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Madhuparna Ganguly

Indira Gandhi Institute of Development Research, Mumbai
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Email(corresponding author): madhuparna@igidr.ac.in

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JEL Code: Competition intensity, Damage rules, Patent strength, Scientist mobility

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Madhuparna Ganguly†
Indira Gandhi Institute of Development Research (IGIDR), India

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†**Corresponding Address:** Indira Gandhi Institute of Development Research (IGIDR), Film City Road, Santosh Nagar, Goregaon (E), Mumbai - 400065, India. Email: madhuparna.ganguly1994@gmail.com, madhuparna@igidr.ac.in.

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1 Introduction

Consistent novel innovations are central to the development of the world's economies, and businesses and organizations play a pivotal role in driving technological progress through persistent R&D initiatives. Over the past few decades, firms have been engaging in their own R&D efforts to foster development of new products and processes rather than relying on licensing agreements with independent scientists (Kim & Marschke, 2005). However, in spite of its benefits, an in-house approach to R&D comes with the risk of exposing innovating firms to undesired knowledge transfer through intra-industry movement of their scientists. To protect their novel idea from infringement, innovating firms may use patents as a device to discourage their scientists from joining or setting up a rival firm. Patents ideally aim to grant the innovator an exclusive right to produce (use) the patented product (process). However, in reality they provide only 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). This means, although a patent may not deter infringement, it allows the patentee to establish a right to extract applicable penalties from the infringer as remedial compensation for the injury caused. In the study of six jurisdictions, namely, the U.S., Japan, Germany, U.K., France and the Netherlands, Reitzig et al. (2008) find primarily three types of damage award calculations that are prevalent with minor variations across different legal systems. These are "lost profits", "infringer's profits" and "reasonable royalty rates"[1]. The underlying damage measure and the strength of the patent system stipulate the expected amount of recovery in case infringement occurs. This paper investigates the effects of an increase in strength of indemnification rules on patenting and movement behavior in presence of scientist mobility and identifies implications of a stricter patent regime on the profitability and required investment of an innovation project. The study shows that stronger patents fail to reduce movement but increase patenting. While a stricter patent regime may not serve its primary purpose of protecting innovators, it can encourage research initiatives by augmenting R&D investment. We explicitly model product

[1]See discussions on different damage rules in the next section.

market competition to examine the relationship of intensity of competition with patenting, movement, profit and R&D expenditure, and find that the expected effects manifest for markets with moderate competitive pressure. The results suggest important considerations for patent reforms.

The base model closely follows the structure of Kim and Marschke (2005). Kim and Marschke (2005) assess the impact of an increase in labour mobility, induced by an increase in the value of the scientist's knowledge, on patenting probability of firms. We define into this structure a damage recovery rule which mandates the infringing rival to compensate the innovator in case the innovation is patented. The innovating firm suffers a loss in profits due to the unsolicited competition that it is exposed to as a result of its scientist's movement to a rival firm. The expected reparation depends on the strength of the patent system, which is reflected in the reasonable success rate of a patent lawsuit and the amount of patent infringement awards (Hu et al., 2020). Accordingly, we define the "measure of strength" of the patent system as a function of litigation success probability and expected recovery proportion to analyze the effects of a stricter patent regime on the innovator and the innovation. An explicit model of market competition for the new product identifies the effect of stronger patents at different levels of competition intensity. We suppose that the appearance of a rival firm attracts new consumer base to the market and makes mobility a feasible outcome in equilibrium. Specifically, we use the Hotelling framework where the inverse of the degree of product differentiation measures intensity of competition. Market expansion due to technology diffusion facilitates product market competition in equilibrium when the joint profit under duopoly exceeds monopoly profit. We find that although patenting propensity increases with an increase in patent strength, it does not suffice to deter infringement and further, fails to reduce the probability of such instances. Even though a stronger patent system does not reduce infringement, it seems reasonable to expect that it may protect the innovator through higher damage recovery. Counterintuitively, we find that the expected profitability of the innovator falls and the R&D expenditure of the innovation rises as the patent regime is made stronger. Our results further show a non-monotone relation of patenting propensity, innovation profitability and investment in R&D with the level of competition intensity in the product market. However, intra-industry labor movement has a monotone relation to competitive pressure. The analysis indicates an effect of the increase in patent strength only in moderately competitive markets.

The intuition behind the results follows from the avenues through which a stricter patent regime affects revenues accruing to the entrepreneur and the scientist from participating in the innovation project. The first is a direct effect which increases expected loss recovery from patenting, thereby increasing the patenting propensity of the entrepreneur. However, a second effect, which is an opposing wage effect, counters this positive effect on the entrepreneur's expected profit. Higher anticipated reparation and more frequent patenting increase the expected damage cost borne by the rival and reduce the scientist's expected returns from joining the entrepreneur's project, through a reduction in gains from moving. This necessitates a higher wage offer from the entrepreneur to match the scientist's reservation earning and impels him to join her initiative, thus generating a negative effect on her expected profit. The two effects exactly offset each other, resulting in a decrease in the entrepreneur's profitability owing to a third effect generated by higher patenting costs from more frequent patenting. Further, the entrepreneur's R&D expenditure rises owing to higher wage payments. For the scientist, an equal increase in the reparation cost and the joining wage leaves total expected earnings from the project constant and thus renders no change in movement behaviour.

An expected increase in competition intensity decreases potential profits from marketing the new product under duopoly. However, it entails higher consumer alignment when a single product is available in the market, raising the prospective monopoly return. Therefore, as competitive pressure rises, the gap between the entrepreneur's return with and without competition widens and the scientist's potential gain from movement contracts. Intuitively then, one may expect the higher potential damage from competition to increase incidence of patenting and the lower expected return at the rival to cease movement beyond a threshold level of competition intensity. While this intuition is correct for movement behavior, implying a monotone relation between competition intensity and scientist mobility, it is not the case for patenting. The entrepreneur initiates patenting beyond a lower threshold of competition intensity where patenting serves to reduce loss from scientist movement and loss reduction is sufficient, but terminates it beyond a higher threshold where the purpose of patenting is wage reduction and savings on wage is no longer sufficient. It turns out, patenting behavior exhibits a non-monotone relation to competition intensity. Profit decreases as long as movement occurs and increases henceforth, implying a non-monotone trend with an increase in competition intensity. On the contrary, R&D expenditure increases while movement occurs as decreasing potential gain from movement mandates a higher joining wage for the scientist but stabilizes at the scientist's total reservation wage when he stays. Consequently, the relationship of R&D investment with competition intensity is non-monotone as well.

We already saw that a stricter patent regime suggests a fall in expected profitability of the research project through higher patenting cost due to increased patenting. The model of market competition suggests that this effect can only actualize at moderate levels of competition intensity. This is because, at very low intensity of competition stronger patents fail to induce patenting as the damage from duopoly is sufficiently small. Again, at relatively high competition intensity patenting occurs in equilibrium even with weaker patents. As a result, stricter patent laws trigger additional patenting only at moderate competition intensity where the resulting increase in recovery renders immediate loss reduction due to patenting sufficient to cover its cost. Further, increased patenting and recovery prompt higher wage in equilibrium when movement and patenting occur simultaneously, raising R&D expenditure in the level of competition intensity that supports both.

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 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 stricter 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 a stricter patent regime on R&D investment, for which the equilibrium co-occurrence of patenting and movement is crucial. Additionally, our main results stand robust when we consider an alternate approach of modeling market competition. The alternate model uses a supply schedule framework where the slope of the supply function measures competition intensity. However, this model setup does not admit the possibility of market expansion due to appearance of the rival and hence, prevents equilibrium movement. Thus, although the analysis in this framework follows analogous to our main model, it restricts the delineation of our complete results.

The rest of the paper is organized as follows. The next section discusses the relevant literature. Section 3 develops the base model and formalizes the results. Section 4 introduces competition intensity into the framework. Section 5 presents the results of a stricter patent regime at different levels of competition intensity. Section 6 discusses the implications of relaxing assumptions. Section 7 provides the alternate model of competition intensity. Section 8 summarizes the main findings and concludes.

2 Related Literature

The existing literature on labor turnover and information diffusion widely proclaims scientist mobility as a primary channel for knowledge spillover within industries (Agarwal et al., 2009; Almeida & Kogut, 1999; Rønde, 2001). In an early mention of difficulties concerning absolute appropriability of information, Arrow (1962) heralds mobility of scientific personnel across firms as an important mechanism for information diffusion, as the intangible nature of information limits the complete applicability of property rights. Knowledge flows generated through labor mobility can remain geographically localized as well as disseminate across borders. Considering the semiconductor industry, Almeida and Kogut (1999) provide empirical evidence that localized knowledge spillovers happen through scientist mobility. Kaiser et al. (2015) analyze patenting data of the old and new employers of a mobile scientist from information on R&D active Danish firms and find that labor mobility enhances overall innovation of a region through knowledge transfer. Oettl and Agrawal (2008) identify benefits from labor mobility beyond the boundaries of a country, region or the hiring organization through cross border movement. Another strand of literature emphasizes knowledge transmission through scientist mobility due to learning initiatives of innovating firms. Rosenkopf and Almeida (2003) suggest that mobility of inventors helps firms to seek knowledge beyond geographical and technological boundaries. Song et al. (2003) study factors driving learning-by-hiring from the recruiting firm's perspective to identify conditions that aid knowledge acquisition through poaching other firms' scientists. Palomeras and Melero (2010), in analyzing from the inventor's perspective, find that inventor characteristics such as quality of work, complementarity of knowledge with that of other inventors and area expertise influence their propensity to get hired as a part of firms' learning objectives. The absence of strict enforcement of non-compete covenants in some regions may further exacerbate the incidence of scientist mobility or spin-off (Franco & Mitchell, 2008). Pakes and Nitzan (1983) discuss the problem of hiring of a scientist in presence of potential knowledge spillovers through labor mobility. They design an optimal contract and identify the implications of mobility of scientists on project profitability and research employment. They subsequently discuss conditions under which the optimal contract allows for mobility in equilibrium. Kim and Marschke (2005) use the framework of Pakes and Nitzan (1983) to study the relationship between patenting probability of an innovating firm and mobility decision of its scientist. Emphasizing that a substantial part of technological knowledge transfer happens through inter-firm mobility of labour, they underscore the role of a patent in protecting an innovating firm from "insiders". Our study aims to understand how patent reforms aimed at protecting the innovator affect innovation attributes and patenting propensity in presence of knowledge transfusion through scientist mobility. We use the structure of Kim and Marschke (2005) for the purpose and define into it a damage reparation regime with probabilistic patents to analyze the implications of an increase in the strength of the patent system.

