Competition and Innovation: the effects of scientist mobility and stronger patent rights

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Abstract: We analyze the relationship between innovation attributes and competition intensity in a framework of endogenous knowledge spillover due to scientist mobility, and identify the effects of stronger patents on innovation at different levels of product market competition. We find non-monotone relations of patenting propensity, innovation incentives and investment in R&D, and monotone relation of scientist mobility, with potential product market competition intensity. The study further shows that stronger patent laws reduce (increase) innovation profitability (R&D expenditure) when the market for the new product is moderately competitive, and have no effect otherwise. The results suggest important implications for patent policy reforms.

JEL CLASSIFICATION: D43, J60, L11, L13, O34

KEYWORDS: Competition intensity, Innovation, Patent strength, Scientist mobility

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1 Introduction

This paper examines implications of product market competition on patenting, knowledge spillover, innovation profits and R&D expenditure. Developing a simple two period model of in-house innovation with endogenous knowledge spillover due to scientist mobility, wherein an entrepreneur first innovates a technology and then produces and sells a final good, it demonstrates the following. First, patenting propensity has a non-monotone relation with product market competition intensity. Second, scientist mobility has a monotone relation with competition. Third, the innovation's total profitability and R&D expenditure have non-monotone relations with competition intensity. Fourth, increase in patent strength decreases the innovation's profitability and increases R&D expenditure when product market competition intensity is moderately low, and has no effect otherwise. The results suggest important considerations for patent reforms, not just in their effect on innovation, but also in their interaction with potential product market competition.

In our model of innovation, the entrepreneur requires a scientist's aid only during the development of the new technology. Therefore, during the commercialization phase of the project, the scientist may join or establish a rival enterprise in the product market. In the spirit of Pakes and Nitzan (1983), we suppose knowledge spillover to be endogenous in that the entrepreneur can influence labor mobility through her second period wage offer. Further, following Kim and Marschke (2005), we allow the entrepreneur to use patents to protect the innovation against infringement. A differentiating feature in our paper is that we introduce within this framework of mobility and innovation, an explicit model of product market competition á la Hotelling, to analyze the significance of competition intensity on innovation attributes and effectiveness of patent reforms. For this purpose, we first examine the relationships of patenting, mobility, innovation incentives and investment in R&D with the intensity of product market competition. Next, we study the effect of increase in patent strength on these relationships and accordingly identify its implications at different levels of competition intensity.

We find, as competition intensity in the product market increases, the entrepreneur initiates patenting beyond a lower threshold of competition intensity but terminates it beyond a higher threshold, implying a non-monotone relation of patenting propensity with product market competition intensity. However, higher potential competition ceases movement beyond a threshold, implying a monotone relation between competition intensity and scientist mobility. The innovation's profitability decreases as long as movement occurs and increases henceforth, implying a non-monotone trend of innovation incentive with competition intensity. On the contrary, R&D expenditure increases while movement occurs but stabilizes thereafter, also carving a non-monotone trend with competitive pressure. Our results conform to the existing literature, which extensively documents non-monotone relationships of competition intensity with innovation attributes such as patenting activity (Aghion et al., 2005), value of innovation (Boone, 2001) and total R&D expenditure (Houngbonon & Jeanjean, 2016; Sacco & Schmutzler, 2011; Tishler & Milstein, 2009). However, the specific relationships in our model are determined by the difference in equilibrium knowledge spillover due to scientist mobility at different levels of competition intensity.

As the patent regime is tightened, any potential benefit to the entrepreneur due to greater expected reparation is neutralized through an equal increase in the scientist's joining wage, to ensure successful launch of the innovation. Thus, stronger patents reduce expected innovation profitability through higher costs from increased patenting when scientist mobility drives knowledge spillover. Further, they augment expected R&D expenditure by requiring higher scientist wage. Our analysis of market competition reveals that these expected effects manifest only when product market competition intensity is moderate, not otherwise. The reason is, at very low competition stronger patents fail to induce patenting as the damage from duopoly is small. Again, for neck-to-neck competition patenting occurs in equilibrium even with weaker patents. It follows, tighter patents can trigger additional patenting only at moderate competition intensity, thereby reducing innovation profitability in this range. Further, they induce higher wages only at moderate levels of competition that support simultaneous patenting and movement, raising R&D expenditure in this range.

Mobility of scientist personnel is a persistent source of knowledge externalities for innovating firms (Almeida & Kogut, 1999; Møen, 2005). In industries prone to this phenomenon, poaching of competitors' human capital forms an integral part of firms' learning-by-hiring objectives (Palomeras & Melero, 2010; Song et al., 2003). While strict enforcement of non-compete covenants are often absent in the interest of employee freedom (Franco & Mitchell, 2008), thereby exacerbating the incidence of undesired knowledge spillover through scientist movement, keeping of trade secrets from a firm's own employees, although optimal under certain conditions, may reduce production efficiency (Rønde, 2001). In this context, the role of intellectual property rights (IPR) in driving research initiatives takes prominence when firms undertake internal R&D efforts to spur innovation. Indeed, greater risk of scientist mobility may induce more frequent patenting (Kim & Marschke, 2005). In fact, firms that acquire a reputation for IP toughness from frequently litigating their patents can avert some mobility and knowledge spillover (Agarwal et al., 2009; Ganco et al., 2015). However, difficulties concerning absolute appropriability of information remain as the intangible nature of information limits complete applicability of property rights (Arrow, 1962).

Patents provide innovators a partial property right in that, they do not provide the patentee "a right to exclude", but rather, "a right to *try* to exclude" (Shapiro, 2003). Supposing that the goal of patent rights is to achieve a balance between promoting innovation incentives and restricting welfare-loss from limited technology spread (Reitzig et al., 2008), some uncertainty in the patent system may be desirable in practice (Ayres & Klemperer, 1999). The inherent uncertainties in the IPR regime provide a rationale for considering probabilistic patents in economic models (Allison & Lemley, 1998; Lemley & Shapiro, 2005) and this construct has seen extensive use in the literature on restitution laws (see Anton and Yao (2007), Chen and Sappington (2018), Choi (2009), Schankerman and Scotchmer (2005) and Shapiro (2016), to mention a few)[1]. However, recent patent reforms aim to strengthen IPR

[1]Damage rules are a recently emerging area in the literature on IPR. Primarily, two types of damage rules are prevalent - (i) the "lost profit" (LP, henceforth) rule which measures damages as the reduction in

protection by augmenting associated damage recovery, through improving the patentee's success-rate in litigations as well as enhancing damage awards. Examples abound in patent policy changes, not just in the U.S. (Gallini, 2002; Jaffe, 2000; Moore, 2000) but across jurisdictions such as Europe, Australia and Canada (Chien et al., 2018), and China and Japan (Hu et al., 2020). Our paper studies the implications of market competition intensity on innovation and further, its interactive effects with strengthening of the patent regime, in presence of endogenous knowledge spillover due to scientist mobility.

The first part of our analysis primarily contributes to the perpetual discussion on the relationship between intensity of competition and innovation. Despite umpteen analyses, the literature has not reached a consensus between the contrasting arguments of Schumpeter (1943), that suggests market concentration stimulates innovation, and Arrow (1962), that propounds higher competition generates higher innovation. Instead, a large section of subsequent studies agree on a non-monotone relation between innovation and competition intensity (Aghion et al., 2005; Boone, 2001; De Bondt & Vandekerckhove, 2012; Houngbonon & Jeanjean, 2016; Negassi et al., 2019), its specific nature varying by different measures of competition and types of innovation (Belleflamme & Vergari, 2011; Tang, 2006; Vives, 2008)[2]. For example, Pal (2010) shows the relation of innovation and competition (negative vs. positive) reverses by cost of technology-adoption. Bonanno and Haworth (1998) find variation in choice of innovation (product vs. process) by competition intensity, the optimal choices reversing depending on firm's quality. In contrast to existing studies that focus on creation of knowledge, Jansen (2011) studies the effects of competition on diffusion of

profit (or royalties, in case of licensing) of the patent owner due to infringement, and (ii) the "unjust enrichment" rule (UE, henceforth) which measures damages as the infringer's profit from infringement. Another commonly referred damage regime, the "reasonable royalty rates" rule, measures damages as the likely royalty rate in a hypothetical ex-ante licensing agreement between the innovator and the infringer. In the preceding definition, this is subsumed under the LP rule. See Anton and Yao (2007), Choi (2009), Schankerman and Scotchmer (2001) and Schankerman and Scotchmer (2005) for a comparison of the LP and UE rules, and Chen and Sappington (2018) for an analysis of their linear combination.

[2]See De Bondt and Vandekerckhove (2012) for a structured discussion of existing studies that support the non-monotone trend of innovation with competition in the industrial organization literature.

knowledge by observing differential strategy choice for innovation protection (patenting vs. secrecy) by modes of competition. Our paper examines the effects of competition intensity on incentives to develop as well as diffuse an innovation by examining the implications of product market competition on innovation attributes and patenting propensity in a model of endogenous knowledge spillover due to scientist mobility. We depart from the existing literature in that we analyze the relationship of competition and innovation in a framework of scientist mobility[3].

The second part of our analysis identifies the interactive effects between intensity of competition and patent strength. An extensive literature on IPR have analyzed the implications of stronger patents on innovation[4]. While there is consensus that stronger patents induce greater patenting, ambiguity persists in their ability to stimulate greater innovation (Bessen & Maskin, 2009; Ganguly, 2021; Hall, 2007; Lerner, 2009). Closest to our setup of innovation and patent strength is the study by Ganguly (2021). Ganguly (2021) examine effects of strengthening of property rights through patent reforms in industries characterized by scientist mobility. However, they analyze this in a general model based on ex-ante expected returns from the innovation. Our paper adds a new dimension to this model by explicitly analyzing the characteristics of the market that the innovation affects. Specifically, we identify the levels of market competition intensity at which the effects of a stronger patent regime manifest.

A key assumption of our analysis of relationship of competition intensity with innovation attributes is the perfect inference of potential market competition by the entrepreneur and the scientist at the beginning of the research project's development phase. We subsequently relax this assumption to consider the possibility that although the scientist

[3]Although some existing studies consider R&D spillover (Hinloopen & Vandekerckhove, 2009; Qiu, 1997; Schmutzler, 2010), they do not explicitly model the mechanism through which knowledge diffuses.

