# Stronger Patent Regime, Innovation and Scientist Mobility

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**Abstract:** This paper analyzes the effects of a stronger patent regime on innovation incentives, patenting propensity and scientist mobility when an innovating firm can partially recover its damage due to scientist movement from the infringing rival. The strength of the patent system, which is a function of litigation success probability and damage recovery proportion, stipulates expected indemnification. We show that stronger patents fail to reduce the likelihood of infringement and further, decrease the innovation's expected profitability. Higher potential reparation also reduces the scientist's expected return on R&D knowledge, entailing greater R&D investment. Our results suggest important considerations for patent reforms.

JEL CLASSIFICATION: J60, K40, L13, O34

KEYWORDS: Damage rules, Infringement, Patent strength, Scientist mobility

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# 1 Introduction

In the recent decades, businesses and organizations have consciously shifted to internal R&D for advancing innovations as opposed to relying on licensing agreements with independent scientists (Kim & Marschke, 2005). However, in spite of its benefits, an in-house approach to R&D risks exposing innovating firms to undesired knowledge transfer through intra-industry scientist movement. In this context, patents serve as a device that innovating firms may use 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 (Shapiro, 2003). This means, although they may not deter infringement, they allow patentees to establish the right to extract applicable penalties from the infringer as remedial compensation for the injury caused. The underlying damage measure and the likelihood of proving infringement in court of law stipulate the expected amount of recovery in case infringement occurs. This paper investigates the effects of a stronger patent regime on patenting and movement propensity in presence of scientist mobility, and identifies the implications of increase in patent strength on the profitability and required investment of an innovation project.

We develop a model of patenting and movement decision in which innovation is static and certain[1]. The innovating entrepreneur develops a new product with the help of a scientist aid and commercializes it to yield profits. Scientist mobility inflicts a loss in profit to the innovator through unsolicited product market competition. To protect against potential infringement, the innovator may choose to patent the innovation by incurring a cost. We define damages á la the "lost profit" rule such that a part of the loss suffered by the incumbent is recovered from the entrant in case the innovation is patented[2]. The strength of

[1] The structure follows the development in Kim and Marschke (2005).

[2] 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 profit", which indicates the patent owner's reduction in profit due to infringement, "infringer's profit" or "unjust enrichment", which indicates the profit accruing to the infringer due to infringement, and "reasonable royalty rate", which indicates the

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), determines expected amount of reparation. 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 stronger patent regime on the innovator and the innovation in an industry prone to scientist mobility.

Our results demonstrate that an increase in patent strength increases patenting propensity but does not suffice to deter infringement and further, fails to reduce the probability of such instances[3]. Nevertheless, 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 as the patent regime is made stronger, thereby weakening incentives to innovate[4]. However, stronger patents augment the innovation's R&D expenditure. Existing empirical studies on the impact of patent strength on patenting and R&D spending indicate similar effects. In conducting a survey of R&D managers and executives in the semiconductor industry, which is an industry characterized by substantial scientist mobility, Hall and Ziedonis (2001) find evidence of a causal relationship between greater patent strength and increased patenting. Arora et al. (2008) study the effect of patent reforms on the Indian pharmaceutical market and show that stronger patents increase R&D spending[5]. This paper introduces a theoretical construct of patent strength in a framework of scientist mobility and demonstrates that, in the aim of protecting against threat of infringement from insiders, stronger patents are not only inefficacious but also unfavourable to profits. The results suggest important considerations for patent reforms.

royalty rate that would have been applicable had the infringer entered into a licensing agreement with the patent owner before infringement.

[3]We additionally test the ineffectiveness of stronger patents on mobility under exogenous patenting following the closely related model structure in Ganco et al. (2015) to show that our finding is consistent for models of endogenous as well as exogenous patenting.

[4]We suppose innovations are motivated by expected profits (as in Moser (2005)).

[5]In our model of certain innovation, increase in R&D expenditure manifests as increase in total wage bill.

The intuition behind the results follows from the avenues through which a stronger 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 impel 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.