While the optimal breadth and length of patenting is extensively discussed in the existing literature, pecuniary penalties ("damages") for patent infringement are a recently emerging area of interest (Chen & Sappington, 2018). The current literature broadly recognizes the "lost profit" and "unjust enrichment" damage rules as follows - (i) the "lost profit" rule (LP, henceforth) measures damages as the reduction in profit (or royalties, in case of licensing) of the patent owner due to infringement, and (ii) the "unjust enrichment" rule (UE, henceforth) measures damages as the profits accruing to the infringer due to infringement[2]. In a recent paper on damage rules, Chen and Sappington (2018) propose a linear combination of the LP and UE rules together with a lumpsum monetary transfer, with sequential innovation and uncertainty in the success of patent litigation, and show that the optimal linear rule generates highest welfare among all rules that ensure a balanced budget in the industry, and in some cases, achieves the socially optimal welfare level. They find, an increase in the proportion of recovery due to LP (UE) leads to an increase in joint profits when price and valuation of the patent owner's (infringer's) product is higher. Additionally, an increase in recovery due to lost profits leads to a higher profit for the incumbent. Schankerman and Scotchmer (2005) evaluate infringement deterrence under the LP rule with licensing as the counterfactual. They provide two examples to bolster that the LP rule will deter infringement when infringement of patent dissipates profits, not otherwise. Infringement does not dissipate joint profit when it may allow for a collusive outcome, which is prohibited under licensing by antitrust laws. Shapiro (2016) evaluates the effectiveness

[2]The "reasonable royalty rates" rule measures damages as the royalty rate that would have been applicable had the infringer entered into a licensing agreement with the patent owner before infringement. In the above definition, this is subsumed under the LP rule.

of the damage rule regime versus injunction in the primary goal of protecting the patent holder and discusses circumstances under which either remedy may be appropriate. For further discussions on damage rules, see Schankerman and Scotchmer (2001) who provide a comparison of the LP and UE regimes and suggest that their relative efficiency vary by the resulting entry deterrence at equilibrium and the nature of the product under consideration. They adopt a framework where competition results only from infringement. Anton and Yao (2007) analyse the LP damage rule when competition may occur with or without infringement.[3] Our paper aims to study the implications of the LP damage regime in industries where R&D is heavily dependent on internal efforts and scientist mobility is a common phenomenon.

An optimal indemnification rule is one that attempts to increase innovation incentives by sufficiently rewarding the innovator for his/her work while balancing the loss in social surplus due to restricted use of the technology (Reitzig et al., 2008). Clearly, the two goals are counteractive. Ayres and Klemperer (1999) suggest that some amount of uncertainty in the patent system can work towards achieving this goal. Uncertainty in patent litigation is well-established in the literature on damage rules. See, for example, Allison and Lemley (1998), Anton and Yao (2007), Ayres and Klemperer (1999), Chen and Sappington (2018), Choi (2009), Dey et al. (2019), Lemley and Shapiro (2005), Schankerman and Scotchmer (2005), Shapiro (2003) and Shapiro (2016). According to Allison and Lemley (1998) only 54% of all litigated patents are found to be valid. Lemley and Shapiro (2005) discuss the inherent uncertainties in the scope of patent rights and attribute them to inbuilt mechanisms in the patent system that encourage excessive patenting. In analysing the issues that potential reforms of the patent system should account for, they emphasize the need to bear in mind the interest of the end parties that it affects. In this context, they

[3] Dey et al. (2019) provide an analysis of damage regimes in a different context. They investigate the interdependencies between trade policy and liability doctrines, and find that the preferred damage rule of the home economy varies with the variation in the prevalent trade regime when a foreign firm is infringed by a domestic rival in home market. The study also identifies the optimal trade policy under different liability doctrines by specifying a linear combination of the LP and UE damage regimes.

provide a rationale for incorporating the probabilistic nature of patents in economic models. A probabilistic patent model may also be interpreted as a partial damage regime where the patent owner is entitled to a fixed proportion of the entire damage amount (Ayres & Klemperer, 1999). This paper models a partial recovery damage rule where the strength of the patent regime determines the proportion of loss recovery.

Patent reforms aim at strengthening the patent system by not only increasing the coverage provided by patents but also improving the assurance that they afford. A particular example is the creation of the Court of Appeals of the Federal Circuit under the U.S. Patent Reforms in 1982, a specialized court set up to handle issues on patent infringement and validity. After the court's creation, the number of validity and infringement findings that were upheld on appeal rose to 90% as compared to the 62% before, whereas the reversal of decisions of invalidity or no infringement rose to 28% from the previous rate of 12% before the establishment of the court (Gallini, 2002; Jaffe, 2000).[4] Certain patent systems also allow for higher damage awards, enhanced upto one to three times, if the infringement is found to be wilful or malicious. Such punitive awards, although evaluated against strict standards, remain relatively common in the U.S. and are extant in other jurisdictions such as Europe, Australia and Canada (Chien et al., 2018). In evaluating patent infringement awards across jurisdictions, Hu et al. (2020) find that reforms may provide discretionary power to courts in deciding reasonable damage awards (eg., the Patent Act of 1998 in Japan) and increase damage amounts (eg., doubling of limits of statutory compensation in China, which prevail in 90% of the country's infringement litigations). In the U.S., there has been a surge in decisions ruled by juries, where juries are significantly more likely than judges to find patents valid, infringed and wilfully infringed (Moore, 2000). Hence, the primacy of the amount of damage awards and the success rate of infringement suits in

[4] See Jaffe (2000) and Gallini (2002) for an overview of the U.S. patent reforms and discussion on their plausible implications. Jaffe (2000) analyses the major changes in the U.S. patent policy during the 1980s and 1990s, reviews existing studies on their effect on patenting and innovation, and finds a paucity of robust empirical results. Gallini (2002) provides a background of the U.S. patent reforms and evaluates the extent of their impact on innovation, disclosure and technology transfer.

liability rules is undeniable.

3 Model of Patenting and Movement Behavior

This section employs the framework of Kim and Marschke (2005) to develop a model of patenting and movement behavior, and additionally defines in it a liability rule such that a part of the loss suffered by the incumbent is recovered from the entrant. However, unlike Kim and Marschke (2005), it explicitly models patent strength to study the implications of a stricter patent regime on scientist mobility, innovation and optimal patenting behavior. Suppose an entrepreneur who has an idea for a new product and can hire a scientist to develop the idea into a tangible. There are two periods in the game. In the first period, the scientist develops the entrepreneur's idea into a usable product. In the second period, the entrepreneur commercializes the product without any aid from the scientist and realizes profits. The life of the product is only till the end of the second period. The timing of events are as follows. At the beginning of the first period the entrepreneur makes an offer to the scientist consisting of the first period wage w_0 and second period wage w_1. The scientist, conscious that the entrepreneur will act to maximize current returns when the second period arrives, accepts the offer if and only if his expected pay-off equals or exceeds his reservation earning in the two periods combined. The scientist's reservation wage in each period is $\bar{w}$. Optionally, at the beginning of the second period, the scientist can use his knowledge from the first period to move to or set up a rival firm that produces and markets a competing product in the second period. Let ρ_i ($\in \mathbb{R}^+$) and ρ_e ($\in \mathbb{R}$) denote the revenues accruing to the entrepreneur (innovator) and the rival firm (entrant) respectively in the second period [5]. ρ_i and ρ_e are random variables having joint density f, which is common knowledge.

Appearance of a rival product reduces the entrepreneur's second period revenue by $\lambda\rho_i$,

[5] As in Kim and Marschke (2005), ρ_i is the 'internal' value of the innovation and ρ_e is the value of the scientist's knowledge to the rival, the 'external' value net of moving costs.

$\lambda \in [0, 1]$. Hence, at the end of the first period, the entrepreneur can choose to patent the new development to insure herself against infringement, the nature and strength of patent laws determining expected recovery. The strength of the patent system depends on the patent's success probability as well as entitled recovery. We define a "measure of strength" of the patent regime as,

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

where, $r \in [0, 1]$ denotes the probability of a successful litigation for the patentee and $\delta \in [0, 1]$ denotes the proportion of damage recovery. Notice that when $r < 1$, the model defined is one of probabilistic patents, and when $\delta < 1$, the damage rule defined is one of partial recovery. The composite strength measure σ and the LP rule of damage measure together imply an expected recovery amount of $\sigma\lambda\rho_i$, $\sigma \in [0, 1]$, for the entrepreneur in the event a rival appears and the product is patented. As an increase in σ could be caused by either a more certain patent system implying greater chances of litigation success for the patentee, or a stricter damage specification implying higher recovery amount, or both, the implications of stronger liability laws (explored in the following subsection) apply to either reform of the patent system. In the damage rule under consideration, the entire recovery cost is borne by the infringer in case the product is patented. Thus patenting also reduces the rival's gain by $\gamma\rho_i$ where $\gamma \in [0, 1]$ is the coefficient of recovery and $\sigma\lambda\rho_i = \gamma\rho_i$. The cost of patenting is c.

The values of ρ_e and ρ_i are realized at the beginning of the second period and become common knowledge. The entrepreneur then makes the decision on patenting and second period wage taking the scientist's movement decision as given. If the scientist decides to stay with the entrepreneur in the second period, he receives wage w_1 and performs work to generate value equal to his reservation earning $\bar{w}$. Alternatively, if he joins or sets up a rival firm his earning equals ρ_e (or $\rho_e - \gamma\rho_i$ if the product is patented), which is the value of his acquired knowledge to the rival, in addition to the value generated by his work $\bar{w}$. Finally, the scientist may move to a non-R&D sector in the second period where he earns $\bar{w}$.

Given this set-up, the expected profit of the entrepreneur is as follows:

$$
\begin{aligned}
E(\pi) = \ & -w_0 \ + \iint\limits_{S,p=1} [\rho_i - w_1(p=1) + \bar{w}] f(\rho_e, \rho_i) \, d\rho_e d\rho_i \\
& + \iint\limits_{M,p=1} [\rho_i - (1-\sigma)\lambda\rho_i] f(\rho_e, \rho_i) \, d\rho_e d\rho_i \ - \iint\limits_{p=1} c f(\rho_e, \rho_i) \, d\rho_e d\rho_i \\
& + \iint\limits_{S,p=0} [\rho_i - w_1(p=0) + \bar{w}] f(\rho_e, \rho_i) \, d\rho_e d\rho_i \\
& + \iint\limits_{M,p=0} [\rho_i - \lambda\rho_i] f(\rho_e, \rho_i) \, d\rho_e d\rho_i \ + \iint\limits_{N} \rho_i f(\rho_e, \rho_i) \, d\rho_e d\rho_i
\end{aligned} \tag{1}
$$

where p is an indicator variable taking value 1 when the product is patented and 0 otherwise, S is the set of ρ_e and ρ_i for which the scientist decides to stay with the entrepreneur, M is the set of ρ_e and ρ_i for which the scientist moves to the rival and N denotes the set of ρ_e and ρ_i for which the scientist joins a non-R&D sector[6]. The entrepreneur hires the scientist if the expected profit is positive. The scientist will join the entrepreneur in the first period if expected earnings exceed the combined reservation wage in two periods $2\bar{w}$. The scientist's participation constraint is as follows:

$$
\begin{aligned}
2\bar{w} \leq \ & w_0 \ + \iint\limits_{S,p=1} w_1(p=1) f(\rho_e, \rho_i) \, d\rho_e d\rho_i \\
& + \iint\limits_{M,p=1} [\rho_e - \gamma\rho_i + \bar{w}] f(\rho_e, \rho_i) \, d\rho_e d\rho_i \ + \iint\limits_{S,p=0} w_1(p=0) f(\rho_e, \rho_i) \, d\rho_e d\rho_i \\
& + \iint\limits_{M,p=0} (\rho_e + \bar{w}) f(\rho_e, \rho_i) \, d\rho_e d\rho_i \ + \iint\limits_{N} \bar{w} f(\rho_e, \rho_i) \, d\rho_e d\rho_i
\end{aligned} \tag{2}
$$

The entrepreneur's problem is to choose p, w_0 and w_1 to maximize (1) subject to (2). To solve this, the first step is to solve for the second period choice variables: the optimal second period wage, patenting decision of the entrepreneur and movement decision of the scientist, for any given ρ_i and ρ_e. Following the simplification in Kim and Marschke (2005), assume that $\rho_e = \bar{\rho}_e + \epsilon_e$ and $\rho_i = \bar{\rho}_i + \epsilon_i$ where ϵ_e and ϵ_i are zero mean random variables having joint density g, $\bar{\rho}_e$ and $\bar{\rho}_i$ are the constant means of ρ_e and ρ_i respectively. Figure 1 depicts

[6]Following Kim and Marschke (2005), we ignore discounting for simplicity.