[4]For example, see Gallini (1992), Gilbert and Shapiro (1990) for a discussion on optimal patent length and breadth, Allred and Park (2007), Chen and Puttitanun (2005), Dinopoulos and Kottaridi (2008), Iwaisako et al. (2011) for relative preferences of the north vs. south and Kanwar and Evenson (2003), Kyle and McGahan (2012), Sakakibara and Branstetter (2001) for analysis in the context of patent reforms.

and the entrepreneur have some belief regarding possible future competition, the actual intensity is known only when the product is ready to be marketed. It turns out, while the nature of relationship of patenting, movement, profitability and R&D expenditure with competition intensity remain identical to that in the main analysis, the level of competitive pressure at which a stronger patent regime is efficacious alters, suggesting a further aspect of consideration for patent reforms. A second assumption restricts the patenting cost in the main analysis to be low enough to not only allow for the possibility of patenting but also initiate the same at sufficiently low competition where movement occurs. Relaxing this assumption proves all our main results robust except for the effect of stronger patents on R&D investment, for which the equilibrium co-occurrence of patenting and movement is crucial. Additionally, our main results stand robust when we use an alternate approach of modeling market competition, wherein we consider strategic supply function competition in the product market.

The rest of the paper is organized as follows. Section 2 develops and solves the model of innovation and market competition. Section 3 presents the results of a stronger patent regime at different levels of competition intensity. Section 4 discusses the implications of relaxing the model's assumptions. Section 5 provides the alternate model of competition intensity. Section 6 concludes the paper.

2 The Model

We develop a model in which innovation is static, certain and facilitated by firm's internal R&D efforts. The game takes place in two periods. In period 1, an innovating entrepreneur hires a scientist to develop a novel idea into a tangible product. In period 2, she markets the product to realize profits without any help from the scientist. The scientist joins the entrepreneur's firm in period 1 if his total expected earning from the research project exceeds his reservation wage in two periods combined, his single-period reservation wage equaling the value of his effort $\bar{w}$. If he joins the project, he receives first period wage w_0.

In period 2, he chooses to either (i) stay at the entrepreneur's firm and earn second period wage w_1, or (ii) leverage his knowledge from period 1 to move to or set up a rival firm and earn product market profit in addition to $\bar{w}$, or (iii) join the non-R&D sector and earn $\bar{w}$.

The appearance of the rival in period 2 infringes the entrepreneur's innovation. Accordingly, the second period product market is a duopoly (monopoly) if the scientist moves (does not move) to a rival enterprise. Let ρ_i and ρ_e denote the monopoly profit of the entrepreneur and the duopoly profit of the rival in case it appears, respectively, from second period product market competition. The rival's appearance reduces the entrepreneur's earning under monopoly by a proportion λ, rendering her duopoly profit equal to $(1-\lambda)\rho_i$. However, at the beginning of the second period, the entrepreneur can decide to patent the innovation, thereby acquiring the right to partially recover her damages due to infringement, the strength of the patent system determining the expected amount of recovery. Following Ganguly (2021), we define a composite "measure of strength" of the patent regime as

$$\sigma(r, \delta) = r \cdot \delta$$

where r, which denotes the probability of success if the patent is litigated in court of law, captures the strength of enforcement, and δ, which denotes the proportion of damage recovery when litigation is successful, captures the strength of the stipulated law. Thus, patenting grants the innovator expected damage recovery amounting to $\sigma\lambda\rho_i$. The cost of patenting is c.

This setup of innovation and scientist mobility is exactly same as that in Ganguly (2021)[5]. However, unlike Ganguly (2021), we explicitly model product market competition and analyze the relationship of intensity of competition with patenting propensity, scientist mobility, innovation profitability and R&D investment. We subsequently investigate the interactive effects of competition intensity with patent regime strength. Let θ denote the second period product market competition intensity. Now, notice that realized second

[5]Other studies that use a similar model of innovation and scientist mobility include Ganco et al. (2015), Kim and Marschke (2005).

period profits depend on market competition intensity. Consequently, the entrepreneur's loss due to infringement also varies with potential product market competition. Therefore, we write λ as $\lambda(\theta)$ and further, express the rival's profit as a proportion of the entrepreneur's duopoly profit, as $\rho_e(\theta) = \kappa.[1 - \lambda(\theta)]\rho_i(\theta)$, where $\kappa = 1$ when the two firms face symmetric optimization problems. For the rest of the analysis, we use a Hotelling model with market expansion due to technology diffusion, to model product market competition. Section 5 provides an alternative model using the supply schedule framework of competition intensity to bolster our main results.

We solve the game by backward induction. Deriving the second period expected earnings at any given level of competition intensity, we solve for the entrepreneur's (scientist's) second period patenting (movement) decision. Each agent is aware that the other will act optimally when the second period arrives. Accordingly, the entrepreneur makes a first period wage offer to match the scientist's total reservation wage, which the scientist accepts, thereby successfully launching the research project.

2.1 Hotelling Model of Competition Intensity

Suppose a Hotelling city of length L. If the entrepreneur's idea is developed into a viable product in period 2, the entrepreneur's firm (firm 1) locates at point 0. If the scientist moves to or sets up a rival in period 2, the rival firm (firm 2) locates at point L. We allow market expansion due to scientist mobility by defining $L = 1$ if only firm 1 operates in the market and $L \geq 1$ if firm 2 appears[6]. Consumers are uniformly distributed along the interval $[0, L]$. Thus, scientist mobility aids technology diffusion by expanding the potential consumer base[7]. Consumers value each firm's product at v and incur transportation cost t. Each consumer can consume a maximum of one unit of the product. We normalize costs of each firm to 0 and assume $v \geq 2t$ to ensure market coverage. Under monopoly, firm 1's

[6] This structure of market expansion due to technology diffusion follows Chen and Sappington (2018).

[7] This is likely when the rival's appearance attracts consumers in a different geographical location or demographic group.

profit maximization exercise yields $\rho_i = v - t$. To derive the duopoly profits, suppose x is the indifferent consumer on the interval $[0, L]$ such that $v - xt - p_1 = v - (L - x)t - p_2$, where p_i is the price of firm i's product. Therefore, $x = \frac{L}{2} + \frac{p_2 - p_1}{2t}$. Maximizing firm i's profit $\pi_i = \left(\frac{L}{2} + \frac{p_j - p_i}{2t}\right)p_i$ with respect to p_i yields $(1 - \lambda)\rho_i = \rho_e = \frac{L^2 t}{2}$. The expressions for ρ_i and ρ_e imply the loss to the entrepreneur due to appearance of the rival is $\lambda = 1 - \frac{L^2 t}{2(v-t)}$. The inverse of the transportation cost measures the competitive pressure in the market, implying $\theta = \frac{1}{t}$. Thus, the second period returns to the entrepreneur, the rival if it appears, and the loss to the entrepreneur if the rival appears are expressed as functions of intensity of competition as follows:

$$\rho_i = \frac{v\theta - 1}{\theta};$$

$$(1 - \lambda)\rho_i = \rho_e = \frac{L^2}{2\theta};$$

$$\lambda = 1 - \frac{L^2}{2(v\theta - 1)};$$

To solve for the optimal choice variables of the entrepreneur and the scientist in the game of innovation, we make the following assumptions:

Assumption 1: The second period realized θ becomes common knowledge at the beginning of the first period after the entrepreneur conceptualizes the product.

Assumption 2: (a) $c < \dfrac{L^2 v\sigma}{(1+\sigma)L^2 + 2\sigma}$, (b) $c < \dfrac{L^2 v\sigma}{2(L^2+1)}$.

Assumption 1 implies the entrepreneur and the scientist are able to correctly infer second period competition intensity at the beginning of the first period, when the entrepreneur perceives the idea for the product. Therefore, the second period optimal behavior and corresponding returns are known to the entrepreneur and scientist while making first period choices. Assumption $2a$ requires cost of patenting to be sufficiently low given expected recovery such that patenting is feasible. Assumption $2b$ states a stricter condition on patenting cost to ensure patenting for some levels of competition intensity at which movement occurs. We subsequently discuss the implications of relaxing Assumptions 1 and $2b$ in Section 4.

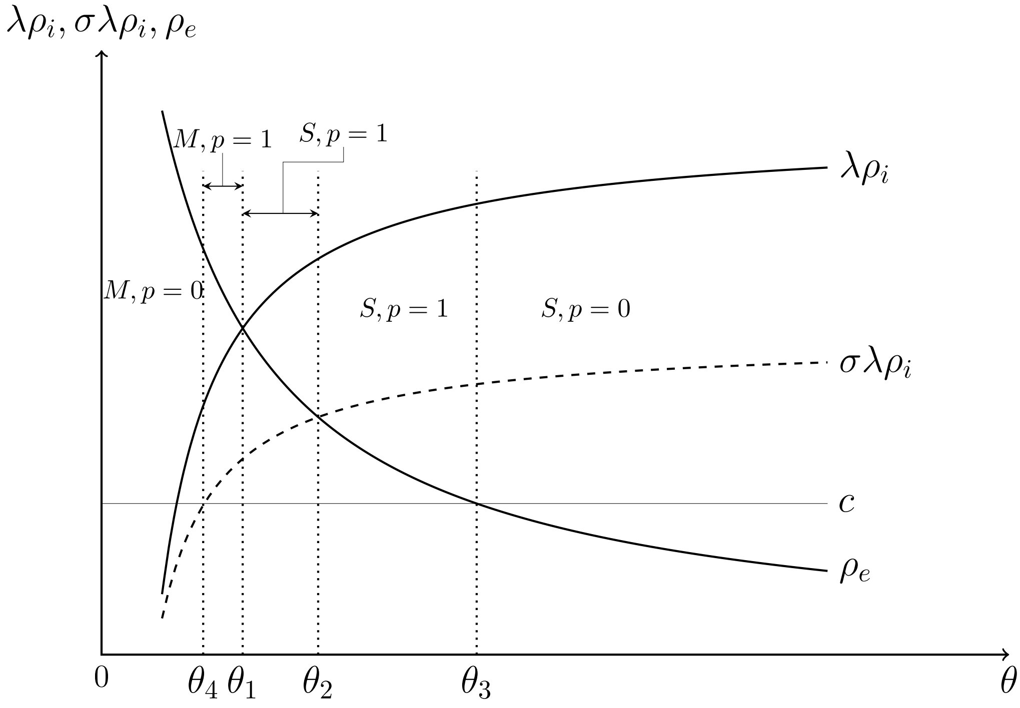


Figure 1: Patenting and Mobility by Competition Intensity

2.2 Patenting and Movement

Let $p = 1$ (0) denote the entrepreneur's decision to patent (not patent) the innovation and M (S) denote the scientist's decision to move to a rival firm (stay at the entrepreneur's firm), in period 2. Figure 1 illustrates the equilibrium patenting behavior of the entrepreneur and movement behavior of the scientist for different levels of product market competition intensity (see Appendix A for complete derivation).