Our paper is primarily a contribution to the literature on patent strength. The existing literature on IPRs extensively studies patent strength in the context of optimal patent length and breadth (Gallini, 1992; Gilbert & Shapiro, 1990), preferences of developed vs. developing countries (Allred & Park, 2007; Chen & Puttitanun, 2005; Dinopoulos & Kottaridi, 2008; Iwaisako et al., 2011) and patent reforms (Kanwar & Evenson, 2003; Kyle & McGahan, 2012; Sakakibara & Branstetter, 2001). Evidences from theoretical as well as empirical analyses have suggested that although stronger patents unambiguously increase patenting, their role in protecting and enhancing innovation incentives is ambiguous (Bessen & Maskin, 2009; Cohen et al., 2000; Hall, 2007; Hall & Ziedonis, 2001; Lerner, 2009). For example, Falvey et al. (2006) empirically observe differential effect of patent strength on innovation by a country's income level. Encaoua and Lefouili (2005) suggest differential patenting by innovation size using a theoretical model such that greater patent strength increases patenting propensity for medium innovations. Bessen and Maskin (2009) show that stronger patents can inhibit innovation when innovation is sequential. We study the effectiveness of stronger IPRs in protecting the innovator and the innovation when innovating firms face infringement threat from movement of their scientists.

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 toward 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 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). Our study models a damage rule with probabilistic patents where the strength of the patent system determines the proportion of entrepreneur's recovery from her loss due to infringement[6].

[6]Pecuniary penalties ("damages") for patent infringement are a newly emerging area of interest in the existing literature (Chen & Sappington, 2018). In a recent study on damage rules, Chen and Sappington (2018) underscore the significance of regime design by proposing a linear combination of the "lost profit" and "unjust enrichment" rules together with a lumpsum monetary transfer, and obtaining that the welfare-maximizing linear rule is optimal among all rules that ensure a balanced budget in the industry,

We consider scientist mobility to be the only potential source of infringement. The existing literature on labour turnover and information diffusion widely proclaims scientist mobility as a primary channel for knowledge spillover within industries (Agarwal et al., 2009; Almeida & Kogut, 1999; Arrow, 1962; Rønde, 2001). Such knowledge flows can remain geographically localized (Almeida & Kogut, 1999; Kaiser et al., 2015) or disseminate across regional borders (Oettl & Agrawal, 2008). Incidentally, hiring of other firms' scientists is an important learning mechanism for innovators seeking knowledge across geographical and technological borders (Rosenkopf & Almeida, 2003). Pakes and Nitzan (1983) design an optimal contract for hiring a scientist who can potentially move to or set up a rival enterprise and indicate conditions under which it permits 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 labour mobility, they underscore the role of patents in protecting an innovating firm from "insiders". Our paper attempts to understand how patent reforms aimed at protecting the innovator affect innovation attributes and patenting propensity in presence of knowledge transfusion due to scientist mobility.

In this study, we seek to establish an interrelationship between intellectual property rights and scientist mobility. To the best of our knowledge, the only other studies that do so are Kim and Marschke (2005), Hellmann (2007), Agarwal et al. (2009) and Ganco et al. (2015). However, unlike the existing studies, we explicitly model patent strength as a composite index comprising the strength of the specified law, reflected in the expected recovery proportion, and the strength of enforcement, reflected in the litigation success

regardless of patent strength. Shapiro (2016) evaluates the effectiveness 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 a discussion on the relative efficiency of "lost profit" and "unjust enrichment" regimes under alternative counterfactuals and natures of innovation, see Anton and Yao (2007), Schankerman and Scotchmer (2001, 2005).

probability, to identify the effect of tighter patents on patenting, mobility and innovation[7].

The rest of the paper is organized as follows. Section 2 develops and solves the base model of innovation. Section 3 formalizes the effects of increase in patent strength on patenting, mobility, innovation profitability and R&D expenditure. Section 4 summarizes the main findings and concludes.

## 2 A Model of Innovation

We develop a model of innovation with endogenous patenting and movement following Kim and Marschke (2005). Here, innovation is certain and static. Within this framework, we additionally define the following – (i) a liability rule entailing damage recovery á la "lost profits", and (ii) an explicit measure of patent strength.

An innovating entrepreneur obtains 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 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 $\rho_i$ ($\in \mathbb{R}^+$) and $\rho_e$ ($\in \mathbb{R}$) denote the revenues accruing to the entrepreneur (innovator) and the rival firm (entrant) respectively in the second period [8]. $\rho_i$ and $\rho_e$ are random variables having joint

[7]See Papageorgiadis and Sharma (2016) for an empirical analysis of patent strength and innovation using a composite index of patent strength that comprises both stipulated law and enforcement strength.