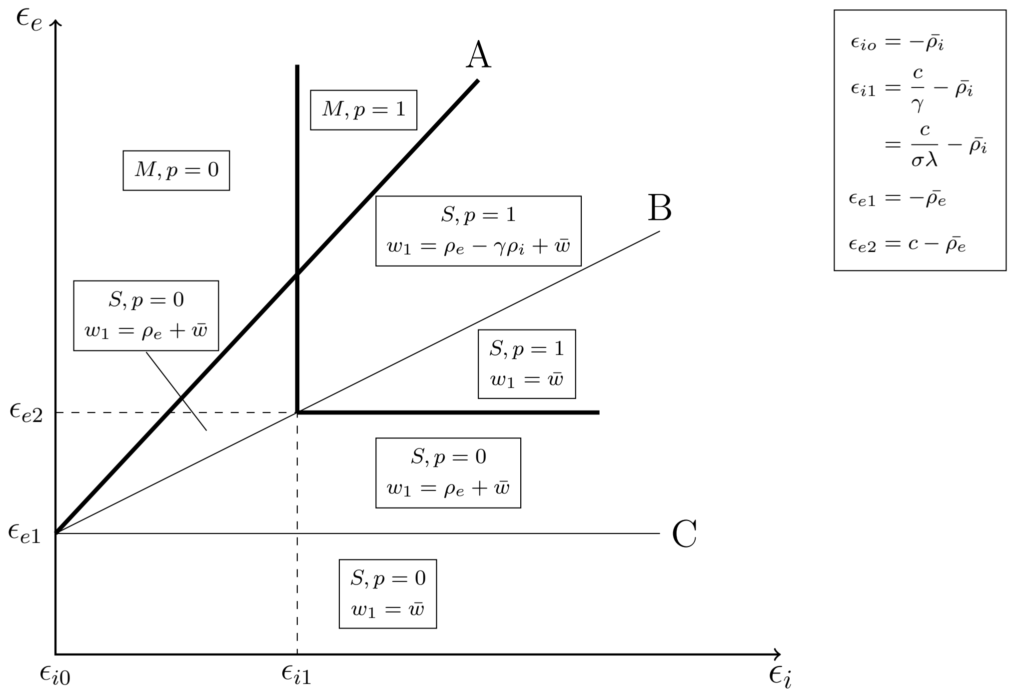

Figure 1: Mobility, Patenting and Wage Decisions

the optimal second period wage, patenting and movement decisions on the $\epsilon_i - \epsilon_e$ space. Detailed derivation of the figure is available in Appendix A.

In the region above line A, the entrepreneur's loss from the scientist moving is less than the scientist's gain from moving to a rival, irrespective of whether the product is patented. Hence there is no wage the entrepreneur can optimally offer to retain the scientist in the second period and the scientist joins or sets up a rival, receiving a return of $\rho_e + \bar{w}$ or $\rho_e - \gamma\rho_i + \bar{w}$ according as the product is not patented or patented. The entrepreneur patents the innovation when the loss recovery exceeds the cost of patenting. In this case, patenting does not aid in preventing establishment of the rival but is solely a device to reduce the entrepreneur's loss when such loss is sufficiently high. Between line A and line B, the entrepreneur's loss from the scientist moving exceeds the scientist's gain from moving. Hence the entrepreneur finds it optimal to retain the scientist. Patenting reduces the entrepreneur's loss and the scientist's gain by the same amount, thus having no effect on movement. In the region between line B and line C, the scientist's gain at the rival, even though higher than his reservation wage $\bar{w}$ without patent, falls below the same when the product is patented. In both these cases (the region between line A and line C), patenting works to reduce the second period wage the entrepreneur needs to offer in order to retain the scientist when such reduction is sufficiently high. When the valuation of the scientist's knowledge to the rival is high (between line A and line B), patenting reduces scientist's gain through high anticipated loss recovery, whereas when the valuation of the scientist's knowledge is lower, patenting renders movement to the non-R&D sector preferable, thus reducing incentive to move. When the valuation of the scientist's knowledge is sufficiently low to eliminate any possibilities of movement to the rival, the entrepreneur always retains the scientist by offering the reservation wage and never patents. This corresponds to the area below line C. Therefore, in a patenting regime where damage recovery cost is borne by the infringer, patenting has a loss reducing effect when the scientist chooses to move and losses are high, and a wage reducing effect when the scientist chooses to stay and anticipated returns from moving are high.

Intuitively, the patenting and movement behavior under a regime of damage recovery from the rival, as reflected in Figure 1, are congruent to that in Kim and Marschke (2005). For any given ϵ_i, the scientist is more likely to move when ϵ_e is high inducing greater returns from movement. For any given ϵ_e, the scientist is more likely to stay when ϵ_i is high as greater losses from movement compel the entrepreneur to retain the scientist. Further, when ϵ_e is sufficiently low, patenting does not occur for any ϵ_i because the scientist's incentive to move is negligible. When ϵ_i is sufficiently low, patenting does not occur for any ϵ_e as the entrepreneur's potential loss from movement is insignificant.

Substituting the optimal wage, patent and mobility decisions in equation (2) with equality gives the optimal first period wage w_0. Substituting w_0 in equation (1) gives the expression for expected profit, as shown in Lemma 1.

Lemma 1. *The expected profit of the entrepreneur under a patent regime with cost recovery* *from the infringer is given as:*

$$
\begin{aligned}
E(\pi) = \; & -\bar{w} \; + \iint\limits_{S} \rho_i f(\rho_e, \rho_i)\, d\rho_e d\rho_i \\
& + \iint\limits_{M} [\rho_i + \rho_e - \lambda\rho_i] f(\rho_e, \rho_i)\, d\rho_e d\rho_i \; - \iint\limits_{p=1} c f(\rho_e, \rho_i)\, d\rho_e d\rho_i
\end{aligned}
\tag{3}
$$

Proof. See Appendix A.

We saw that if the scientist decides to stay in period 2, the entrepreneur patents the innovation to reduce the second period wage of the scientist when such reduction is sufficiently high. Intuition suggests that such reduction in wage increases the expected profit of the entrepreneur. However, the second term in equation (3) implies otherwise. The reason is that any reduction in the second period expected pay-off of the scientist, which in this case is the second period wage, must be adjusted for by an equal increase in the first period wage that the entrepreneur offers to prompt the scientist to join the firm in period 1. Again, if the entrepreneur patents when the scientist decides to move in the second period, it reduces her loss in revenue due to product market competition which implies a positive effect on profit. But the loss recovery is extracted from the rival, lowering the scientist's expected gain from moving and thus entailing an equal increase in the first period wage. The two effects exactly cancel leaving no net effect of patenting on entrepreneur's expected profit when the scientist moves to a rival firm in the second period, as implied by the third term in equation (3). Finally, the fourth term represents the cost of patenting when the entrepreneur optimally decides to patent.

3.1 Stricter Patent Regime

A stricter patent regime implies a higher expected amount of loss recovery from patenting for the entrepreneur in the event that a rival product appears in the market. We suppose two mechanisms for tightening indemnification laws - (i) an increase in the success probability of

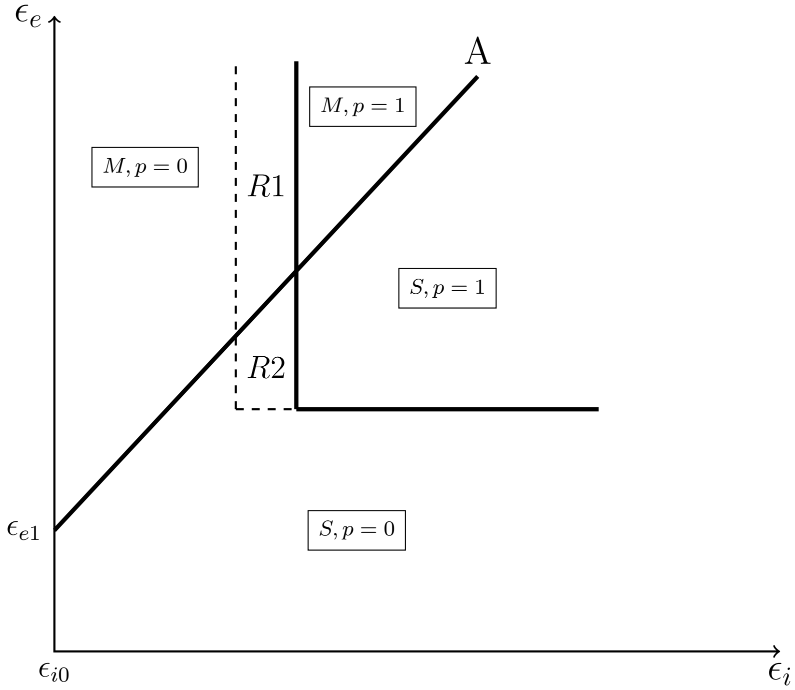

Figure 2: Effect of Stricter Patent Regime

a patent in court of law making damage awards more likely, i.e. an increase in r, and (ii) an increase in the entitled restitution of the entrepreneur in case an infringement is successfully established, i.e. an increase in δ. Accordingly, a stronger liability regime augments the measure of strength σ. When the rival's product appears in the market, the incumbent suffers a loss equal to $\lambda\rho_i$, σ proportion of which may be recovered from the rival if the product is patented. This reparation equals the reduction in revenue of the rival ($= \gamma\rho_i$). A stricter damage rule characterized by an increase in σ implies a proportionate increase in the recovery coefficient γ (λ being exogenously determined), thus increasing the entrepreneur's expected recovery amount $\sigma\lambda\rho_i$.

Figure 2 illustrates the effects of a stricter patent regime on the second period patenting decision of the entrepreneur and movement decision of the scientist in the $\epsilon_i - \epsilon_e$ space. The solid lines show the boundaries between patenting vs. not patenting and moving vs. staying decisions of the entrepreneur and the scientist respectively. As γ rises, line B (shown in Figure 1) becomes steeper and ϵ_{i1} shifts to the left. The dotted lines show the new boundaries segregating the decision alternatives of the entrepreneur and the scientist. Regions $R1$ and $R2$ denote the values of ϵ_e and ϵ_i (and thus, ρ_e and ρ_i) where there is a change of behaviour. As stronger patents allows the entrepreneur to recover a larger portion of her loss due to infringement, it is intuitive that she will patent more frequently as the patent regime tightens. This intuition is indeed true. The entrepreneur now additionally chooses to patent in both regions $R1$ and $R2$, where she was initially not patenting. A stricter regime also reduces the pay-off that the scientist can generate by marketing his knowledge to join or set up a rival as the rival now has to sustain a higher reparation if the product is patented. Intuition suggests that this would discourage movement by the scientist and increase his propensity to stay with the entrepreneur. However, it turns out that this intuition is not correct. A greater patent strength has no effect on the movement decision of the scientist in the second period. In region $R1$ ($R2$), his initial decision to move (stay) still remains optimal. The following proposition summarizes the results.

Proposition 1. *The following define the effect of a stricter patent regime on the second period patenting decision of the entrepreneur and movement decision of the scientist.*

(i) A tightening of the patent system increases the entrepreneur's propensity to patent the innovation.

(ii) A tightening of the patent system has no effect on the scientist's propensity to move to or set up a rival.

