for optimal RPAs). In addition, one can rewrite $a_{12} = -(1+\eta_x)[\Psi_1^2(t)/\Psi_2^2(t)]I(t)$, which is negative.

Let ζ_1 and ζ_2 be the two characteristic roots of the dynamical system (A.5). The trace of the Jacobian is given by $\text{Tr} = \zeta_1 + \zeta_2 = a_{11} + a_{22} > 0$. Moreover, the determinant of the Jacobian is given by $\text{Det} = \zeta_1 \zeta_2 = a_{11}a_{22} - a_{12}a_{21} > 0$. Therefore, the two characteristic roots are both positive. Given that both $\Psi_1(t)$ and $\Psi_2(t)$ are jump variables, the above findings imply that the dynamical system (A.5) displays saddle-point stability such that $\Psi_1(t)$ and $\Psi_2(t)$ must jump to their steady-state values given by the intersection of the $\dot{\Psi}_1(t) = 0$ and $\dot{\Psi}_2(t) = 0$ loci.