First consider $\theta < \theta_1$. Very low intensity of competition implies high product differentiation and high potential duopoly profits for the entrepreneur and the rival. Further, greater consumer misalignment under monopoly implies lower return to the entrepreneur from retaining her monopoly stature. Therefore, the scientist's gain from movement exceeds the entrepreneur's loss due to product market competition. Consequently, there is no wage at which the entrepreneur finds it optimal to retain the scientist, thereby permitting movement in equilibrium. Within this range, when $\theta_4 \leq \theta < \theta_1$, relatively high damage from competition induces the entrepreneur to patent the innovation, not to deter movement but rather to reduce her loss from infringement.

Next suppose $\theta_1 < \theta < \theta_2$. Relatively higher competition intensity shrinks duopoly profits and suggests higher return under monopoly. As a result, the entrepreneur's loss due to advent of a rival exceeds the scientist's potential gain at the rival, rendering it optimal for the entrepreneur to expend the required second period wage to retain the scientist and prevent movement. Patenting occurs in equilibrium when the savings in wage, which equals damage recovery under movement, exceeds its cost. Now, as patenting occurs in $\theta_4 < \theta < \theta_1$, the potential damage recovery (and hence, savings in wage) must exceed the cost of patenting at relatively higher competition intensity in $\theta_1 < \theta < \theta_2$ where the damage from infringement is higher, implying equilibrium patenting in this entire range. It follows, for $\theta_1 < \theta < \theta_2$, $w_1 = \rho_e - \sigma\lambda\rho_i + \bar{w}$.

When $\theta > \theta_2$, duopoly returns are very low and loss to the entrepreneur due to competition is high implying high potential damage payment. Therefore, the scientist's preferred movement alternative is the non-R&D sector (rival firm) if the innovation is patented (not patented). Accordingly, the entrepreneur offers $w_1 = \bar{w}$ ($w_1 = \rho_e + \bar{w}$) to retain the scientist in equilibrium. Patenting occurs (does not occur) in equilibrium when competition is relatively less (more) intense, i.e. $\theta_2 < \theta < \theta_3$ ($\theta > \theta_3$), such that relatively higher (lower) profit at the rival suggests significant (insufficient) savings in wage from patenting. Proposition 1 summarizes the relationship of patenting and movement behavior with competition intensity.

Proposition 1. *The following define the nature of relationship between intensity of competition and second period equilibrium patenting and movement.*

(i) Patenting behavior has a non-monotone relation to the level of competitive pressure in the market.

(ii) Movement behavior has a monotone relation to the level of competitive pressure in the market.

Proof. See Appendix A.

To understand the result, first consider the incidence of patenting. Intuitively, one may expect firms to patent more frequently as product market competition intensity increases to protect novel innovations from infringement and appropriate monopoly profits. However, in markets where mobility is a common phenomenon, this is not necessarily true. A rise in intensity of competition causes an innovating entrepreneur to go from not patenting to patenting if competition intensity is relatively low but reverses this behavior if competitive pressure is high. The intuition follows from the entrepreneur's motive behind patenting. With a damage recovery regime where reparation cost is borne by the infringing rival, the reason for patenting is loss (wage) reduction at low (high) levels of competition intensity. While at low levels of competition, relative increase in competition intensity implies increase in loss recovery and induces patenting, at high competition intensity, its increase above a threshold value leads to low duopoly profits and thus, low wage reduction due to patenting, rendering patenting unprofitable. As a result, the rise of competition intensity above a threshold increases the incidence of patenting when competitive pressure is low but reduces the same when competitive pressure is relatively higher. Contrastingly, movement, being induced at low values of competitive pressure due to attractive returns and meager damages, and ceasing at higher levels as losses rise and returns diminish, admits a monotone relation to competition intensity.

2.3 Profit and R&D

The innovator's return from the research project comprises her profit from commercializing the new product, the value of the scientist's work if he stays at her firm in period 2, and her expected damage recovery in case infringement occurs and the innovation is patented. Her expenditures include the scientist's total wage bill and the cost of patenting wherever applicable. Lemma 1 derives the total profitability of the research project for different combinations of patenting and movement decision alternatives.

Lemma 1. *The entrepreneur's realized profit from the innovation is as follows:*

$$\pi = \begin{cases} -\bar{w} + \rho_i + \rho_e - \lambda\rho_i, & M, p = 0 \\ -\bar{w} + \rho_i + \rho_e - \lambda\rho_i - c, & M, p = 1 \\ -\bar{w} + \rho_i - c, & S, p = 1 \\ -\bar{w} + \rho_i, & S, p = 0 \end{cases}$$

Proof. See Appendix A.

The entrepreneur's R&D expenditure excluding patenting cost comprises the total outlay toward scientist wage[8]. This includes only the first period wage if the scientist moves in period 2, and the sum of first and second period wages if he stays at the entrepreneur's firm. Lemma 2 derives the R&D expenditure of the research project for different combinations of patenting and movement decision alternatives.

Lemma 2. *The innovation's total R&D expenditure is as follows:*

$$R\&D = \begin{cases} \bar{w} - \rho_e, & M, p = 0 \\ \bar{w} - \rho_e + \sigma\lambda\rho_i, & M, p = 1 \\ 2\bar{w}, & S, p = 0 \ or \ 1 \end{cases}$$

Proof. See Appendix A.

Mapping total profitability (R&D expenditure) for the decision alternatives in Lemma 1 (Lemma 2) with corresponding ranges of competition intensity in Figure 1, we derive the direction of movement in π ($R\&D$) within each range of θ. Lemma 3 delineates.

Lemma 3. *The following describe the direction of effect of increase in competition intensity on profit and R&D expenditure by levels of θ:*

(i) 0 *to* θ_4*: Profit decreases; R&D increases*

[8]This definition of R&D expenditure follows Ganguly (2021) and Kim and Marschke (2005).

(ii) θ_4 *to* θ_1*: Profit decreases; R&D increases*

(iii) θ_1 *to* θ_2*: Profit increases; R&D remains constant*

(iv) θ_2 *to* θ_3*: Profit increases; R&D remains constant*

(v) θ_3 *to* ∞*: Profit increases; R&D remains constant*

Proof. See Appendix A.

As intensity of competition increases, profit initially decreases when θ is low and then increases when θ is moderate or high. On the contrary, R&D expenditure increases with an increase in competition intensity at low levels of θ and remains constant for moderate and high θ. Proposition 2 summarizes the resulting relationship of profit and R&D expenditure to competition intensity in presence of scientist mobility.

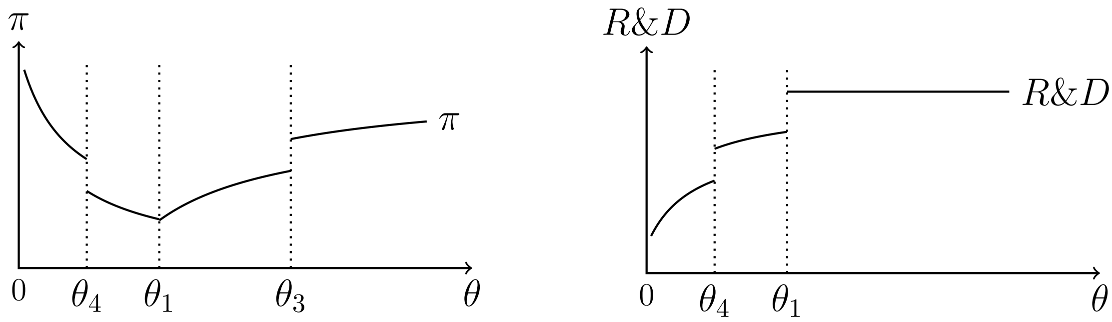
Proposition 2. *The following define the nature of relationship of intensity of competition with total profitability and R&D expenditure of the innovation.*

(i) Total profitability has a non-monotone relation to the level of competitive pressure in the market.

(ii) R&D expenditure has a non-monotone relation to the level of competitive pressure in the market.

Proof. Follows directly from Lemma 3.

To understand the result, notice that entrepreneur's total profitability with scientist movement is the sum of the second period duopoly profits net of the scientist's reservation wage and patenting cost if patenting occurs. Therefore, the innovation's total profitability falls for the first two ranges of θ where movement occurs, as an increase in competition intensity diminishes duopoly profits. However, as competitive pressure rises further, movement ceases, resulting in a monopoly in the second period. Therefore, total profit, which now consists of the entrepreneur's monopoly profit net of reservation wage and patenting cost wherever applicable, rises as intensity of competition increases due to lower



(a) Total Profitability

(b) R&D Expenditure

Figure 2: Total Profitability and R&D Expenditure by Competition Intensity

transportation cost implying greater consumer alignment. R&D expenditure increases with increase in competition intensity at low levels of θ as the decrease in duopoly profits due to increase in competition intensity implies lower second period return to the scientist when movement occurs, requiring an increase in the first period wage. However, as higher values of competition intensity prevent movement, R&D expenditure remains constant and equal to the total reservation earning of the scientist. Figure 2 illustrates the results[9].

An interesting observation can be made here. Note that at θ_1 the profit trend is continuous, as breaks occur only at points of reversal of patenting behavior. As a result, comparing the values of θ marginally above θ_1 to those sufficiently below θ_1 reveals the possibility of higher profitability for the entrepreneur under duopoly as compared to that in case she retains her monopoly stature. This is because, the possibility of scientist mobility facilitates market expansion due to technology diffusion, which in turn allows the industry profit under duopoly to exceed monopoly profit when competition in the duopoly market is not too intense. As adjustments in the scientist's first period wage neutralize his returns, the entire benefit of higher industry profit is reaped by the entrepreneur, resulting in higher profitability of her innovation under duopoly as compared to that under monopoly. Corollary 1 formalizes the result.

Corollary 1. *For an innovation facilitated by internal R&D efforts, technology diffusion*

[9]The graphs are illustrative and not drawn to scale.

through scientist mobility can augment the project's profitability.

3 Stronger Patent Regime and Competition Intensity

Patent reforms seek to strengthen patent rights by enhancing not only the degree but also the credibility of IPR protection. Accordingly, we suppose strengthening of the patent regime through increase in either the litigation success probability (r), or the damage recovery proportion (δ), or both, thereby implying an increase in the measure of strength (σ). This section explores the interactive effects of regime strength and competition intensity on the innovator and the innovation. We analyze the implications of increase in patent strength on the relationship of competition intensity with patenting propensity, scientist mobility, total profitability and R&D expenditure, and further, identify the effects of stronger patents at varying levels of market competition.