First, consider the entrepreneur's patenting decision. Recall that when the scientist chooses to move, the entrepreneur patents the innovation to reduce the loss incurred in case of an infringement. With patenting cost remaining constant, if loss recovery increases the entrepreneur finds it beneficial to patent even when loss without patenting is not too high. Alternatively, when the scientist chooses to stay, the entrepreneur uses patenting as a device to reduce the scientist's second period wage by limiting his expected pay-off from a rival. As a higher expected loss recovery augments the reduction in scientist's expected pay-off, a stricter damage rule allows greater wage reduction and thus engenders a higher propensity to patent. Next, consider the scientist's movement decision. A tightening of the regime reduces the scientist's expected second period pay-off by increasing the damage liability incurred by the rival in case of a patent. For any given first period wage, this lowers the scientist's total expected pay-off in two periods combined below his total reservation wage. Therefore, the entrepreneur has to adjust for any such reduction by an equal increase in the first period wage, in order to be able to hire the scientist for the development process. Consequently, a stronger patent system leaves the scientist's total expected pay-off unaltered, rendering no effect on his second period movement decision.

A stricter patent regime aims to protect innovations from infringement and encourage R&D activities. An increase in the loss recovery amount reduces the damage that the entrepreneur suffers in case a rival appears in the market, and the resulting higher occurrence of patenting further mitigates such loss. Intuitively then, we would expect a tightening of the patent system to increase the profitability of the research project. But this intuition is not valid. On the contrary, the expected profit of the entrepreneur decreases with an increase in the strength measure. The following proposition formalizes the effect of stronger patents on the profitability of the entrepreneur.

Proposition 2. *Strengthening of the patent regime decreases the profitability of the research project.*

Proof. See Appendix A.

To understand this result, note that any reduction in the scientist's expected second period pay-off must be countered by an equal increase in his first period wage for successful initiation of the research project. As an increase in recovery cost to the rival reduces the scientist's expected pay-off, the first period wage must rise. And given a higher first period wage, when the second period arrives it is optimal for the entrepreneur to patent more frequently. The augmentation of the entrepreneur's profitability resulting from the benefit of patenting in the second period is exactly offset by its contraction due to higher wage payment in the first period. However, for any positive cost of patenting ($v > 0$), greater patenting activity in the second period increases total cost of patenting incurred by the entrepreneur. Thus, the combined effect of a stricter patent rule on the expected profitability of the entrepreneur is negative.

Next, we look at the impact of tighter patents on R&D expenditure. Following Kim and Marschke (2005), we define expected R&D expenditure of the research project, excluding patenting cost, as follows:

$$\begin{aligned} R\&D &= w_0 \ + \iint\limits_{S,p=1} w_1(p=1) g(\epsilon_e, \epsilon_i)\, d\epsilon_e d\epsilon_i \ + \iint\limits_{S,p=0} w_1(p=0) g(\epsilon_e, \epsilon_i)\, d\epsilon_e d\epsilon_i \\ &= 2\bar{w} \ - \iint\limits_{M,p=1} [\bar{\rho}_e + \epsilon_e - \gamma\bar{\rho}_i - \gamma\epsilon_i + \bar{w}] g(\epsilon_e, \epsilon_i)\, d\epsilon_e d\epsilon_i \ - \iint\limits_{M,p=0} [\bar{\rho}_e + \epsilon_e + \bar{w}] g(\epsilon_e, \epsilon_i)\, d\epsilon_e d\epsilon_i \end{aligned} \tag{4}$$

where the second equality comes from the participation constraint of the scientist (equation (2)), which is satisfied with equality in equilibrium. The following proposition states the effect of a stricter patent regime on R&D expenditure of the entrepreneur.

Proposition 3. *Strengthening of the patent regime increases the entrepreneur's R&D expenditure for the research project.*

Proof. See Appendix A.

A higher recovery amount prompted by a tighter regime incentivizes the entrepreneur to patent the innovation more often. This has a twofold effect on the scientist's second period expected pay-off: (a) more frequent patenting leads to lower gains from moving, and (b) higher loss recovery increases the cost incurred due to patenting when he moves. As a result, the entrepreneur has to compensate for the reduction in the scientist's expected gain by offering a higher remuneration in the first period, thus rendering launching of the research project costlier.

In the present context, an increase in R&D expenditure implies an increase in the scientist's initial wage offer. Specifically, observe from Figure 1 and Figure 2 that the second period wage w_1 either remains same or falls as σ (and therefore, γ) rises. Thus, the increase in total wage offer is induced by an increase in first period wage w_0. Further, note from Figure 1 that (i) $w_1 \geq \bar{w}$, and (ii) returns from movement must exceed $\bar{w}$ for movement to occur. As the scientist's expected earning equals his reservation wage in two periods $(= 2\bar{w})$ in equilibrium, we have $w_0 \leq \bar{w}$ implying a negative wage differential for R&D (as compared to non-R&D wage) equal to $w_0 - \bar{w}$ in period 1. A stricter patent system entails a higher joining wage for the scientist and reduces magnitude of the wage differential, thereby potentially attracting greater scientist talent to the R&D sector.

4 Intensity of Competition

The intensity of market competition determines the realized profit of the entrepreneur and the rival in case it appears when the product is commercialized in the second period. This section studies the relationship of competition intensity with patenting behavior of the entrepreneur and movement behavior of the scientist, and the corresponding implications for profitability and R&D expenditure of the research project. Recall, the rival's appearance reduces the entrepreneur's monopoly profit ρ_i by a proportion λ, rendering her duopoly profit equal to $(1-\lambda)\rho_i$. As the amount of loss depends on the competition intensity in the market, denoted by θ, we express λ as $\lambda(\theta)$. Further, we express the rival's profit ρ_e as a proportion of the entrepreneur's duopoly profit, as $\rho_e = \kappa.[1-\lambda(\theta)]\rho_i$, where $\kappa = 1$ when the two firms are homogenous. To explicitly model product market competition, we develop a Hotelling model with market expansion due to technology diffusion through scientist mobility. Section 6 provides an alternative model using the supply schedule framework of competition intensity to bolster our main results.

4.1 Hotelling Model of Competition Intensity

Consider 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 follow Chen and Sappington (2018) and 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. Consumers are uniformly distributed along the interval $[0, L]$. Thus, scientist mobility aids technology diffusion by expanding the potential consumer base. Consumers value each firm's product at v and incur a 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 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 the intensity of competition as follows:

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

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

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

4.2 Patenting and Movement Decision

The Hotelling set-up expresses the second period potential gains of the entrepreneur and the rival as functions of competition intensity. To derive the effect of competitive pressure on optimal patenting and movement decisions, assume the following:

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

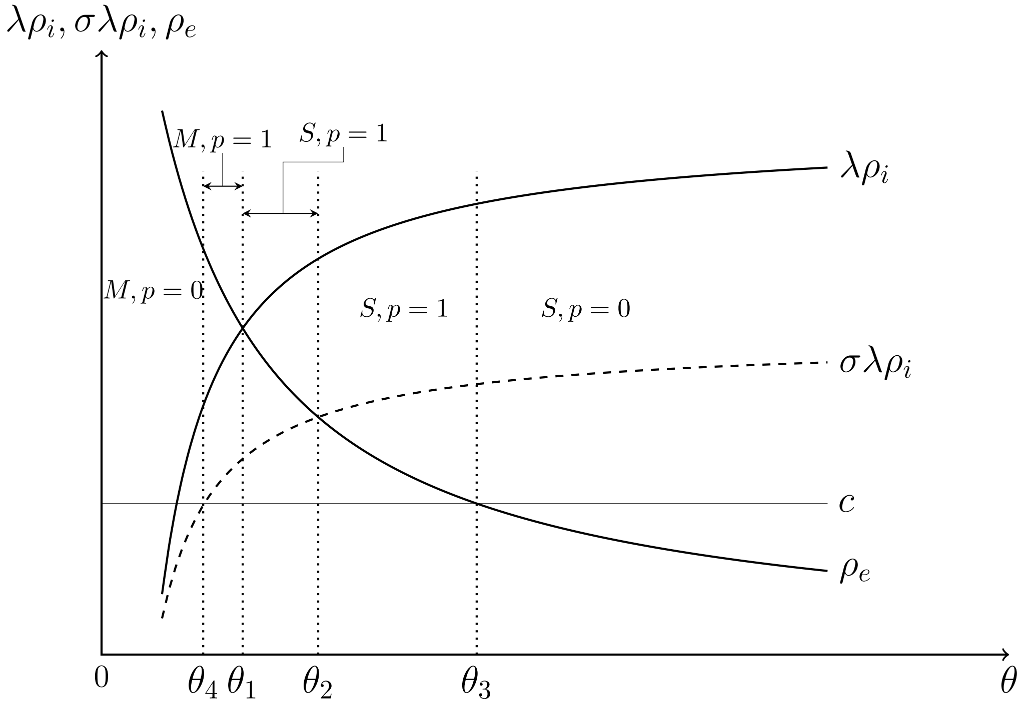

Figure 3: Patenting and Mobility by Competition Intensity

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 2.a requires cost of patenting to be sufficiently low given the expected recovery such that patenting is possible. Assumption 2.b 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 2.b in Section 5.

Figure 3 illustrates the equilibrium patenting behavior of the entrepreneur and movement behavior of the scientist for different levels of competitive pressure in the market (see Appendix A for complete derivation). For very low intensity of competition, duopoly profits are relatively high implying higher return to the scientist from movement and lower proportion of loss to the entrepreneur due to loss of her monopoly stature. Additionally, low competitive pressure suggests high transportation cost which curtails monopoly returns and further mitigates the difference between the entrepreneur's monopoly and duopoly profits. As a result, the case for $\theta < \theta_1$ corresponds to the region above line A in Figure 1. 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 when movement occurs. As competition intensity rises, duopoly profits contract and the corresponding monopoly return is higher. Thus, the case for $\theta_1 < \theta < \theta_2$ corresponds to the region between lines A and B in Figure 1. Here, patenting lowers the wage required to retain the scientist by the amount of reparation. Patenting occurs in equilibrium when savings in wage, which is equivalent to damage recovery due to patenting if movement occurs, exceeds its cost. Assumption 2.b ensures $\theta_4 < \theta_1$, suggesting sufficiently high expected recovery such that the reparation amount exceeds patenting cost when $\theta_4 < \theta < \theta_1$. Therefore, for relatively greater competition intensity in the range $\theta_1 < \theta < \theta_2$, savings in wage must exceed patenting cost, implying equilibrium patenting in this entire range. For higher competition intensity in $\theta > \theta_2$, very low duopoly returns combined with high potential loss to the entrepreneur renders movement to the rival unprofitable when the innovation is patented. Accordingly, this case corresponds to the region between lines B and C in Figure 1. When competition is relatively less intense i.e. $\theta_2 < \theta < \theta_3$, higher duopoly profits suggest a significantly large gap between the rival's profit and the non-R&D returns, rendering patenting beneficial for the entrepreneur. However, for $\theta > \theta_3$, lower return at the rival suggests insufficient savings to the entrepreneur from patenting, leading to no patenting in equilibrium. Proposition 4 summarizes the relationship of patenting and movement behavior with competition intensity.

Proposition 4. *The following define the nature of relationship between intensity of competition and second period equilibrium patenting and movement behavior.*

(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.

To understand the result, first consider the incidence of patenting. Intuitively, one may expect firms to patent more frequently as competition increases to protect novel innovations and appropriate monopoly profits. However, in markets where mobility is a common phenomenon, this is not necessarily true. When scientist movement is possible, a rise in intensity of competition causes an innovating entrepreneur to go from not patenting to patenting if competition intensity is low or moderate 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 the reparation cost is borne by the infringing rival, the reason for patenting is loss reduction at low levels of competition intensity and wage reduction at moderate and high competitive pressure. While for low and moderate competition, relatively larger levels of competition intensity imply high loss recovery and induce patenting, at high competition intensity, when its level is above a threshold value, low duopoly profits imply low wage reduction due to patenting and render patenting unprofitable. As a result, the rise of competition intensity above a threshold increases the incidence of patenting when competitive pressure is low or moderate but reduces the same when competitive pressure is high. Contrastingly, movement, being induced at low values of competitive pressure due to attractive returns and meager damages, and ceasing at moderate and high levels as losses rise and returns diminish, admits a monotone relation to competition intensity.