[8]As in Kim and Marschke (2005), $\rho_i$ is the 'internal' value of the innovation and $\rho_e$ is the value of the

density $f$, which is common knowledge.

Appearance of a rival reduces the entrepreneur's second period revenue by $\lambda\rho_i$, $\lambda \in [0,1]$. Hence, at the end of the first period, the entrepreneur can choose to patent the innovation to insure herself against infringement, the nature and strength of patent laws determining expected recovery. We define the "measure of strength" of the patent system 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 $\sigma$ and the "lost profit" 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 $\sigma$ 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 section) apply to either reform of the patent system. As the damage recovery cost is borne by the infringer in case the product is patented, patenting 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 $\rho_e$ and $\rho_i$ 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 $\rho_e$ (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

scientist's knowledge to the rival, the 'external' value net of moving costs.

$\bar{w}$. Equation 1 gives the expected profit of the entrepreneur.

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

where $p$ is an indicator variable taking value 1 when the product is patented and 0 otherwise, $S$ is the set of $\rho_e$ and $\rho_i$ for which the scientist decides to stay with the entrepreneur, $M$ is the set of $\rho_e$ and $\rho_i$ for which the scientist moves to the rival and $N$ denotes the set of $\rho_e$ and $\rho_i$ for which the scientist joins a non-R&D sector[9]. The entrepreneur hires the scientist if her expected profit from the innovation project is positive. The scientist will join the entrepreneur in the first period if his total expected earnings in two periods combined exceeds his total reservation wage $2\bar{w}$. Equation 2 gives the scientist's participation constraint:

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

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 $\rho_i$ and $\rho_e$. Let $\rho_e = \bar{\rho_e} + \epsilon_e$ and $\rho_i = \bar{\rho_i} + \epsilon_i$ where $\epsilon_e$ and $\epsilon_i$ are zero

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

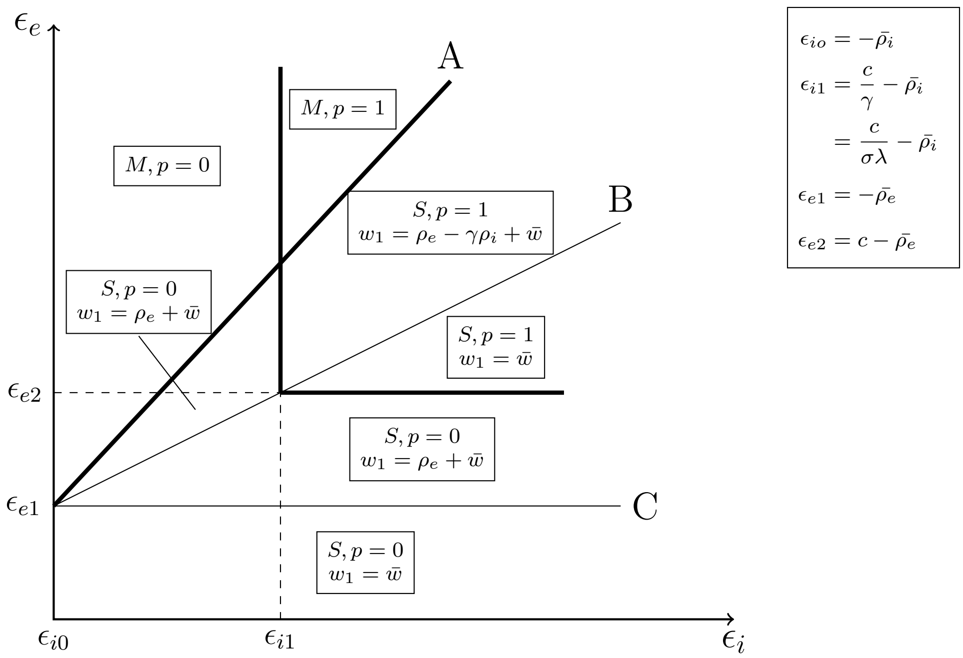


Figure 1: Mobility, Patenting and Wage Decisions

mean random variables having joint density $g$, $\bar{\rho}_e$ and $\bar{\rho}_i$ are the constant means of $\rho_e$ and $\rho_i$ respectively. Figure 1 depicts the optimal second period wage, patenting and movement decisions on the $\epsilon_i - \epsilon_e$ space. Detailed derivation of the figure is available in the appendix.