3.1 Patenting and Movement

Figure 3 delineates the interactive effects of patent strength and competition intensity on the second period equilibrium patenting and movement decisions in the $\sigma - \theta$ plane. By Assumption $2a$ we have $\theta_4 < \theta_2 \implies \sigma \in [\sigma_B, 1]$. Further, by Assumption $2b$ we have $\theta_4 < \theta_1 \implies \sigma \in [\sigma_A, 1]$[10]. Hence, for the rest of the analysis, we refer to the range $[\sigma_A, 1]$. A detailed derivation of Figure 3 is available in Appendix A. Lemma 4 summarizes the effect of stronger patent laws on the relation of competition intensity with equilibrium patenting and movement, as depicted in Figure 3.

Lemma 4. *Tightening of the patent system sustains the non-monotone (monotone) relation of competitive pressure with patenting (movement).*

Proof. See Appendix A.

Although increase in patent strength does not affect the nature of relationship between

[10] $\sigma_B < 1$ and $\sigma_A < 1$ hold by Assumption $2a$.

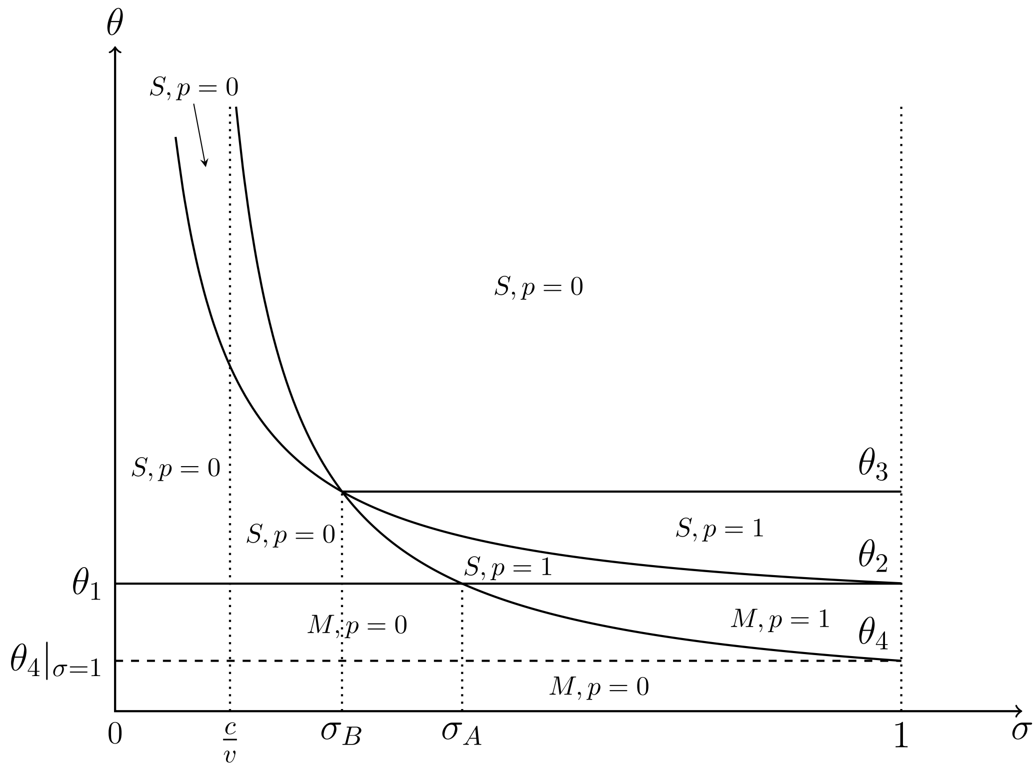


Figure 3: Interaction between Patent Strength and Competition Intensity

competition intensity and second period equilibrium choices, it does influence the incidence of patenting. The incidence of movement, however, remains unaltered[11]. Lemma 5 summarizes.

Lemma 5. *The following define the effect of a stronger patent regime on second period equilibrium patenting and movement.*

(i) Tightening of the patent system expands the range of competition intensity over which patenting occurs by initiating additional patenting at relatively lower competition.

(ii) Tightening of the patent system has no effect on the range of competition intensity over which movement occurs.

Proof. See Appendix A.

The intuition behind Lemma 4 and Lemma 5 is as follows. A greater patent strength

[11]This is in accordance with the finding in Ganguly (2021) that stronger IPRs lead to increase in expected patenting propensity but do not thwart potential movement.

augments expected recovery from patenting such that it exceeds patenting cost at relatively low competition where loss is small. However, even with full recovery, the threshold level of competition intensity below which patenting is unprofitable remains positive, implying no equilibrium patenting at some very low intensity of competition, thereby sustaining the non-monotone relation between competition intensity and patenting. Further, as an increase in expected recovery does not alter movement at any level of competition intensity, there is no change in either its nature of relation with or its incidence at different levels of competition intensity.

3.2 Profit and R&D

Given the effects of stronger patents on the second period decision alternatives, we now derive their corresponding implications for total profit and R&D expenditure of the research project. Corollary 2 provides the effect of increase in patent regime strength on trends of profit and R&D expenditure with competition intensity.

Corollary 2. *Tightening of the patent system sustains the non-monotone relation of competition intensity with total profitability and R&D expenditure of the innovation.*

Proof. See Appendix A.

To derive the interactive effects of stronger patents and competition intensity on project profitability and R&D expenditure, we define the following.

Definition 1. *Given* $\theta_4(\sigma)$, $\theta_4'(\sigma) < 0$ *and* $\theta_4''(\sigma) > 0$, *let* $\hat{\theta}_4 = \theta_4(\sigma = 1)$.

By Definition 1, $\hat{\theta}_4$ denotes the lower threshold above which patenting initiates for maximum patent strength. Therefore, it is the minimum level of competition intensity at which patenting can occur in equilibrium, such that even for the strongest patent that provides full protection guarantee, the entrepreneur does not find it optimal to expend the patenting cost to protect against potential infringement. Proposition 3 (Proposition 4) derives the effect of strengthening of the patent regime on realized profit (R&D expenditure) at different levels of competition intensity.

Proposition 3. *Stronger patents can decrease innovation profitability when market competition intensity is moderately low (i.e.* $\hat{\theta}_4 < \theta < \theta_1$*), but have no effect otherwise.*

Proof. See Appendix A.

Although one may expect strengthening of the patent regime to boost innovation incentives, we show that, counter-intuitively, stronger patents are detrimental to the patent holder's profits. Ganguly (2021) depict a similar effect of increase in patent strength in a general model of innovation and scientist mobility. They show that reforms aimed at tightening the patent system decrease the ex-ante expected profitability of an innovation[12]. However, unlike Ganguly (2021), we derive the explicit market conditions under which the expected decrease in profitability manifests. Our results suggest that the counter-intuitive effect of stronger patents on innovation profitability may materialize only in those industries prone to scientist mobility where product market competition is moderately low. However, if product market competition is very low or highly intense, patent strength has no effect on innovation profitability. The result provides the importance of market structure in determining the (in)efficacy of patent policy reforms in advancing innovation incentives.

The intuition behind the result emanates from the reason for a fall in profit due to an increase in regime strength: the increased incidence of patenting. Patenting is not optimal at very low and very high intensity of competition due to low losses from market competition implying low recovery and insignificant wage reduction due to patenting, respectively, that do not suffice to cover the patenting cost. Thus, the possibility of an increase in the incidence of patenting remains in the middle values of θ where patenting may occur. As we suppose a sufficiently high σ to ensure patenting for some levels of competition intensity

[12]This effect of stronger patents on ex-ante expected profitability holds in our model of competition as well. To check this, suppose f is the density function of θ. We can write:

$$E(\pi) = -\bar{w} + \int_0^{\theta_1} (\rho_i - \lambda\rho_i + \rho_e) f(\theta)\, d(\theta) + \int_{\theta_1}^{\infty} \rho_i . f(\theta)\, d(\theta) - \int_{\theta_4}^{\theta_3} c . f(\theta)\, d(\theta)$$

Differentiating $E(\pi)$ with respect to σ gives the result. Calculations are available upon request.

that induce movement, an increase in expected recovery additionally prompts patenting for moderately low values of competitive pressure that did not initially support it.

Proposition 4. *Stronger patents can increase R&D investment when market competition intensity is moderately low (i.e.* $\hat{\theta}_4 < \theta < \theta_1$*), but have no effect otherwise.*

Proof. See Appendix A.

Proposition 4 provides specific market conditions under which the general result of higher ex-ante expected R&D expenditure in Ganguly (2021) holds[13]. To understand the result, notice that at relatively high competition intensity, when the scientist optimally decides to stay with the entrepreneur, any reduction in second period wage due to increase in potential loss recovery is countered by an equal increase in the first period wage, rendering total R&D expenditure constant at the scientist's total reservation wage. Further, at very low values of competition intensity at which patenting is not optimal despite scientist movement in equilibrium, a higher expected recovery has no effect on scientists' return, and therefore, R&D investment. As a result, a stronger patent regime induces higher R&D investment in the middle range of competition intensity where both movement and patenting occur in equilibrium. It suggests, policies aimed at increasing R&D investment via stronger patent rules must take into account the competitive pressure in the concerned market to prove effective.

4 Relaxing Assumptions

The primary implications of the analysis prevail relevant when we consider possible alternatives to our assumptions. This section discusses how relaxing Assumptions 1 and $2b$

[13]To derive this result in our model of competition, differentiate the following with respect to σ:

$$R\&D = 2\bar{w} \; - \int_{\theta_4}^{\theta_1} (\rho_e - \sigma\lambda\rho_i + \bar{w}) f(\theta)\, d(\theta) \; - \int_{0}^{\theta_4} (\rho_e + \bar{w}) f(\theta)\, d(\theta)$$

Calculations are available upon request.

modify our main results.