4.3 Profit and R&D Expenditure

Intensity of competition influences realized second period returns as well as the first period wage offer through second period patenting and movement. To study the relationship of profitability and R&D expenditure of the research project to competition intensity, consider the realized profit and R&D expenditure for any given level of θ. Given Assumption 1, the entrepreneur knows the second period optimal behavior of the scientist, and hence his second period return, at the beginning of the first period. She accordingly makes a wage offer that satisfies the scientist's participation constraint with equality. The scientist, also aware of his actual second period return, accepts this offer. Equation (3) stipulates the entrepreneur's realized profit from the innovation as follows[7]:

$$\pi = \begin{cases} -\bar{w} + \rho_i + \rho_e - \lambda\rho_i, & M, p = 0 \\ -\bar{w} + \rho_i + \rho_e - \lambda\rho_i - c, & M, p = 1 \\ -\bar{w} + \rho_i - c, & S, p = 1 \\ -\bar{w} + \rho_i, & S, p = 0 \end{cases} \tag{5}$$

The R&D expenditure of the project comprises only the scientist's first period wage or the sum of his first and second period wages according as he moves to a rival or stays with the entrepreneur in period 2. Given Assumption 1, Equation (2) stipulates the R&D expenditure of the innovation for a given θ as follows:

$$R\&D = \begin{cases} \bar{w} - \rho_e, & M, p = 0 \\ \bar{w} - \rho_e + \sigma\lambda\rho_i, & M, p = 1 \\ 2\bar{w}, & S, p = 0 \text{ or } 1 \end{cases} \tag{6}$$

It is straightforward to check that $\frac{\partial(\rho_i + \rho_e - \lambda\rho_i)}{\partial\theta} > 0$. Further, $\frac{\partial\rho_i}{\partial\theta} > 0$, $\frac{\partial(\sigma\lambda\rho_i)}{\partial\theta} > 0$ and $\frac{\partial\rho_e}{\partial\theta} < 0$. Table 1 describes the direction of effect of an increase in competition intensity on profit and R&D expenditure within the different ranges of θ in Figure 3.

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

[7]This can be verified by explicitly solving the entrepreneur's profit maximization problem subject to scientist's participation constraint for each case implied by the ranges of θ.

Range of θ	Movement Decision	Patenting Decision	Profit	R&D Expenditure
$0 - \theta_4$	M	$p = 0$	Decreases	Increases
$\theta_4 - \theta_1$	M	$p = 1$	Decreases	Increases
$\theta_1 - \theta_2$	S	$p = 1$	Increases	Remains constant
$\theta_2 - \theta_3$	S	$p = 1$	Increases	Remains constant
$\theta_3 - \infty$	S	$p = 0$	Increases	Remains constant

Table 1: Profit and R&D Expenditure by Competition Intensity

high θ. Proposition 5 summarizes the resulting relationship of profit and R&D expenditure to competition intensity in presence of scientist mobility.

Proposition 5. *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.

The entrepreneur's profit 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 transportation cost. An interesting observation can be made here. Note that at θ_1 the profit expression 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 neutralizes his returns, the entire benefit of a higher industry profit is reaped by the entrepreneur, resulting in higher profitability of her innovation under duopoly as compared to that under monopoly. 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 imply lower second period return to the scientist when movement occurs, requiring an increase in the first period wage. However, as moderate and high values of competition intensity prevent movement, R&D expenditure remains constant and equal to the total reservation earning of the scientist.

5 Stricter Patent Regime and Competition Intensity

The model of market competition facilitates identifying implications of a stricter liability regime for varying levels of competition intensity. We analyze effects of a tighter patent system on the relationships of patenting, movement, total profitability and R&D expenditure with competition intensity and evaluate its consequences for entrepreneur's profit and R&D investment.

Figure 4 manifests the second period optimal decisions in the $\sigma - \theta$ plane. For patenting to be possible at a given value of σ, we must have $\theta_4 < \theta_2$, which holds by Assumption 2.a. Therefore, σ_B must lie in the domain of σ, which is nothing but Assumption 2.a at $\sigma = 1$. It suggests, for a given patenting cost, the maximum regime strength must induce patenting for patenting to be possible at atleast some value of expected recovery. Further, for patenting possibility at some movement inducing competition intensity, we must have $\theta_4 < \theta_1$, which holds by Assumption 2.b. This is true when the patent regime is sufficiently strong i.e. $\sigma > \sigma_A$. A detailed derivation of the figure is available in Appendix A. Lemma 2

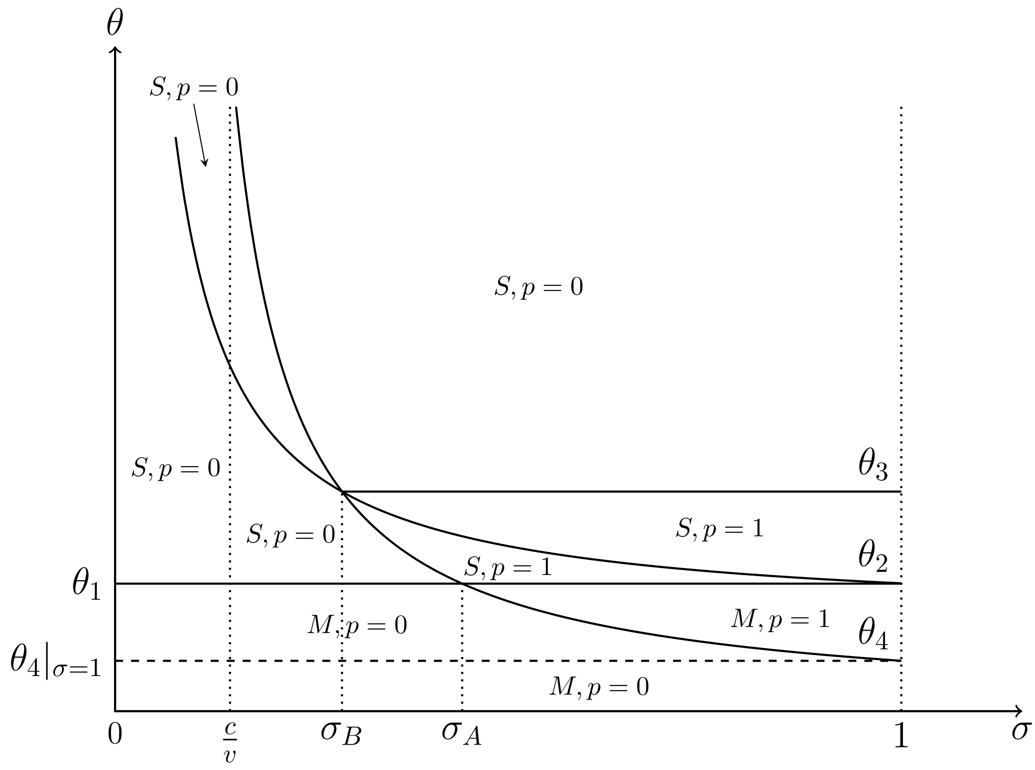

Figure 4: Interaction between Patent Strength and Competition Intensity

summarizes the effect of stronger patent laws on the relation of patenting and movement behavior with competition intensity as depicted in Figure 4.

Lemma 2. *The following define the effect of a stricter patent regime on the relationship between competition intensity and equilibrium patenting and movement.*

(i) A tightening of the patent system sustains the non-monotone (monotone) relation of competitive pressure with patenting (movement).

(ii) A tightening of the patent system initiates patenting at lower competition, expanding the range of competition intensity over which patenting occurs. The range over which movement occurs remains constant.

Lemma 2 suggests, while an increase in patent strength does not affect the nature of relation between patenting and competition intensity, it does influence the incidence of patenting at some low levels of competitive pressure. This is because, a greater patent strength 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, there is no change in either its nature of relation with or its incidence at different levels of competition intensity.

It follows, as σ rises, the ranges of θ defining different patenting and movement decisions remain equivalent to those in Table 1 with a widening of the second and fourth ranges and a narrowing of the third range. Equation (5) implies no change in profit within any range of θ for an increase in σ. Equation (6) indicates an increase in R&D expenditure only within the second range of θ as σ rises. Therefore, the nature of relation of competition intensity with realized profit and R&D expenditure remains unaltered due to strengthening of the patent system. Corollary 1 summarizes.

Corollary 1. *The following define the effect of a stricter patent regime on the relationship of competition intensity with total profitability and R&D expenditure of the innovation.*

(i) A tightening of the patent system sustains the non-monotone relation of total profitability with competitive pressure.

(ii) A tightening of the patent system sustains the non-monotone relation of R&D investment with competitive pressure.

Recall that a stronger patent regime reduces expected profitability and augments R&D expenditure of the research project. While a similar effect on the ex-ante expected profit and R&D expenditure holds in the Hotelling model of competition[8], the framework additionally

[8]To check this, suppose h is the density of θ. Using equations (3) and (4) we can write:

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

equips us to identify the levels of competition intensity at which the expected effect actually manifests. Proposition 6 summarizes the effect of strengthening the patent system on realized profit and R&D expenditure at different levels of competition intensity.

Proposition 6. *The following define the effect of a stricter patent regime on realized profitability and R&D expenditure of the innovation by intensity of competition.*

(i) A stronger patent system decreases the innovation's profitability at moderately low levels of competition intensity, but has no effect at relatively low or high competitive pressure.

(ii) A stronger patent system increases R&D investment at moderately low levels of competition intensity, but has no effect at relatively low or high competitive pressure.

Proof. See Appendix A.

Proposition 6 suggests the counter-intuitive effect of tightening the patent regime on profitability may manifest in markets with moderately low competitive pressure. 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 that induce movement, an increase in expected recovery additionally prompts patenting for moderately low values of competitive pressure that did not initially support it. Next, consider the result for R&D expenditure. Notice, at relatively high competition intensity, when the scientist optimally decides to stay with the entrepreneur, any reduction in the second period wage

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

Differentiate the above with respect to σ to obtain the result. Calculations available upon request.

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 stricter 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.

6 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 2.b 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 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 stricter 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 2.b 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 a stronger patents on R&D expenditure at moderate competition, which proves ineffective due to no equilibrium patenting in case movement occurs. A detailed analysis of relaxing the assumptions is available in the Appendix B.

7 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.

8 Conclusion

This paper studies the issue of regime strength in presence of probabilistic patents or partial recovery guarantee when an innovating firm encounters threat of infringement from its own research aid, and further investigates its interactive effect with the intensity of product market competition. The findings show that strengthening the patent system to ensure higher expected damage recovery to a patent owner not only fails to reduce the threat of mobility of the scientist, it further exacerbates the woes of the innovator by adversely affecting the expected profitability of the entrepreneur. These findings shed light on an important point to consider regarding reforms of the patent system - the end goal of patents is to protect innovation incentives and attempts at strengthening the patent system must remain cognizant of this goal. However, stronger patents may attract greater scientist talent by mitigating the negative differential between R&D and non-R&D wage through an increase in the required R&D investment for the innovation.

The results also 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. Further, 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. Therefore, patent reforms aimed at protecting innovating entrepreneurs or raising scientist wages must take into account the competitive pressure in their targeted markets.