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, regardless of whether the product is patented. Hence, there is no wage at which the entrepreneur can optimally retain the scientist in the second period and the scientist moves to a rival, receiving a return of $\rho_e + \bar{w}$ ($\rho_e - \gamma\rho_i + \bar{w}$) if the product is not patented (patented). The entrepreneur patents the innovation when loss recovery due to patenting exceeds its cost. 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 entrepreneur's loss and 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 that 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 ($\rho_e$) 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. It follows, 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[10].

Substituting the optimal wage, patenting and movement decisions in (2) with equality gives the optimal first period wage $w_0$. Substituting $w_0$ in (1) gives the expression for expected profit in Lemma 1.

**Lemma 1.** *The expected profit of the entrepreneur from the innovation project is given as:*

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

**Proof.** See appendix.

[10]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 $\epsilon_i$, the scientist is more likely to move when $\epsilon_e$ is high inducing greater returns from movement. For any given $\epsilon_e$, the scientist is more likely to stay when $\epsilon_i$ is high as greater losses from movement compel the entrepreneur to retain the scientist. Further, when $\epsilon_e$ is sufficiently low, patenting does not occur for any $\epsilon_i$ because the scientist's incentive to move is negligible. When $\epsilon_i$ is sufficiently low, patenting does not occur for any $\epsilon_e$ as the entrepreneur's potential loss from movement is insignificant.

We saw that if the scientist decides to stay in period 2, the entrepreneur patents the innovation to reduce his second period wage 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 (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 her 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 (3). Finally, the fourth term represents the cost of patenting when the entrepreneur optimally decides to patent.

# 3 Stronger Patent Regime

A stronger patent regime implies higher expected amount of loss recovery from patenting for the entrepreneur in the event that a rival product appears in the market. Patent reforms aim at strengthening the patent system by not only increasing the coverage that patents provide 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).[11] Certain patent systems also allow

[11] 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

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 liability rules is undeniable.

We suppose two mechanisms for tightening indemnification laws - (i) increase in the success probability of establishing a patent in court of law making damage awards more likely, i.e. increase in $r$, and (ii) increase in the entitled restitution of the entrepreneur in case infringement is successfully established, i.e. increase in $\delta$. Accordingly, a stricter liability regime augments the measure of strength $\sigma$, thus increasing the entrepreneur's expected recovery amount $\sigma\lambda\rho_i$. As this reparation equals the reduction in revenue of the rival ($= \gamma\rho_i$), a stronger patent regime characterized by an increase in $\sigma$ also implies a proportionate increase in the recovery coefficient $\gamma$ ($\lambda$ being exogenously determined).

## 3.1 Patenting and Movement Decision

Figure 2 illustrates the effects of stronger patents on 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

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.