Assumption 1 supposes situations in which the innovating entrepreneur and her scientist are able to perfectly foresee the second period competition intensity in case a duopoly arises. For example, an existing firm innovating a new product may be aware of the location of her potential rival due to competition in the market for other products. In this case, the consumers' transportation cost and hence, the level of competition are common knowledge. Alternatively, the actual level of competition intensity may be realized and known only at the beginning of the second period if the scientist sets up a rival whose location is priorly unknown. In this case, the first period decisions depend on the distribution of θ. Our main results regarding the nature of relationship between competition intensity and patenting, movement, profit and R&D expenditure remain unaltered in case we suppose the latter. However, the effect of a stronger patent regime on total profit and R&D expenditure at different levels of competition intensity are reversed. It follows, policies aimed at effecting innovation profitability or investment must not only consider the new product market's competition intensity but also heed the agents' knowledge of the same. On the other hand, relaxing Assumption 2b renders patenting cost high enough to prevent patenting at any level of competition which induces movement. Our main results remain unchanged, except for the effect of stronger patents on R&D expenditure at moderate competition, which proves ineffective due to no equilibrium patenting when movement occurs. A detailed analysis of relaxing the assumptions is available in Appendix B.

5 Alternate Model of Competition Intensity

As an alternate to the Hotelling framework with linear transportation cost, we consider a linear supply schedule framework where the slope of the supply function measures intensity of competition. Employing the model from Menezes and Quiggin (2012) to derive the second period profit expressions under monopoly and duopoly as functions of competition intensity, we find that the competition levels defining boundaries for reversals in second period equilibrium patenting and movement exactly correspond to the ranges of θ in the preceding analysis. Therefore, the results from the supply schedule model of competition intensity will follow analogous to the Hotelling model discussed in our main analysis. However, this framework does not suppose market expansion due to technology diffusion and thus, eliminates the possibility of movement in equilibrium. The complete derivation of this model is available in Appendix C.

6 Conclusion

This study aims to further the understanding of implications of patent regime strength and intensity of product market competition, and their joint effects, on patenting, labor mobility, R&D expenditure and profitability of innovating firms. The first part of the analysis reports the relationships of innovation attributes with competition intensity in the market for the new technology, when scientist mobility is a prevalent source of knowledge spillover within industries. The results suggest surprising relations between the market's competitive pressure and the incidence of patenting and movement. While higher potential competition does not necessarily sustain patenting, it does halt movement. However, preventing movement may not be favorable to profit. We find that even though a moderate level of expected competition retains monopoly, it renders the entrepreneur's profit lower as compared to her duopoly profit under less intensive competition that permits movement.

The second part of the paper identifies the interaction effects between increase in patent strength and market competition intensity on patenting, scientist movement and innovation. Greater patent strength leads to lower profitability through increased patenting in moderately competitive markets, although very lenient as well as highly competitive markets are exempt from its effect. It turns out, in markets where scientist mobility is feasible and competition is moderate, patenting, resulting from the profit motive, is in practice counter-profitable. Higher expected R&D investment resulting from stronger patents also actualizes only in moderately competitive markets. The results suggest that patent policy reforms aimed at protecting innovating entrepreneurs or raising scientist wages must take into account not only their expected repercussions but also the competitive pressure in their targeted markets.

The above results follow for a model of product innovation and certain R&D, with the degree of product differentiation indicating market competitive pressure. As further analyses, it would be interesting to introduce knowledge spillover due to scientist mobility in alternative models of R&D and oligopoly structure to analyze how our predictions modify under different innovation choices and modes of competition.

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Appendix A

Construction of Figure 1

Case I: Let $\rho_e > \lambda\rho_i \implies \theta < \frac{L^2+1}{v} = \theta_1$, say. It follows, the scientist's gain at the rival exceeds the entrepreneur's loss due to infringement. Therefore, movement occurs in equilibrium. Patenting occurs if $\sigma\lambda\rho_i \geq c \implies \theta \geq \frac{\sigma(2+L^2)}{2(v\sigma-c)} = \theta_4$, say, as $\sigma > \frac{c}{v}$ by Assumption 2a. We have $\theta_4 < \theta_1$ by Assumption 2b.

Case II: Let $\rho_e \leq \lambda\rho_i \implies \theta \geq \theta_1$ but $\rho_e > \sigma\lambda\rho_i \implies \theta < \frac{(\frac{1}{\sigma}+1)L^2+2}{2v} = \theta_2$, say ($\theta_2 > \theta_1$ as $\sigma < 1$). The first inequality implies the entrepreneur finds it optimal to retain the scientist as opposed to suffering loss in profit due to movement. Therefore, movement does not occur in equilibrium. The second inequality suggests that the scientist prefers moving to the rival firm as opposed to the non-R&D sector, regardless of whether the innovation is patented. Patenting occurs if $\sigma\lambda\rho_i \geq c \implies \theta \geq \theta_4$, which is true for all θ in this case. Consequently, $w_1 = \rho_e - \sigma\lambda\rho_i + \bar{w}$.

Case III: Let $0 < \rho_e \leq \sigma\lambda\rho_i$. The first part of the inequality holds trivially. The second part implies $\theta \geq \theta_2$. It follows, the scientist prefers moving to the non-R&D sector (rival firm) if the innovation is patented (not patented). Consequently, $w_1 = \bar{w}$ ($w_1 = \rho_e + \bar{w}$). Clearly, movement does not occur in equilibrium. Patenting occurs when $\rho_e \geq c \implies \theta \leq \frac{L^2}{2c} = \theta_3$, say. Assumption 2$a$ ensures $\theta_3 > \theta_2$.

It is straightforward to check that $\frac{\partial(\lambda\rho_i)}{\partial\theta} > 0$, $\frac{\partial(\rho_e)}{\partial\theta} > 0$, $\frac{\partial^2(\lambda\rho_i)}{\partial\theta} < 0$ and $\frac{\partial^2(\rho_e)}{\partial\theta} < 0$. Further, $\sigma\lambda\rho_i$ is a downward shift of the curve $\lambda\rho_i$ by $(1-\sigma)$ with the curvature remaining unchanged. The curves intersect to partition the range of θ into segments indicated by θ_1, θ_2, θ_3 and θ_4 derived above and accordingly determine whether patenting and movement occur for a given level of competition intensity. ■

Proof of Proposition 1

The proof follows directly from Figure 1. In $0 < \theta < \theta_4$, $p = 0$. Then, in $\theta_1 < \theta < \theta_3$, $p = 1$, but again in $\theta > \theta_3$, $p = 0$. Therefore, patenting behavior exhibits a non-monotone trend with increase in θ. For movement, we have M in $\theta < \theta_1$ and S in $\theta > \theta_1$, implying a monotone trend. ■

Proof of Lemma 1

First consider the decision alternatives $M, p = 0$. This corresponds to $\theta < \theta_4$. As the scientist moves and the entrepreneur chooses not to patent the innovation, the scientist's second period earning equals $\rho_e + \bar{w}$. Accordingly, the scientist's participation constraint implies $w_0 = 2\bar{w} - (\rho_e + \bar{w}) = \bar{w} - \rho_e$. $\therefore \pi = (1-\lambda)\rho_i - (\bar{w} - \rho_e) = -\bar{w} + \rho_i + \rho_e - \lambda\rho_i$.

Next consider $M, p = 1$ which corresponds to $\theta_4 < \theta < \theta_1$. The scientist's second period earning equals $\rho_e - \sigma\lambda\rho_i + \bar{w}$. The participation constraint implies $w_0 = 2\bar{w} - (\rho_e - \sigma\lambda\rho_i + \bar{w}) = \bar{w} - \rho_e + \sigma\lambda\rho_i$. $\therefore \pi = (1-\lambda)\rho_i + \sigma\lambda\rho_i - (\bar{w} - \rho_e + \sigma\lambda\rho_i) - c = -\bar{w} + \rho_i + \rho_e - \lambda\rho_i - c$.

The choice of decision alternatives $S, p = 1$ corresponds to $\theta_1 < \theta < \theta_3$. In $\theta_1 < \theta < \theta_2$, $w_1 = \rho_e - \sigma\lambda\rho_i + \bar{w}$. Therefore, $w_0 = 2\bar{w} - (\rho_e - \sigma\lambda\rho_i + \bar{w}) = \bar{w} - \rho_e + \sigma\lambda\rho_i$. $\therefore \pi = \rho_i + \bar{w} - (\rho_e - \sigma\lambda\rho_i + \bar{w}) - (\bar{w} - \rho_e + \sigma\lambda\rho_i) - c = -\bar{w} + \rho_i - c$. In $\theta_2 < \theta < \theta_3$, $w_1 = \bar{w}$. Therefore, $w_0 = 2\bar{w} - (\bar{w}) = \bar{w}$. $\therefore \pi = \rho_i + \bar{w} - (\bar{w} + \bar{w}) - c = -\bar{w} + \rho_i - c$.

Finally, $S, p = 0$ corresponds to $\theta > \theta_3$. Here, $w_1 = \rho_e + \bar{w}$. Therefore, $w_0 = 2\bar{w} - (\rho_e + \bar{w}) = \bar{w} - \rho_e$. $\therefore \pi = \rho_i + \bar{w} - (\rho_e + \bar{w}) - (\bar{w} - \rho_e) = -\bar{w} + \rho_i$. ■

Proof of Lemma 2

We already derived the expressions for w_0 and w_1 in the proof of Lemma 1. When $M, p = 0$ for $\theta < \theta_4$, wage expenditure consists only the first period wage. $\therefore R\&D = w_0 = \bar{w} - \rho_e$. Similarly, when $M, p = 1$ in $\theta_4 < \theta < \theta_1$, $R\&D = w_0 = \bar{w} - \rho_e + \sigma\lambda\rho_i$. Finally, when the scientist stays (S), his participation constraint implies $R\&D = w_0 + w_1 = 2\bar{w}$, regardless of whether the innovation is patented. ■

Proof of Lemma 3

It is straightforward to check that $\frac{\partial(\rho_i+\rho_e-\lambda\rho_i)}{\partial\theta} < 0$, $\frac{\partial\rho_i}{\partial\theta} > 0$, $\frac{\partial(\sigma\lambda\rho_i)}{\partial\theta} > 0$ and $\frac{\partial\rho_e}{\partial\theta} < 0$. Further, $\bar{w}$ and c are constants with respect to θ. Therefore, the proof follows from Lemma 1, Lemma 2 and the following decision alternatives within the ranges of θ: (i) 0 to θ_4: $M, p = 0$; (ii) θ_4 to θ_1: $M, p = 1$; (iii) θ_1 to θ_2: $S, p = 1$; (iv) θ_2 to θ_3: $S, p = 1$; (v) θ_3 to ∞: $S, p = 0$. ■

Construction of Figure 3

We have, $\theta_1 = \frac{L^2+1}{v}$, $\theta_2 = \frac{(\frac{1}{\sigma}+1)L^2+2}{2v}$, $\theta_3 = \frac{L^2}{2c}$ and $\theta_4 = \frac{\sigma(2+L^2)}{2(v\sigma-c)}$. θ_1 and θ_3 are constant with respect to σ. For θ_2, $\frac{\partial\theta_2}{\partial\sigma} < 0$ and $\frac{\partial^2\theta_2}{\partial\sigma^2} > 0$. Also, $\sigma \to 0 \implies \theta_2 \to \infty$ and $\sigma = 1 \implies \theta_2 = \theta_1$. Accordingly, the graph for θ_2 follows. To derive the graph for θ_4, observe Assumption 2a requires $\sigma > \frac{c}{v}$. Therefore, $\theta_4 > 0$, $\frac{\partial\theta_4}{\partial\sigma} < 0$ and $\frac{\partial^2\theta_4}{\partial\sigma^2} > 0$. Now, $\theta_1 = \theta_4$ at $\sigma = \frac{2c(L^2+1)}{L^2v} = \sigma_A$ and $\theta_2 = \theta_4$ at $\sigma = \frac{L^2c}{L^2(v-c)-2c} = \sigma_B$. Further, $\theta_2 = \theta_3$ at $\sigma = \sigma_B$. It is straightforward to check that both $\sigma_A < 1$ and $\sigma_B < 1$ require $c < \frac{L^2v}{2(L^2+1)}$, which holds given Assumption 2a. Again, as $\theta_2 > \theta_1$ at $\sigma < 1$, $\sigma_B < \sigma_A$.