The present study defines damage awards using the "lost profit" rule. However, a similar analysis follows when the underlying patent system imposes the "unjust enrichment" damage regime. It can be easily checked that the effects of a stricter patent regime on patenting behaviour of the innovating firm, movement behaviour of the scientist, and the profitability and R&D expenditure of the entrepreneur remain exactly as under the "lost profit" damage regime characterized in this paper. The reason is as follows. When the rival is required to forego profit under the "unjust enrichment" rule, the scientist's expected second period pay-off falls. This is analogous to a devaluation of the scientist's knowledge to the rival in the second period. The entrepreneur, then, must offer a higher first period wage to induce the scientist to join her development project. These equal and opposite effects of the strengthening of the patent system leaves the scientist's total expected pay-off unaltered, thus having no effect on his second period movement decision. However, when the second period arrives, the entrepreneur finds it optimal to patent the innovation more often, thus increasing patenting expenditure and reducing profitability, with the higher first period wage resulting in an overall higher R&D expenditure. It is evident that the results of this analysis will continue to hold in a more general framework encompassing a linear combination of the two types of damage rules discussed here[9]. However, a full characterization of the generalized case is beyond the scope of this paper and remains open for future research.

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[9]The general form of the damage function is written as:

$$D = \sigma[\alpha\rho_e + (1-\alpha)\lambda\rho_i]$$

where σ comprises the proportion of recovery and the probability of a patent being successfully litigated. For $\alpha = 0$, damages are as under the LP rule, measured as $D^{LP} = \sigma\lambda\rho_i$, which corresponds to the case developed in this paper. For $\alpha = 1$, damages are as under the UE rule, measured as $D^{UE} = \sigma\rho_e$. See Chen and Sappington (2018), Dey et al. (2019) for analysis of damage rules using a linear combination of LP and UE.

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Appendix A

Construction of Figure 1

Suppose $\rho_e > \lambda\rho_i$ or $\epsilon_e > \lambda\bar{\rho}_i - \bar{\rho}_e + \lambda\epsilon_i$. As $\gamma\rho_i = \sigma\lambda\rho_i$, the inequality holds irrespective of whether the product is patented. The scientist always moves to a rival earning $\rho_e + \bar{w}$ (or $\rho_e - \gamma\rho_i + \bar{w}$ if patented). Patenting occurs when the cost of patenting is less than the reduction in loss due to patenting, i.e. $\sigma\lambda\rho_i \geq c$ or $\epsilon_i \geq \frac{c}{\sigma\lambda} - \rho_i \implies \epsilon_i \geq \frac{c}{\gamma} - \rho_i$. This case corresponds to the area above line A in Figure 1.

Suppose $\rho_e \leq \lambda\rho_i$ or $\epsilon_e \leq \lambda\bar{\rho}_i - \bar{\rho}_e + \lambda\epsilon_i$. But $\rho_e - \gamma\rho_i + \bar{w} > \bar{w} \implies \epsilon_e > \gamma\bar{\rho}_i - \bar{\rho}_e + \gamma\epsilon_i$. The entrepreneur offers wage $w_1 = \rho_e + \bar{w}$ (or $w_1 = \rho_e - \gamma\rho_i + \bar{w}$ when patented) and the scientist chooses to stay. Patenting occurs when savings in wage exceeds patenting cost i.e. $\gamma\rho_i \geq c \implies \epsilon_i \geq \frac{c}{\gamma} - \rho_i$. This case corresponds to the area between lines A and B.

Suppose $0 < \rho_e \leq \gamma\rho_i \implies -\bar{\rho}_e < \epsilon_e \leq \gamma\bar{\rho}_i - \bar{\rho}_e + \gamma\epsilon_i$. Without patent, the scientist considers moving to a rival, hence second period wage offered by the entrepreneur must be $w_1 = \rho_e + \bar{w}$. When the product is patented, it is sufficient to offer the reservation wage to persuade the scientist to stay, i.e. $w_1 = \bar{w}$. Patenting occurs when the wage reduction exceeds the patenting cost, $\rho_e \geq c \implies \epsilon_e \geq c - \bar{\rho}_e$. This case corresponds to the area between lines B and C.

Finally, suppose $\rho_e \leq 0 \implies \epsilon_e \leq -\bar{\rho}_e$. The scientist then never finds it optimal to move to a rival and the entrepreneur offers wage $w_1 = \bar{w}$ to retain the scientist. Patenting does not occur in this case. This corresponds to the area below line C.

It is easy to see now why the scientist never finds it optimal to move to the non-R&D sector. As long as moving to the rival yields higher returns to the scientist, the scientist will either move to a rival or stay with the entrepreneur, but never move to the non-R&D sector (i.e. when $\rho_e + \bar{w} > \bar{w}$ without patenting or $\rho_e - \gamma\rho_i + \bar{w} > \bar{w}$ with patenting). When moving to the rival renders lower returns than moving to the non-R&D sector, the entrepreneur's loss from the scientist leaving exceeds the required wage for retaining the scientist, thus inducing the entrepreneur to offer $w_1 = \bar{w}$ and retain the scientist.

Proof of Lemma 1

Replacing the expected second period pay-off of the scientist in equation 2 with equality:

$$
\begin{aligned}
2\bar{w} = \; & w_0 \; + \int_{\epsilon_{i1}}^{\infty}\int_{\epsilon_{eB}}^{\epsilon_{eA}} [\bar{\rho}_e + \epsilon_e - \gamma\bar{\rho}_i + \gamma\epsilon_i + \bar{w}] g(\epsilon_e, \epsilon_i)\, d\epsilon_e d\epsilon_i \; + \int_{\epsilon_{i1}}^{\infty}\int_{\epsilon_{e2}}^{\epsilon_{eB}} \bar{w} g(\epsilon_e, \epsilon_i)\, d\epsilon_e d\epsilon_i \\
& + \int_{\epsilon_{i1}}^{\infty}\int_{\epsilon_{eA}}^{\infty} [\bar{\rho}_e + \epsilon_e - \gamma\bar{\rho}_i + \gamma\epsilon_i + \bar{w}] g(\epsilon_e, \epsilon_i)\, d\epsilon_e d\epsilon_i \; + \int_{\epsilon_{i0}}^{\infty}\int_{-\infty}^{\epsilon_{e1}} \bar{w} g(\epsilon_e, \epsilon_i)\, d\epsilon_e d\epsilon_i \\
& + \int_{\epsilon_{i0}}^{\epsilon_{i1}}\int_{\epsilon_{e1}}^{\epsilon_{eB}} [\bar{\rho}_e + \epsilon_e + \bar{w}] g(\epsilon_e, \epsilon_i)\, d\epsilon_e d\epsilon_i \; + \int_{\epsilon_{i1}}^{\infty}\int_{\epsilon_{e1}}^{\epsilon_{e2}} [\bar{\rho}_e + \epsilon_e + \bar{w}] g(\epsilon_e, \epsilon_i)\, d\epsilon_e d\epsilon_i \\
& + \int_{\epsilon_{i0}}^{\epsilon_{i1}}\int_{\epsilon_{eB}}^{\epsilon_{eA}} [\bar{\rho}_e + \epsilon_e + \bar{w}] g(\epsilon_e, \epsilon_i)\, d\epsilon_e d\epsilon_i \; + \int_{\epsilon_{i0}}^{\epsilon_{i1}}\int_{\epsilon_{eA}}^{\infty} [\bar{\rho}_e + \epsilon_e + \bar{w}] g(\epsilon_e, \epsilon_i)\, d\epsilon_e d\epsilon_i
\end{aligned}
$$

where $\epsilon_{i0} = -\bar{\rho}_i$, $\epsilon_{i1} = \frac{c}{\gamma} - \bar{\rho}_i$, $\epsilon_{e1} = -\bar{\rho}_e$, $\epsilon_{e2} = c - \bar{\rho}_e$, $\epsilon_{eA} = \lambda\bar{\rho}_i - \bar{\rho}_e + \lambda\epsilon_i$, $\epsilon_{eB} = \gamma\bar{\rho}_i - \bar{\rho}_e + \gamma\epsilon_i$.

$$
\begin{aligned}
\therefore \; w_0 = \; & 2\bar{w} \; - \Bigg[\int_{\epsilon_{i1}}^{\infty}\int_{\epsilon_{eB}}^{\epsilon_{eA}} [\bar{\rho}_e + \epsilon_e - \gamma\bar{\rho}_i + \gamma\epsilon_i + \bar{w}] g(\epsilon_e, \epsilon_i)\, d\epsilon_e d\epsilon_i \; + \int_{\epsilon_{i1}}^{\infty}\int_{\epsilon_{e2}}^{\epsilon_{eB}} \bar{w} g(\epsilon_e, \epsilon_i)\, d\epsilon_e d\epsilon_i \\
& + \int_{\epsilon_{i1}}^{\infty}\int_{\epsilon_{eA}}^{\infty} [\bar{\rho}_e + \epsilon_e - \gamma\bar{\rho}_i + \gamma\epsilon_i + \bar{w}] g(\epsilon_e, \epsilon_i)\, d\epsilon_e d\epsilon_i \; + \int_{\epsilon_{i0}}^{\infty}\int_{-\infty}^{\epsilon_{e1}} \bar{w} g(\epsilon_e, \epsilon_i)\, d\epsilon_e d\epsilon_i \\
& + \int_{\epsilon_{i0}}^{\epsilon_{i1}}\int_{\epsilon_{e1}}^{\epsilon_{eB}} [\bar{\rho}_e + \epsilon_e + \bar{w}] g(\epsilon_e, \epsilon_i)\, d\epsilon_e d\epsilon_i \; + \int_{\epsilon_{i1}}^{\infty}\int_{\epsilon_{e1}}^{\epsilon_{e2}} [\bar{\rho}_e + \epsilon_e + \bar{w}] g(\epsilon_e, \epsilon_i)\, d\epsilon_e d\epsilon_i \\
& + \int_{\epsilon_{i0}}^{\epsilon_{i1}}\int_{\epsilon_{eB}}^{\epsilon_{eA}} [\bar{\rho}_e + \epsilon_e + \bar{w}] g(\epsilon_e, \epsilon_i)\, d\epsilon_e d\epsilon_i \; + \int_{\epsilon_{i0}}^{\epsilon_{i1}}\int_{\epsilon_{eA}}^{\infty} [\bar{\rho}_e + \epsilon_e + \bar{w}] g(\epsilon_e, \epsilon_i)\, d\epsilon_e d\epsilon_i \Bigg]
\end{aligned}
$$