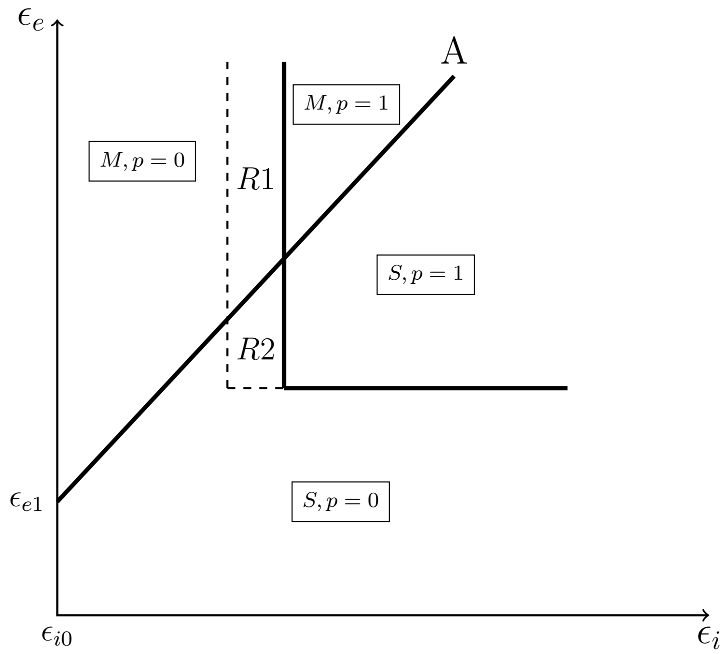


Figure 2: Effect of Stricter Patent Regime

of the entrepreneur and the scientist respectively. As $\gamma$ rises, line B (shown in Figure 1) becomes steeper and $\epsilon_{i1}$ 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 $\epsilon_e$ and $\epsilon_i$ (and thus, $\rho_e$ and $\rho_i$) for which there is a change of behaviour. As stronger patents allow 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 at a rival as the rival now has to sustain a higher reparation if the product is patented. Intuition suggests that this would discourage scientist movement and increase his propensity to stay with the entrepreneur. However, it turns out that this intuition is not correct. Greater patent strength has no effect on scientist's second period movement decision. 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 stronger patent regime on the second period patenting decision of the entrepreneur and movement decision of the scientist.*

*(i) Tightening of the patent system increases the entrepreneur's propensity to patent the innovation.*

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

**Proof.** See appendix.

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. Tightening of the regime reduces scientist's expected second period pay-off by increasing the damage liability incurred by the rival in case the innovation is patented. 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.

At this point, it is worthwhile to note an important distinction between our study and a seemingly related study by Ganco et al. (2015) who also use Kim and Marschke (2005)'s framework of innovation. They consider a firm's reputation for litigiousness as a measure of IP toughness and find that IP toughness reduces scientist mobility through increase in prospective patenting[12]. At first glance, this may seem contrary to our result in Proposition 1($ii$). However, notice that Ganco et al. (2015) define IP toughness as a firm's reputation for litigiousness whereas our paper defines patent strength as a characteristic of patent laws which is buttressed by patent reforms. Consequently, they consider litigation propensity to be exogenously given (as opposed to endogenous patenting in our model), the probability of patenting being the measure of litigiousness[13]. Introducing exogenous patenting decision in our model, we find that an exogenous increase in patenting propensity reduces mobility, which is in line with Ganco et al. (2015). Corollary 1 summarizes.

**Corollary 1.** *Exogenous increase in patenting propensity reduces scientist mobility.*

**Proof.** See appendix.

Further, Corollary 2 shows that when we consider exogenous patenting á la Ganco et al. (2015) but increase our "measure of strength" without changing the measure of firm's litigiousness, mobility falls, which is in accordance with our result in Proposition 1($ii$).

**Corollary 2.** *Increase in patent strength has no effect on scientist mobility when patenting propensity is exogenously given.*

**Proof.** See appendix.

From Corollary 1 and Corollary 2, it follows that patent toughness due to firm litigiousness

[12]Agarwal et al. (2009) and Toh and Kim (2013) discuss similar characterizations of IP toughness.

[13]Patenting propensity in our model may be interpreted as litigation propensity (given that the innovation is patented). To understand this, consider the probability of occurrence of a patent litigation:

$$P(\text{Patent litigation}) = p \cdot l$$

where $p$ and $l$ denote the propensity of patenting and litigation, respectively. Our model parameterizes patenting propensity $p$ and implicitly assumes $l = 1$ such that $P(\text{Patent litigation}) = p$. That is to say, if the entrepreneur patents the innovation, the scientist expects her to always litigate in case he infringes, and therefore makes his equilibrium choices taking into consideration the potential repercussions. Alternatively, if the innovator owns a patent with certainty implying $p = 1$, we have $P(\text{Patent litigation}) = l$ such that litigation propensity is the parameter, as in Ganco et al. (2015).

affects scientist mobility differently as compared to that due to patent reforms. Thus, extending our model to include Ganco et al. (2015)'s framework of exogenous patenting helps us generalize our result in Proposition 1($ii$), as Corollary 3 delineates.

**Corollary 3.** *Strengthening of the patent regime is inefficacious in deterring mobility regardless of whether patenting propensity is exogenously given or endogenously determined.*

**Proof.** Follows directly from Proposition 1 and Corollary 2.

## 3.2 Profitability and R&D Expenditure

A stronger patent regime aims to protect innovations from infringement and encourage R&D activities. Increase in loss recovery due to stronger patents 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 innovating entrepreneur decreases with an increase in patent strength. The following proposition formalizes the effect of stronger patents on the entrepreneur's profitability.