To understand Assumptions 2a and 2b, make the following observations from the figure. At any given value of σ, for patenting to be possible, we must have $\theta_4 < \theta_2 \implies c < \frac{L^2v\sigma}{(1+\sigma)L^2+2\sigma}$, which requires Assumption 2a. At any given value of σ, for patenting to be possible at some levels of θ which induce movement, we must have $\theta_4 < \theta_1 \implies c < \frac{L^2v\sigma}{2(L^2+1)}$, which requires Assumption 2b. ■

Proof of Lemma 4

Suppose $\sigma \in [\sigma_A, 1]$. First consider patenting: $p = 0$ when $0 < \theta < \theta_4$, $p = 1$ when $\theta_4 < \theta < \theta_3$, and again $p = 0$ when $\theta_3 < \theta < \infty$. Further, at maximum strength i.e. $\sigma = 1$, $\theta_4 > 0$. Therefore, the non-monotone relation between patenting and competition intensity sustains $\forall\sigma \in [\sigma_A, 1]$. Next consider movement: M when $\theta < \theta_1$ and S when $\theta > \theta_1$. Further, θ_1 is constant with respect to σ. Therefore, the monotone relation between movement and competition intensity sustains $\forall\sigma \in [\sigma_A, 1]$. ■

Proof of Lemma 5

Suppose $\sigma \in [\sigma_A, 1]$. Patenting occurs in $\theta_4 < \theta < \theta_3$. As $\theta_4'(\sigma) < 0$ and $\theta_3'(\sigma) = 0$, it follows that the range of patenting expands with increase in σ with additional patenting at lower levels of θ. Movement occurs in $0 < \theta < \theta_1$. As $\theta_1'(\sigma) = 0$, there is no change in the range of movement with increase in σ. ■

Proof of Corollary 2

Consider the ranges of θ in Lemma 3. Lemma 5 suggests a widening (narrowing) of the second and fourth (first and third) ranges with increase in σ. Further, Lemma 4 suggests these ranges remain qualitatively equivalent as σ rises. This implies, although the width of the ranges alter due to increase in patent strength, there is no reversal of patenting and movement decision within or across ranges due to increase in σ. Next, consider the direction of movement in profit and R&D with increase in θ within the ranges in Lemma 3. For given patenting and movement decision alternatives, Lemma 1 implies no change in profit with increase in σ, and Lemma 2 indicates an increase in R&D expenditure only for $M, p = 1$ as σ rises. It follows, there is no change in the trend of π and $R\&D$ with θ due to increase in σ within any range of θ. Consequently, the non-monotone trend of π and $R\&D$ with θ remains unaltered as σ rises. ■

Proof of Proposition 3

Lemma 1 implies, at any given θ if the entrepreneur goes from not patenting to patenting the innovation when the scientist moves, profit falls by the amount of patenting cost. Now, check from Figure 3 that as σ rises, θ_4 and θ_2 fall while θ_1 and θ_3 remain constant. Notice that θ_2 does not partition patenting behavior. Let θ_4^0 be the initial threshold below which patenting ceases. As σ increases, let this threshold fall to $\theta_4^{'}$. Therefore, $\theta_4^{'} - \theta_4^0$ gives the range of θ where incidence of patenting increases. Hence, profit falls in this range. It follows, increase in σ has no effect on profitability for values of θ in ranges $0 - \theta_4^{'}$ and $\theta_4^0 - \infty$. As

$\sigma \in [\sigma_A, 1]$, the maximum possible θ_4^0 is θ_1 and the minimum possible $\theta_4^{'}$ is $\hat{\theta}_4$. Consequently, the profit reducing effect of increase in patent strength can only manifest within the range $\hat{\theta}_4 < \theta < \theta_1$. ■

Proof of Proposition 4

Lemma 2 implies, at any given θ if the entrepreneur goes from not patenting to patenting the innovation when the scientist moves, R&D expenditure increases by $\sigma\lambda\rho_i$. Further, an increase in σ increases R&D expenditure when $M, p = 1$ due to increase in damage reparation. Continuing with the notations from the previous proof, we have, R&D expenditure increases over (a) $\theta_4^{'} - \theta_4^0$ due to increased patenting, and (b) $\theta_4^0 - \theta_1$ due to increased expected reparation, as σ rises. It follows, increase in σ has no effect on R&D expenditure for values of θ in ranges $0 - \theta_4^{'}$ and $\theta_1 - \infty$. Now, notice that increase in σ certainly increases R&D expenditure in $\theta_4(\sigma) < \theta < \theta_1$ $\forall \sigma \in [\sigma_A, 1]$. Again, as $\sigma \in [\sigma_A, 1]$, the minimum possible $\theta_4^{'}$ is $\hat{\theta}_4$. Consequently, the R&D augmenting effect of increase in patent strength can manifest within the range $\hat{\theta}_4 < \theta < \theta_1$. ■

Appendix B

Relaxing Assumption 1

We relax Assumption 1 and suppose the entrepreneur and the scientist cannot infer the actual level of competition intensity at the beginning of the first period. Let θ be a random variable with density f, which is common knowledge. As the competition intensity in the market is realized at the beginning of the second period, movement, patenting and second period realized returns remain same as in the main analysis. The entrepreneur, knowing the optimal second period movement behavior for any potential level of competition intensity, maximizes her expected profit at the beginning of the first period to determine the optimal first period wage, subject to the scientist's participation constraint. The scientist, knowing the optimal second period wage offer for each level of competition intensity, participates in the entrepreneur's project in the first period if the expected wage in both periods combined exceeds his total reservation wage $2\bar{w}$. Substituting the second period returns for different levels of competition intensity in the participation constraint of the scientist (which is $2\bar{w} \leq w_0 + E(w_1)$, where $E(w_1)$ denotes his expected return in period 2) gives the first period wage w_0 as:

$$w_0 = \bar{w} \; - \int_0^{\theta_4} \rho_e f(\theta)\, d\theta - \int_{\theta_4}^{\theta_2} [\rho_e - \sigma\lambda\rho_i] f(\theta)\, d\theta \; - \int_{\theta_3}^{\infty} \rho_e f(\theta)\, d\theta \tag{B.1}$$

Table B.1 delineates the realized values of the entrepreneur's second period profit π_1 and the scientist's second period wage w_1 for different ranges of θ. Recall ρ_i and $\sigma\lambda\rho_i$ rise and ρ_e falls as θ rises. The patenting cost c is constant. Therefore, in the first range, an increase in θ causes $\pi_1 = \rho_i - \lambda\rho_i = \rho_e$ to fall, implying an inverse relationship between competition intensity and realized profit. In the second range, $\pi_1 = \rho_i - \lambda\rho_i + \sigma\lambda\rho_i - c = \rho_e + \sigma\lambda\rho_i - c$ increases, remains constant or decreases as θ rises according as $\sigma \gtreqless \frac{L^2}{2+L^2}$. As movement occurs for all values of θ in both ranges, an increase in θ does not induce second period wage payment, leaving w_1 constant at 0. It is straightforward to check that π_1 increases with an increase in θ in the remaining three ranges and w_1 decreases in the third and fifth range while remaining constant over the fourth range of θ. Given w_0, for any level of competition intensity in the second period, the total profit of the entrepreneur is $-w_0 + \pi_1$, where π_1 is the entrepreneur's second period profit. The total R&D expenditure of the research project is w_0 if movement occurs and $w_0 + w_1$ otherwise. As w_0 is determined in the first period and is constant, the relation of competition intensity with realized profit and R&D expenditure of the innovation follow the relation of π_1 and w_1, respectively. It follows, our results on the nature of relation of competition intensity with patenting, movement, realized profit and R&D expenditure of the innovation in Proposition 1 and Proposition 2 hold. However, the direction of change in realized profit and R&D expenditure within each range of θ is not necessarily congruent to the main analysis.