Substituting this in the equation for expected profit, we have:

$$
\begin{aligned}
E(\pi) = \; & -2\bar{w} \; + \Big[\text{ the 8 integration terms in the expression for first period wage } \Big] \\
& + \int_{\epsilon_{i1}}^{\infty} \int_{\epsilon_{eB}}^{\epsilon_{eA}} [\bar{\rho}_i + \epsilon_i - (\bar{\rho}_e + \epsilon_e - \gamma\bar{\rho}_i - \gamma\epsilon_i + \bar{w}) + \bar{w}] g(\epsilon_e, \epsilon_i) \, d\epsilon_e d\epsilon_i \\
& + \int_{\epsilon_{i1}}^{\infty} \int_{\epsilon_{e2}}^{\epsilon_{eB}} [\bar{\rho}_i + \epsilon_i - (\bar{w}) + \bar{w}] g(\epsilon_e, \epsilon_i) \, d\epsilon_e d\epsilon_i \\
& + \int_{\epsilon_{i1}}^{\infty} \int_{\epsilon_{eA}}^{\infty} [\bar{\rho}_i + \epsilon_i - (1-\sigma)\lambda\bar{\rho}_i - (1-\sigma)\lambda\epsilon_i] g(\epsilon_e, \epsilon_i) \, d\epsilon_e d\epsilon_i \\
& - \iint_{p=1} c g(\epsilon_e, \epsilon_i) \, d\epsilon_e d\epsilon_i \\
& + \int_{\epsilon_{i0}}^{\infty} \int_{-\infty}^{\epsilon_{e1}} [\bar{\rho}_i + \epsilon_i - (\bar{w}) + \bar{w}] g(\epsilon_e, \epsilon_i) \, d\epsilon_e d\epsilon_i \\
& + \int_{\epsilon_{i0}}^{\epsilon_{i1}} \int_{\epsilon_{e1}}^{\epsilon_{eB}} [\bar{\rho}_i + \epsilon_i - (\bar{\rho}_e + \epsilon_e + \bar{w}) + \bar{w}] g(\epsilon_e, \epsilon_i) \, d\epsilon_e d\epsilon_i \\
& + \int_{\epsilon_{i1}}^{\infty} \int_{\epsilon_{e1}}^{\epsilon_{e2}} [\bar{\rho}_i + \epsilon_i - (\bar{\rho}_e + \epsilon_e + \bar{w}) + \bar{w}] g(\epsilon_e, \epsilon_i) \, d\epsilon_e d\epsilon_i \\
& + \int_{\epsilon_{i0}}^{\epsilon_{i1}} \int_{\epsilon_{eB}}^{\epsilon_{eA}} [\bar{\rho}_i + \epsilon_i - (\bar{\rho}_e + \epsilon_e + \bar{w}) + \bar{w}] g(\epsilon_e, \epsilon_i) \, d\epsilon_e d\epsilon_i \\
& + \int_{\epsilon_{i0}}^{\epsilon_{i1}} \int_{\epsilon_{eA}}^{\infty} [\bar{\rho}_i + \epsilon_i - \lambda\bar{\rho}_i - \lambda\epsilon_i] g(\epsilon_e, \epsilon_i) \, d\epsilon_e d\epsilon_i
\end{aligned}
$$

$$
\begin{aligned}
\implies E(\pi) = \; & -\bar{w} \; + \iint_S \rho_i f(\rho_e, \rho_i) \, d\rho_e d\rho_i \; + \iint_M [\rho_i + \rho_e - \lambda\rho_i] f(\rho_e, \rho_i) \, d\rho_e d\rho_i \\
& + \iint_{M,p=1} (\sigma\lambda\rho_i - \gamma\rho_i) f(\rho_e, \rho_i) \, d\rho_e d\rho_i - \iint_{p=1} c f(\rho_e, \rho_i) \, d\rho_e d\rho_i
\end{aligned}
$$

The fourth term vanishes as $\sigma\lambda\rho_i = \gamma\rho_i$. Hence the proof. $\blacksquare$

Proof of Proposition 2

Writing the expected profit of the entrepreneur using Lemma 1:

$$\begin{aligned}
E(\pi) = & -\bar{w} + \int_{\epsilon_{i0}}^{\epsilon_{i1}} \int_{-\infty}^{\epsilon_{eA}} [\bar{\rho}_i + \epsilon_i] g(\epsilon_e, \epsilon_i)\, d\epsilon_e d\epsilon_i \\
& + \int_{\epsilon_{i1}}^{\infty} \int_{-\infty}^{\epsilon_{e2}} [\bar{\rho}_i + \epsilon_i] g(\epsilon_e, \epsilon_i)\, d\epsilon_e d\epsilon_i \\
& + \int_{\epsilon_{i1}}^{\infty} \int_{\epsilon_{e2}}^{\epsilon_{eA}} [\bar{\rho}_i + \epsilon_i] g(\epsilon_e, \epsilon_i)\, d\epsilon_e d\epsilon_i \\
& + \int_{\epsilon_{i0}}^{\epsilon_{i1}} \int_{\epsilon_{eA}}^{\infty} [\bar{\rho}_i + \epsilon_i + \bar{\rho}_e + \epsilon_e - \lambda\bar{\rho}_i - \lambda\epsilon_i] g(\epsilon_e, \epsilon_i)\, d\epsilon_e d\epsilon_i \\
& + \int_{\epsilon_{i1}}^{\infty} \int_{\epsilon_{eA}}^{\infty} [\bar{\rho}_i + \epsilon_i + \bar{\rho}_e + \epsilon_e - \lambda\bar{\rho}_i - \lambda\epsilon_i] g(\epsilon_e, \epsilon_i)\, d\epsilon_e d\epsilon_i \\
& - \int_{\epsilon_{i1}}^{\infty} \int_{\epsilon_{e2}}^{\infty} c g(\epsilon_e, \epsilon_i)\, d\epsilon_e d\epsilon_i
\end{aligned}$$

Differentiating the first term with respect to γ yields:

$$\frac{\partial \bar{w}}{\partial \gamma} = 0 \qquad \text{(i)}$$

Differentiating the second term with respect to γ yields:

$$\begin{aligned}
& \frac{\partial}{\partial \gamma} \left[\int_{\epsilon_{i0}}^{\epsilon_{i1}} \int_{-\infty}^{\epsilon_{eA}} [\bar{\rho}_i + \epsilon_i] g(\epsilon_e, \epsilon_i)\, d\epsilon_e d\epsilon_i \right] \\
= & \int_{-\bar{\rho}_i}^{\frac{c}{\gamma} - \bar{\rho}_i} \frac{\partial}{\partial \gamma} \left[\int_{-\infty}^{\epsilon_{eA}} [\bar{\rho}_i + \epsilon_i] g(\epsilon_e, \epsilon_i)\, d\epsilon_e \right] d\epsilon_i - \frac{c}{\gamma^2} \int_{-\infty}^{\frac{c}{\sigma} - \bar{\rho}_e} \frac{c}{\gamma} g(\epsilon_e, \frac{c}{\gamma} - \bar{\rho}_i)\, d\epsilon_e \; - 0 \\
= & \int_{-\bar{\rho}_i}^{\frac{c}{\gamma} - \bar{\rho}_i} \left[\int_{-\infty}^{\epsilon_{eA}} \frac{\partial}{\partial \gamma} \Big[[\bar{\rho}_i + \epsilon_i] g(\epsilon_e, \epsilon_i) \Big] d\epsilon_e + 0 - 0 \right] d\epsilon_i - \frac{c}{\gamma^2} \int_{-\infty}^{\frac{c}{\sigma} - \bar{\rho}_e} \frac{c}{\gamma} g(\epsilon_e, \frac{c}{\gamma} - \bar{\rho}_i)\, d\epsilon_e \; - 0
\end{aligned}$$

$$= -\frac{c}{\gamma^2} \int_{-\infty}^{\frac{c}{\sigma}-\bar{\rho_e}} \frac{c}{\gamma} g(\epsilon_e, \frac{c}{\gamma} - \bar{\rho_i})\, d\epsilon_e \qquad \texttt{(ii)}$$

Similarly, differentiating the third term with respect to γ yields:

$$\frac{c}{\gamma^2} \int_{-\infty}^{c-\bar{\rho_e}} \frac{c}{\gamma} g(\epsilon_e, \frac{c}{\gamma} - \bar{\rho_i})\, d\epsilon_e \qquad \texttt{(iii)}$$

Differentiating the fourth term with respect to γ yields:

$$\frac{c}{\gamma^2} \int_{c-\bar{\rho_e}}^{\frac{c}{\sigma}-\bar{\rho_e}} \frac{c}{\gamma} g(\epsilon_e, \frac{c}{\gamma} - \bar{\rho_i})\, d\epsilon_e \qquad \texttt{(iv)}$$

Differentiating the fifth term with respect to γ yields:

$$-\frac{c}{\gamma^2} \int_{\frac{c}{\sigma}-\bar{\rho_e}}^{\infty} [\bar{\rho_e} + (1-\lambda)\frac{c}{\gamma} + \epsilon_e] g(\epsilon_e, \frac{c}{\gamma} - \bar{\rho_i})\, d\epsilon_e \qquad \texttt{(v)}$$

Differentiating the sixth term with respect to γ yields:

$$\frac{c}{\gamma^2} \int_{\frac{c}{\sigma}-\bar{\rho_e}}^{\infty} [\bar{\rho_e} + (1-\lambda)\frac{c}{\gamma} + \epsilon_e] g(\epsilon_e, \frac{c}{\gamma} - \bar{\rho_i})\, d\epsilon_e \qquad \texttt{(vi)}$$

Differentiating the seventh term with respect to γ yields:

$$-\frac{c}{\gamma^2} \int_{c-\bar{\rho_e}}^{\infty} c g(\epsilon_e, \frac{c}{\gamma} - \bar{\rho_i})\, d\epsilon_e \qquad \texttt{(vii)}$$

It can be easily seen that $\texttt{(i)} + \texttt{(ii)} + \texttt{(iii)} + \texttt{(iv)} + \texttt{(v)} + \texttt{(vi)} = 0$ and $\texttt{(vii)} < 0$. Hence the proof. ■

Proof of Proposition 3

Writing the expression for R&D expenditure using equation (4):

$$R\&D = 2\bar{w} \; - \int_{\epsilon_{i1}}^{\infty} \int_{\epsilon_e A}^{\infty} [\bar{\rho_e} + \epsilon_e - \gamma\bar{\rho_i} - \gamma\epsilon_i + \bar{w}] g(\epsilon_e, \epsilon_i)\, d\epsilon_e d\epsilon_i \; - \int_{\epsilon_{i0}}^{\epsilon_{i1}} \int_{\epsilon_e A}^{\infty} [\bar{\rho_e} + \epsilon_e + \bar{w}] g(\epsilon_e, \epsilon_i)\, d\epsilon_e d\epsilon_i$$

Differentiating the first term with respect to γ yields:

$$\frac{\partial(2\bar{w})}{\partial\gamma} = 0 \qquad \texttt{(viii)}$$

Differentiating the second term with respect to γ yields:

$$-\frac{\partial}{\partial\gamma}\left[\int_{\epsilon_{i1}}^{\infty}\int_{\epsilon_{eA}}^{\infty}[\bar{\rho}_e + \epsilon_e - \gamma\bar{\rho}_i - \gamma\epsilon_i + \bar{w}]g(\epsilon_e, \epsilon_i)\, d\epsilon_e d\epsilon_i\right]$$

$$= -\int_{\frac{c}{\gamma}-\bar{\rho}_i}^{\infty}\frac{\partial}{\partial\gamma}\left[\int_{\epsilon_{eA}}^{\infty}[\bar{\rho}_e + \epsilon_e - \gamma\bar{\rho}_i - \gamma\epsilon_i + \bar{w}]g(\epsilon_e, \epsilon_i)\, d\epsilon_e\right]d\epsilon_i - 0$$

$$- \frac{c}{\gamma^2}\int_{\frac{c}{\sigma}-\bar{\rho}_e}^{\infty}[\bar{\rho}_e + \epsilon_e + \bar{w} - c]g(\epsilon_e, \frac{c}{\gamma} - \bar{\rho}_i)\, d\epsilon_e$$

$$= \int_{\frac{c}{\gamma}-\bar{\rho}_i}^{\infty}\int_{\epsilon_{eA}}^{\infty}[\bar{\rho}_i + \epsilon_i]g(\epsilon_e, \epsilon_i)\, d\epsilon_e d\epsilon_i - \frac{c}{\gamma^2}\int_{\frac{c}{\sigma}-\bar{\rho}_e}^{\infty}[\bar{\rho}_e + \epsilon_e + \bar{w}]g(\epsilon_e, \frac{c}{\gamma} - \bar{\rho}_i)\, d\epsilon_e$$

$$+ \frac{c^2}{\gamma^2}\int_{\frac{c}{\sigma}-\bar{\rho}_e}^{\infty} g(\epsilon_e, \frac{c}{\gamma} - \bar{\rho}_i)\, d\epsilon_e \qquad \texttt{(ix)}$$