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

**Proof.** See appendix.

To understand the result, notice 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 a stronger patent regime increases expected recovery cost of the rival thereby reducing the scientist's expected pay-off, the first period wage must rise. Now, given a higher first period wage, when the second period arrives it is optimal for the entrepreneur to patent more frequently. It turns out, 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 ($c > 0$), greater patenting activity in the second period increases total cost of patenting incurred by the entrepreneur. Thus, the combined effect of stronger patents on the entrepreneur's expected profitability 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 as the total wage bill remunerated to the scientist.

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

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 stronger patents 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 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 $\sigma$ (and therefore, $\gamma$) 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 Conclusion

This paper studies the issue of patent strength in presence of probabilistic patents or partial recovery guarantee when an innovating firm encounters threat of infringement from its own research aid. 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 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[14]. 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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[14]The general form of the damage function can be written as:

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

where $\sigma$ 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

## 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 $\epsilon_i \geq \frac{c}{\sigma\lambda} - \bar{\rho}_i \implies \epsilon_i \geq \frac{c}{\gamma} - \bar{\rho}_i$. 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. ■

## Proof of Proposition 1

We assume $\epsilon_e$ and $\epsilon_i$ are independent normally distributed random variables with $\epsilon_e \sim \mathcal{N}(0,\, \sigma_e^2)$ and $\epsilon_i \sim \mathcal{N}(0,\, \sigma_i^2)$.

$$\therefore \epsilon_e - \lambda\epsilon_i \sim \mathcal{N}(0,\, \sigma_e^2 + \lambda^2\sigma_i^2)$$

**(i) Effect of a Stricter Patent Regime on Patenting Behavior**

Patenting occurs when $\sigma\lambda\rho_i (= \gamma\rho_i) \geq c$ given that $\rho_e > \gamma\rho_i$ or when $\rho_e \geq c$ given that $0 < \rho_e \leq \gamma\rho_i$. When $\rho_e \leq 0$, patenting never occurs. There is no other case in which patenting occurs. Accordingly, the probability of patenting is:

$$\begin{aligned} P(p=1) &= P(\gamma\rho_i \geq c \,\big|\, \rho_e > \gamma\rho_i) + P(\rho_e \geq c \,\big|\, 0 < \rho_e \leq \gamma\rho_i) \\ &= P(\gamma\bar{\rho}_i + \gamma\epsilon_i \geq c \,\big|\, \epsilon_e > \gamma\bar{\rho}_i + \gamma\epsilon_i - \bar{\rho}_e) \\ &\qquad + P(\epsilon_e \geq c - \bar{\rho}_e \,\big|\, -\bar{\rho}_e < \epsilon_e \leq \gamma\bar{\rho}_i + \gamma\epsilon_i - \bar{\rho}_e) \end{aligned} \qquad \texttt{(i)}$$

The first term of equation `(i)` gives:

$$P\left(\epsilon_i \geq \frac{c}{\gamma} - \bar{\rho}_i \,\middle|\, \epsilon_e > \gamma\bar{\rho}_i + \gamma\epsilon_i - \bar{\rho}_e\right) = \frac{P(\epsilon_e > \gamma\bar{\rho}_i + \gamma\epsilon_i - \bar{\rho}_e \,\cap\, \epsilon_i \geq \frac{c}{\gamma} - \bar{\rho}_i)}{P(\epsilon_e > \gamma\bar{\rho}_i + \gamma\epsilon_i - \bar{\rho}_e)}$$

We write,

$$T_1 = \frac{P_{N1}}{P_{D1}}$$

where $P_{N1}$ and $P_{D1}$ denote the numerator and denominator, respectively, of the first term $T_1$.

$$\begin{aligned} \text{Numerator, } P_{N1} &= P(\epsilon_e > \gamma\bar{\rho}_i + \gamma\epsilon_i - \bar{\rho}_e \,\cap\, \epsilon_i \geq \frac{c}{\gamma} - \bar{\rho}_i) \\ &= P\left(\epsilon_e \geq \gamma\bar{\rho}_i + \gamma\left[\frac{c}{\gamma} - \bar{\rho}_i\right] - \bar{\rho}_e\right) \\ &= P(\epsilon_e \geq c - \bar{\rho}_e) \\ &= P\left(\frac{\epsilon_e}{\sigma_e} \geq \frac{c - \bar{\rho}_e}{\sigma_e}\right) \\ &= \Phi\left(-\frac{c - \bar{\rho}_e}{\sigma_e}\right) \end{aligned}$$