Table B.2 compares the effect of increase in competition intensity on profit and R&D expenditure with and without Assumption 1 by range of θ. For profit, relaxing Assumption

Range of θ	Movement Decision	Patenting Decision	π_1	w_1
0 to θ_4	M	$p = 0$	$\rho_i - \lambda\rho_i$	0
θ_4 to θ_1	M	$p = 1$	$\rho_i - \lambda\rho_i + \sigma\lambda\rho_i - c$	0
θ_1 to θ_2	S	$p = 1$	$\rho_i - \rho_e + \sigma\lambda\rho_i - c$	$\rho_e - \sigma\lambda\rho_i + \bar{w}$
θ_2 to θ_3	S	$p = 1$	$\rho_i - c$	$\bar{w}$
θ_3 to ∞	S	$p = 0$	$\rho_i - \rho_e$	$\rho_e + \bar{w}$

Table B.1: Second Period Profit and Wage by Competition Intensity

Range of θ	With Assumption 1		Without Assumption 1	
	Profit	R&D Expenditure	Profit	R&D Expenditure
0 to θ_4	Decreases	Increases	Decreases	Remains constant
θ_4 to θ_1	Decreases	Increases	Ambiguous	Remains constant
θ_1 to θ_2	Increases	Remains constant	Increases	Decreases
θ_2 to θ_3	Increases	Remains constant	Increases	Remains constant
θ_3 to ∞	Increases	Remains constant	Increases	Decreases

Table B.2: Effect of Competition Intensity by Assumption 1

1 contrasts the main analysis in the second range of θ. As θ increases within this range, while duopoly returns contract due to higher competition intensity, recovery from patenting rises due to greater losses. If the expected recovery is sufficiently high as compared to the ratio of the magnitude of change in profit to change in loss incurred for unit increase in competition intensity, the total profit of the entrepreneur under duopoly may increase with an increase in competitive pressure. However, this is not the case when the realized competition intensity is inferred at the beginning of the first period, as any increase in potential damage recovery lowers the scientist's second period return and must be exactly adjusted in the first period wage, implying the effect of competition intensity on the second period realized profit is solely determined by its effect on duopoly returns. Next, consider R&D expenditure. With Assumption 1, a rise in competition intensity in the first two ranges of θ causes scientist's returns from movement to fall, requiring an increase in the first period

wage to compensate. But relaxing Assumption 1 implies the first period wage is determined and paid out based on expected competition intensity, and hence is constant. As a result, increase in realized competition intensity within the first two ranges of θ does not have any effect on w_0, and therefore on R&D expenditure. Similarly, when Assumption 1 holds, adjustments in the first period wage cause the combined wage in both periods to remain at $2\bar{w}$ irrespective of the level of competition intensity. However, without Assumption 1, such adjustments are ruled out and wherever potential duopoly returns determine scientist wage, a decreasing w_1 causes R&D expenditure to decrease with increasing competitive pressure.

A stronger patent regime affects the relation of realized profit and R&D expenditure with competition intensity through two avenues - (i) change in w_0 due to change in expected second period earnings, and (ii) change in π_1 and w_1 within ranges of θ as well as thresholds defining the ranges. Lemma B.1 states the effect of an increase in recovery proportion on the first period wage.

Lemma B.1: *A stricter patent regime augments the first period wage, i.e. w_0 increases with an increase in σ.*

Proof. Differentiating the expression for w_0 in Equation (B.1) with respect to σ yields:

$$\frac{\partial w_0}{\partial \sigma} = 0 \; - \; \frac{\partial}{\partial \sigma}\left[\int_0^{\theta_4} \rho_e f(\theta)\, d\theta\right] - \frac{\partial}{\partial \sigma}\left[\int_{\theta_4}^{\theta_2} [\rho_e - \sigma\lambda\rho_i] f(\theta)\, d\theta\right] - \frac{\partial}{\partial \sigma}\left[\int_{\theta_3}^{\infty} \rho_e f(\theta)\, d\theta\right]$$

The second term yields:

$$\theta_4'(\sigma).\left(\frac{L^2}{2\theta_4}\right).f(\theta_4)$$

The third term yields:

$$\int_{\theta_4}^{\theta_2} (-\lambda\rho_i) f(\theta)\, d\theta + \theta_2'(\sigma).\left[\frac{L^2}{2\theta_2} - \sigma.\left(\frac{2v\theta_2 - 2 - L^2}{2\theta_2}\right)\right].f(\theta_2) - \theta_4'(\sigma).\left[\frac{L^2}{2\theta_4} - \sigma.\left(\frac{2v\theta_4 - 2 - L^2}{2\theta_4}\right)\right].f(\theta_4)$$

$$= -\int_{\theta_4}^{\theta_2} \lambda\rho_i f(\theta)\, d\theta + \theta_2'(\sigma).\left[\frac{L^2}{2\theta_2} - \sigma v + \frac{\sigma(2+L^2)}{2\theta_2}\right].f(\theta_2) - \theta_4'(\sigma).\left[\frac{L^2}{2\theta_4} - \sigma v + \frac{\sigma(2+L^2)}{2\theta_4}\right].f(\theta_4)$$

Check by replacing $\theta_2 = \frac{(1+\sigma)L^2+2\sigma}{2v\sigma}$ that the term within third brackets in the second part of the equation equals 0. The remaining parts simplify as:

$$-\int_{\theta_4}^{\theta_2} \lambda\rho_i f(\theta)\,d\theta \;-\; \theta_4^{'}(\sigma).\frac{L^2}{2\theta_4}.f(\theta_4) \;+\; \theta_4^{'}(\sigma).\left[\frac{2v\sigma\theta_4 - \sigma(2+L^2)}{2\theta_4}\right].f(\theta_4)$$

$$= -\int_{\theta_4}^{\theta_2} \lambda\rho_i f(\theta)\,d\theta \;-\; \theta_4^{'}(\sigma).\frac{L^2}{2\theta_4}.f(\theta_4) \;+\; \theta_4^{'}(\sigma).\left[\sigma\lambda\rho_i|_{\theta=\theta_4}\right].f(\theta_4)$$

The fourth term in $\frac{\partial w_0}{\partial\sigma}$ equals 0.

Combining the above yields:

$$\begin{aligned}\frac{\partial w_0}{\partial\sigma} &= -\,\theta_4^{'}(\sigma).\left(\frac{L^2}{2\theta_4}\right).f(\theta_4) \;+\; \int_{\theta_4}^{\theta_2} \lambda\rho_i f(\theta)\,d\theta \;+\; \theta_4^{'}(\sigma).\frac{L^2}{2\theta_4}.f(\theta_4) \;-\; \theta_4^{'}(\sigma).\left[\sigma\lambda\rho_i|_{\theta=\theta_4}\right].f(\theta_4)\\ &= \int_{\theta_4}^{\theta_2} \lambda\rho_i f(\theta)\,d\theta \;-\; \theta_4^{'}(\sigma).\left[\sigma\lambda\rho_i|_{\theta=\theta_4}\right].f(\theta_4)\end{aligned}$$

As $\theta_4^{'}(\sigma) < 0$ and $\left[\sigma\lambda\rho_i|_{\theta=\theta_4}\right] > 0$, the second term in the above expression is positive. The first term is also positive. Therefore, $\frac{\partial w_0}{\partial\sigma} > 0$. ■

An increase in σ increases the first period wage by Lemma B.1, exerting a negative pressure on total profitability and a positive pressure on R&D expenditure of the innovation. Further, higher σ implies higher π_1 in the second and third ranges of θ and a lower w_1 in the third range of θ from Table B.1. The relevant ranges of θ remain qualitatively similar, with a widening of second and fourth range and a narrowing of the first and third, as in our main analysis. The direction of change in profit in all but the second range, and R&D expenditure in all ranges, with an increase in competitive pressure is independent of σ, implying no change in their relation with competition intensity within these ranges. An increase in σ may reverse the direction of change in profit in the second range of competition intensity if it increases from an initial value less than the threshold to exceed the same. Nevertheless, the relation of profit and R&D expenditure with competition intensity remains non-monotone, implying Corollary 2 from the main analysis holds. Relaxing Assumption 1, however, reverses the effect of increase in patent strength on total profit (R&D expenditure) defined by Proposition 3 (Proposition 4). Proposition B.3 (Proposition B.4) summarizes the results when Assumption 1 does not hold.

Proposition B.3: *A stronger patent system decreases the innovation's profitability at sufficiently low and high levels of competition intensity, but its effect at moderate competitive pressure is ambiguous.*

Proof. w_0 increases with an increase in σ by Lemma B.1. Total profitability is defined by $\pi = -w_0 + \pi_1$. In the first, fourth and fifth ranges of θ, π_1 remains constant with an increase in σ, implying a fall in π through w_0. In the second and third ranges, an increase in σ increases π_1, implying the combined effect on π is ambiguous. ■

Proposition B.4: *A stronger patent system increases R&D investment at low and high levels of competition intensity, but its effect at moderate competitive pressure is ambiguous.*

Proof. R&D expenditure is defined by $R\&D = w_0 + w_1$. In all but the third range of θ, w_1 remains constant as σ increases, implying an increase in $R\&D$ through w_0. In the third range, an increase in σ reduces w_1, implying the combined effect on $R\&D$ is ambiguous. ■

The intuition follows from incomplete information in the first period when the entrepreneur adjusts the scientist's joining offer in response to a decrease in his expected second period returns due to increase in patent regime strength. This adjustment is uniform irrespective of the actual level of competition intensity. At sufficiently low and high competition, patent strength does not affect second period scientist return. Thus, the entrepreneur's second period loss or wage reduction due to patenting is unaffected, rendering the increase in first period wage superfluous and profit reducing. Further, constant second period scientist return combined with increased first period wage induce an increase in total R&D expenditure at low and high levels of competition intensity. At moderate intensity of competition, while the increase in first period wage generates a mitigating (augmenting) effect on total profitability (R&D expenditure) of the innovation, an increase in expected recovery additionally increases (decreases) the second period earning of the entrepreneur (scientist) through higher potential for recovery from patenting. However, in contrast to the main analysis, the first period wage adjustment is not exact due to imperfect information regarding second period intensity of competition. As a result, the opposing effects of a stricter patent rule on profit and R&D expenditure at moderate levels of competition intensity render the combined effect ambiguous.

Relaxing Assumption 2b

We relax Assumption 2b to suppose $\frac{L^2 v\sigma}{2(L^2+1)} < c < \frac{L^2 v\sigma}{(1+\sigma)L^2+2\sigma}$. It implies $\theta_1 < \theta_4 < \theta_2$. In Figure 3, this corresponds to the range $\sigma \in (\sigma_B, \sigma_A)$. Figure B.1 illustrates the second period equilibrium patenting and movement behavior when Assumption 2b does not hold. The difference with the main analysis is the absence of patenting at some low and moderately low levels of competition intensity due to insufficient loss and wage reduction, respectively from patenting. However, notice that while at low competition intensity the entrepreneur never patents the innovation, as competition intensity increases patenting occurs, ceasing again as it exceeds a threshold level, implying a non-monotone relation of patenting with competition intensity. Alternatively, a change in the relative magnitudes of regime strength and patenting cost does not affect movement, implying a monotone relation of the same with the intensity of competition. Thus, relaxing Assumption 2b preserves the results in Proposition 1. Lemma 1 & Lemma 2 in the main analysis give the expressions for realized profit and R&D expenditure, respectively. Using the corresponding movement and patenting behavior for the new ranges of θ in Figure B.1, it can be easily checked that (i) profit falls with an increase in competition intensity in the first range of θ, i.e. $0 < \theta < \theta_1$, and rises henceforth, with discontinuities at θ_4 and θ_3 due to reversal of patenting behavior, and (ii) R&D expenditure rises with an increase in competition intensity in $0 < \theta < \theta_1$ and remains constant henceforth. It follows, the non-monotone relation of competition intensity with total profitability and R&D expenditure of the innovation defined in Proposition 2 remain unaltered when we relax Assumption 2b.