Similarly, differentiating the third term with respect to γ yields:

$$\frac{c}{\gamma^2}\int_{\frac{c}{\sigma}-\bar{\rho}_e}^{\infty}[\bar{\rho}_e + \epsilon_e + \bar{w}]g(\epsilon_e, \frac{c}{\gamma} - \bar{\rho}_i)\, d\epsilon_e \qquad \texttt{(x)}$$

Combining `(viii)`, `(ix)` and `(x)`:

$$\frac{\partial R\&D}{\partial\gamma} = \int_{\frac{c}{\gamma}-\bar{\rho}_i}^{\infty}\int_{\epsilon_{eA}}^{\infty}[\bar{\rho}_i + \epsilon_i]g(\epsilon_e, \epsilon_i)\, d\epsilon_e d\epsilon_i + \frac{c^2}{\gamma^2}\int_{\frac{c}{\sigma}-\bar{\rho}_e}^{\infty} g(\epsilon_e, \frac{c}{\gamma} - \bar{\rho}_i)\, d\epsilon_e$$

The above expression is positive. Hence the proof. ■

Construction of Figure 3

The region above line A in Figure 1 corresponds to $\rho_e > \lambda\rho_i \implies \theta < \frac{L^2+1}{v} = \theta_1$, say. Patenting occurs in this case when $\sigma\lambda\rho_i \geq c \implies \theta \geq \frac{\sigma(2+L^2)}{2(v\sigma-c)} = \theta_4$, say, as

$\sigma > \frac{c}{v}$ by Assumption 2.a. The region between lines A and B in Figure 1 corresponds to $\rho_e \leq \lambda\rho_i \implies \theta \geq \theta_1$ but $\rho_e > \sigma\lambda\rho_i \implies \theta < \frac{(\frac{1}{\sigma}+1)L^2+2}{2v} = \theta_2$, say. Patenting occurs if $\sigma\lambda\rho_i \geq c$, which implies the range of θ relative to θ_4 as described in the previous case. The region between lines B and C in Figure 1 corresponds to $0 < \rho_e \leq \sigma\lambda\rho_i$. The first part of the inequality holds trivially. The second part implies the range $\theta \geq \theta_2$. Patenting occurs when $\rho_e \geq c \implies \theta \leq \frac{L^2}{2c} = \theta_3$, say. Finally, in this framework the region below line C in Figure 1 is not relevant as ρ_e is always positive.

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.

Construction of Figure 4

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 2.a 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 2.a. Again, as $\theta_2 > \theta_1$ at $\sigma < 1$, $\sigma_B < \sigma_A$.

To understand Assumptions 2.a and 2.b, 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 2.a. 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 2.b.

Proof of Proposition 6

Figure 4 implies, 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 θ_4'. Therefore, $\theta_4' - \theta_4^0$ gives the range of θ where incidence of patenting increases and profit falls. 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, an increase in σ has no effect on profitability for values of θ in ranges $0 - \theta_4'$ and $\theta_4^0 - \infty$. It has no effect on R&D expenditure for values of θ in ranges $0 - \theta_4'$ and $\theta_1 - \infty$. ■

Appendix B

Relaxing Assumption 1

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 h, 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. Substituting the second period returns for different levels of competition intensity in the participation constraint of the scientist gives the first period wage w_0 as:

$$w_0 = \bar{w} \; - \int_{0}^{\theta_4} \rho_e h(\theta)\, d\theta - \int_{\theta_4}^{\theta_2} [\rho_e - \sigma\lambda\rho_i] h(\theta)\, d\theta \; - \int_{\theta_3}^{\infty} \rho_e h(\theta)\, d\theta \tag{B.1}$$

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,

Range of θ	Movement Decision	Patenting Decision	π_1	w_1
$0 - \theta_4$	M	$p = 0$	$\rho_i - \lambda\rho_i$	0
$\theta_4 - \theta_1$	M	$p = 1$	$\rho_i - \lambda\rho_i + \sigma\lambda\rho_i - c$	0
$\theta_1 - \theta_2$	S	$p = 1$	$\rho_i - \rho_e + \sigma\lambda\rho_i - c$	$\rho_e - \sigma\lambda\rho_i + \bar{w}$
$\theta_2 - \theta_3$	S	$p = 1$	$\rho_i - c$	$\bar{w}$
$\theta_3 - \infty$	S	$p = 0$	$\rho_i - \rho_e$	$\rho_e + \bar{w}$

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

our results on the nature of relation of competition intensity with patenting, movement, realized profit and R&D expenditure of the innovation in Proposition 4 and Proposition 5 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.

Range of θ	With Assumption 1		Without Assumption 1	
	Profit	R&D Expenditure	Profit	R&D Expenditure
$0 - \theta_4$	Decreases	Increases	Decreases	Remains constant
$\theta_4 - \theta_1$	Decreases	Increases	Ambiguous	Remains constant
$\theta_1 - \theta_2$	Increases	Remains constant	Increases	Decreases
$\theta_2 - \theta_3$	Increases	Remains constant	Increases	Remains constant
$\theta_3 - \infty$	Increases	Remains constant	Increases	Decreases

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

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

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

The second term yields:

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

The third term yields:

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

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

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:

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

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

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

Combining the above yields:

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

$$= \int_{\theta_4}^{\theta_2} \lambda\rho_i h(\theta)\, d\theta \;-\; \theta_4^{'}(\sigma).\big[\sigma\lambda\rho_i|_{\theta=\theta_4}\big].h(\theta_4)$$

As $\theta_4^{'}(\sigma) < 0$ and $\big[\sigma\lambda\rho_i|_{\theta=\theta_4}\big] > 0$, 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 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 1 from the main analysis holds. Relaxing Assumption 1, however, reverses the effect of an increase in recovery proportion on the value of total profit and R&D expenditure defined by Proposition 6. Proposition B.6 summarizes the results when Assumption 1 does not hold.

Proposition B.6: *The following define the effect of a stricter patent regime on total* *profitability and R&D expenditure of the innovation by intensity of competition (without Assumption 1):*

(i) 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.

(ii) A stricter patent system increases R&D investment at 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. First, consider total profitability 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. Next, consider R&D expenditure 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, recovery proportion 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 2.b

Relax Assumption 2.b 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 4, 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 2.b 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 2.b preserves the results in Proposition 4. Equations (5) & (6) 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. $0 - \theta_1$, 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 $0 - \theta_1$ 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 5 remain unaltered when we relax Assumption 2.b.

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

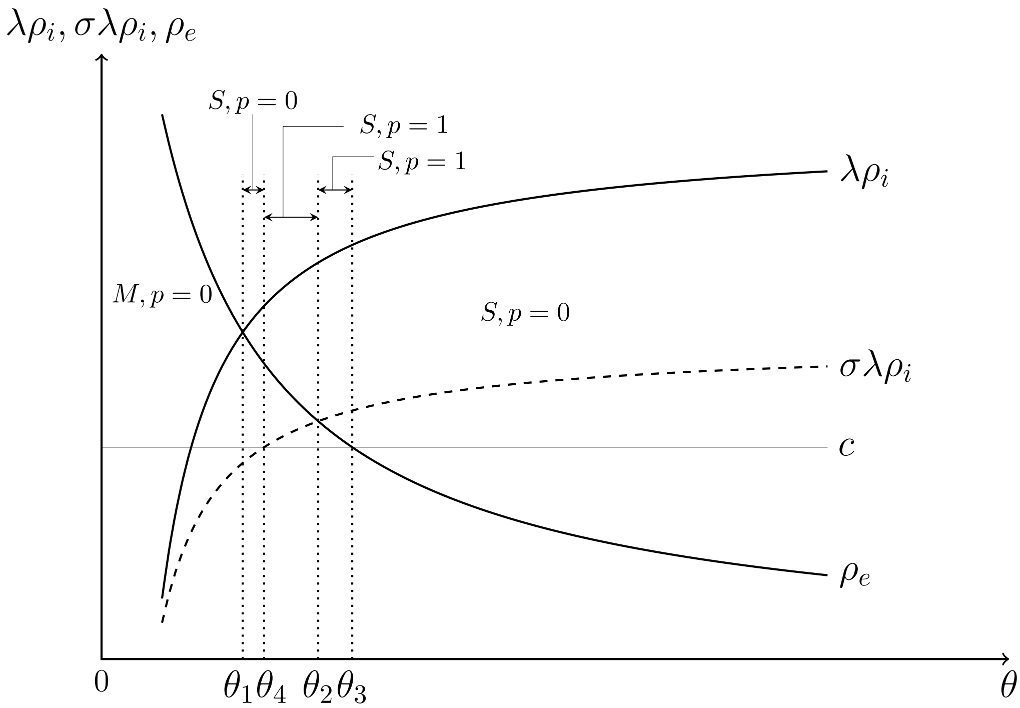

Figure B.1: Patenting and mobility by competition intensity (without Assumption 2.b)

Figure 4 suggests Lemma 2 holds in the range $\sigma \in (\sigma_B, \sigma_A)$, implying the relevant ranges of θ remain qualitatively unchanged as σ increases. Equation (5) 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 recovery proportion 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, Equation (6) 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 1 and Proposition 6.(i) hold without Assumption 2.b, the effect in Proposition 6.(ii) 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:

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

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 case when the scientist finds movement to the non-R&D sector profitable without patenting does not arise.

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 2.b). 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.

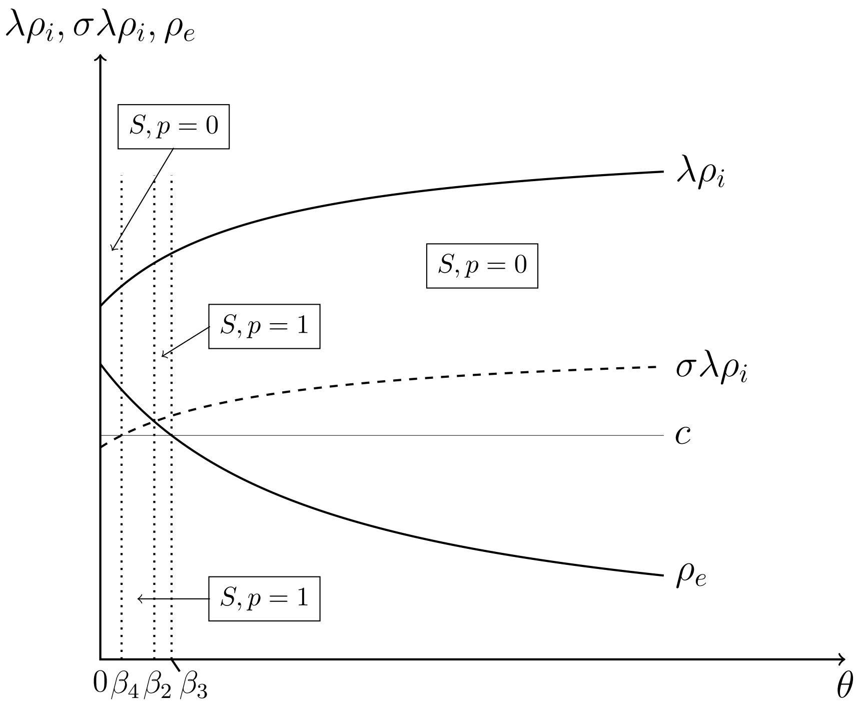

Figure C.1: Patenting and mobility by competition intensity