Next, consider the implications of Assumption 2b on the effects of a stronger patent regime.

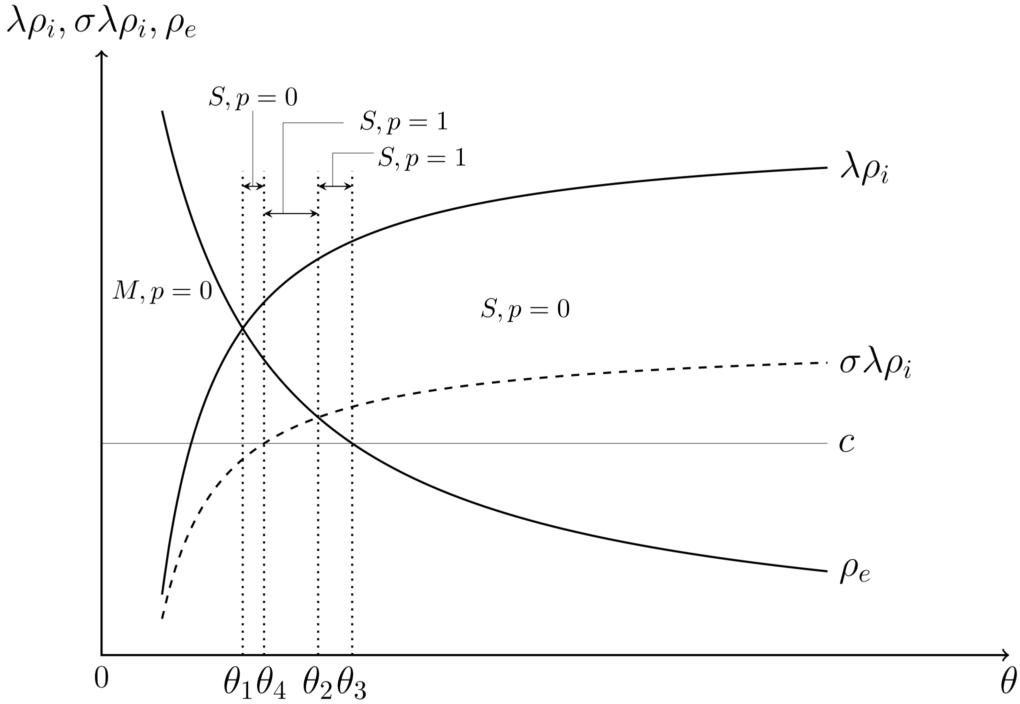

Figure B.1: Patenting and mobility by competition intensity (without Assumption 2.b)

Figure 3 suggests Lemma 4 and Lemma 5 hold in the range $\sigma \in (\sigma_B, \sigma_A)$, implying the relevant ranges of θ remain qualitatively unchanged as σ increases. Lemma 1 implies no change in profit within any range of θ, which conforms to the main analysis. However, the lower threshold determining a reversal of patenting behavior falls as σ rises, causing incidence of patenting to increase and profit to fall in moderate values of competition intensity. On the other hand, in contrast to the main analysis, Lemma 2 implies no change in R&D expenditure within any range of θ as the current range of σ precludes patenting when movement occurs. As recovery proportion affects R&D expenditure only when patenting and movement occur simultaneously, it turns out an increase in σ has no effect on R&D expenditure of the innovation at any level of competition intensity. Therefore, while the results in Corollary 2 and Proposition 3 hold without Assumption 2b, the effect in Proposition 4 manifests only when the assumption holds.

Appendix C

Supply Schedule Model of Competition Intensity

The model of competition exactly follows Menezes and Quiggin (2012). Consider n symmetric firms with marginal cost $k_1 = k_2 = ... = k_n = k < 1$. The linear demand function is:

$$p = 1 - [q_1 + q_2 + ... + q_n]$$

The supply schedule for firm i is:

$$q_i = \left(\alpha_i - \frac{k}{n}\right) + \beta(p - k)$$

where α_i is the choice variable denoting position of the supply function and $\beta \geq 0$ is an exogenous parameter characterizing intensity of competition. We get the profit expression from Menezes and Quiggin (2012) as:

$$\pi^* = \frac{(1 + \beta(n-1))(1-k)^2}{[(n+1) + n\beta(n-1)]^2}$$

Substitute $n = 1$ to get the monopoly profit of the entrepreneur, $n = 2$ to get duopoly returns in case the rival appears in equilibrium, and replace the first expression into the second to get the proportion of loss due to competition, as follows:

$\rho_i = \dfrac{(1-k)^2}{4}$;

$(1-\lambda)\rho_i = \rho_e = \dfrac{(1+\beta)(1-k)^2}{(3+2\beta)^2}$;

$\lambda = \dfrac{5 + 4\beta^2 + 8\beta}{(3+2\beta)^2}$;

This framework does not consider technology diffusion through market expansion due to appearance of the rival in the second period. To derive the second period optimal patenting and movement behavior, first suppose $\rho_e > \lambda\rho_i \implies (1+2\beta)^2 < 0$. However, this can never hold as $\beta > 0$. It implies, the present framework rules out the possibility of movement in equilibrium. This is because the sum of the two duopoly profits in the second period in case movement occurs can never exceed the monopoly profit, implying

$\rho_i \geq \rho_e + (1-\lambda)\rho_i \implies \lambda\rho_i \geq \rho_e$. Therefore, in absence of market expansion due to arrival of a rival, the loss to the entrepreneur from market competition always exceeds the potential gain to the scientist from moving, rendering it profitable for the entrepreneur to retain the scientist.

Next, suppose $\sigma\lambda\rho_i < \rho_e \leq \lambda\rho_i$. We already established the second part of the inequality for all $\beta > 0$. The first part holds if $\sigma < \frac{4+\beta}{5+4\beta^2+8\beta}$. The entrepreneur retains the scientist in this case, and patents the innovation if $\sigma\lambda\rho_i \geq c \implies \sigma \geq \frac{4c(3+2\beta)^2}{(5+4\beta^2+8\beta)(1-k)^2}$, where c is the cost of patenting.

Now suppose $0 < \rho_e \leq \sigma\lambda\rho_i$. The second part of the inequality holds when $\sigma \geq \frac{4+\beta}{5+4\beta^2+8\beta}$. The first part implies $\frac{(1+\beta)(1-k)^2}{(3+2\beta)^2} > 0$, which always holds. In this case, the scientist optimally stays with the entrepreneur. Patenting occurs when $\rho_e \geq c \implies c \leq \frac{(1+\beta)(1-k)^2}{(3+2\beta)^2}$.

As $\rho_e > 0$ for all $\beta > 0$, the scientist never finds movement to the non-R&D sector profitable in absence of equilibrium patenting.

Summarizing, we have $\rho_e \leq \lambda\rho_i$ always holds. $\sigma\lambda\rho_i \gtreqless \rho_e$ according as $\sigma \gtreqless \frac{4+\beta}{5+4\beta^2+8\beta}$. Notice that as β rises, the RHS of the inequality falls. Hence, starting from an initial β such that $\sigma < \frac{4+\beta}{5+4\beta^2+8\beta}$ for a given σ, as β increases, σ eventually equals and then exceeds $\frac{4+\beta}{5+4\beta^2+8\beta}$. Figure C.1 plots the second period equilibrium patenting and movement at different levels of β. Check that $\frac{\partial\lambda}{\partial\beta} > 0$ and $\frac{\partial^2\lambda}{\partial\beta^2} < 0$. ρ_i is constant with respect to β. Thus, the graphs for $\lambda\rho_i$ and $\sigma\lambda\rho_i$ are increasing and concave over β, with $\sigma\lambda\rho_i$ being a downward shift of $\lambda\rho_i$ by a proportion $(1-\sigma)$ at a given β, as in our main analysis. Further, $\rho_e = (1-\lambda)\rho_i \implies \frac{\partial\rho_e}{\partial\beta} = -\frac{\partial\lambda}{\partial\beta}.\rho_i < 0$ and $\frac{\partial^2\rho_e}{\partial\beta^2} = -\frac{\partial^2\lambda}{\partial\beta^2} > 0$.

β_4, β_2 and β_3 in Figure C.1 correspond to θ_4, θ_2 and θ_3, respectively from the main analysis (without Assumption 2b). Therefore, equilibrium patenting behavior has a non-monotone relation to competition intensity, and the nature of the relation is exactly similar to our analysis in the Hotelling framework.

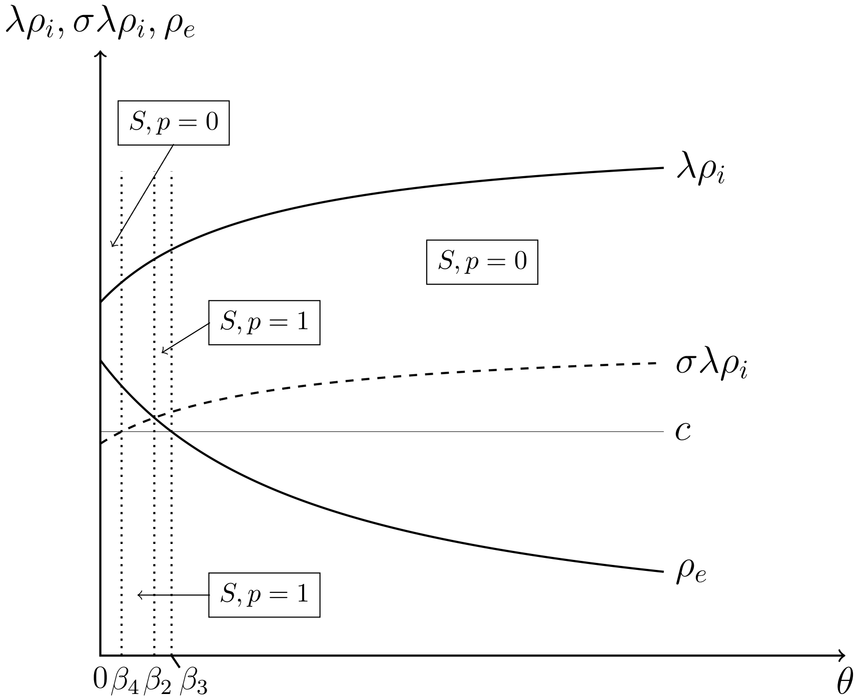

Figure C.1: Patenting and mobility by competition intensity