Differentiating $P_{N1}$ with respect to $\gamma$ yields:

$$\frac{\partial P_{N1}}{\partial \gamma} = 0 \tag{i.a}$$

Denominator, $P_{D1} = P(\epsilon_e > \gamma\bar{\rho}_i + \gamma\epsilon_i - \bar{\rho}_e)$

$$= P(\epsilon_e - \gamma\epsilon_i > \gamma\bar{\rho}_i - \bar{\rho}_e)$$

$$= P\left(\frac{\epsilon_e - \gamma\epsilon_i}{\sqrt{\sigma_e^2 + \gamma^2\sigma_i^2}} > \frac{\gamma\bar{\rho}_i - \bar{\rho}_e}{\sqrt{\sigma_e^2 + \gamma^2\sigma_i^2}}\right)$$

$$= \Phi\left(-\frac{\gamma\bar{\rho}_i - \bar{\rho}_e}{\sqrt{\sigma_e^2 + \gamma^2\sigma_i^2}}\right)$$

Differentiating $P_{D1}$ with respect to $\gamma$ yields:

$$\frac{\partial P_{D1}}{\partial \gamma} = \phi(.).\left[-\left\{\frac{\sqrt{\sigma_e^2 + \gamma^2\sigma_i^2}.(\bar{\rho}_i - (\gamma\bar{\rho}_i - \bar{\rho}_e).\frac{1}{2}(\sigma_e^2 + \gamma^2\sigma_i^2)^{-\frac{1}{2}}.\sigma_i^2.2\gamma}{\sigma_e^2 + \gamma^2\sigma_i^2}\right\}\right]$$

$$= -\phi(.)\left[\frac{\sigma_e^2\bar{\rho}_i + \sigma_i^2\gamma\bar{\rho}_e}{(\sigma_e^2 + \gamma^2\sigma_i^2)^{\frac{3}{2}}}\right] < 0 \tag{i.b}$$

Now, differentiating $T_1$ with respect to $\gamma$ yields:

$$\frac{\partial T_1}{\partial \gamma} = \frac{P_{D1}.\frac{\partial P_{N1}}{\partial \gamma} - P_{N1}.\frac{\partial P_{D1}}{\partial \gamma}}{(P_{D1})^2}$$

$$= -\frac{P_{N1}}{(P_{D1})^2}.\frac{\partial P_{D1}}{\partial \gamma} > 0\,, \tag{ii}$$

$\because \frac{\partial P_{N1}}{\partial \gamma} = 0$ by (i.a) and $\frac{\partial P_{D1}}{\partial \gamma} < 0$ by (i.b).

The second term of equation (i) gives:

$$P\left(\epsilon_e \geq c - \bar{\rho}_e \middle| -\bar{\rho}_e < \epsilon_e \leq \gamma\bar{\rho}_i + \gamma\epsilon_i - \bar{\rho}_e\right) = \frac{P(-\bar{\rho}_e < \epsilon_e \leq \gamma\bar{\rho}_i + \gamma\epsilon_i - \bar{\rho}_e \ \cap \ \epsilon_e \geq c - \bar{\rho}_e)}{P(-\bar{\rho}_e < \epsilon_e \leq \gamma\bar{\rho}_i + \gamma\epsilon_i - \bar{\rho}_e)}$$

We write,

$$T_2 = \frac{P_{N2}}{P_{D2}}$$

where $P_{N2}$ and $P_{D2}$ denote the numerator and denominator, respectively, of the second term $T_2$.

Numerator, $P_{N2} = P(-\bar{\rho}_e < \epsilon_e \leq \gamma\bar{\rho}_i + \gamma\epsilon_i - \bar{\rho}_e \ \cap \ -\bar{\rho}_e + c \leq \epsilon_e)$

$$= P(-\bar{\rho}_e + c \leq \epsilon_e \leq \gamma\bar{\rho}_i + \gamma\epsilon_i - \bar{\rho}_e)$$
$$= P(\epsilon_e \leq \gamma\bar{\rho}_i + \gamma\epsilon_i - \bar{\rho}_e) - P(\epsilon_e < -\bar{\rho}_e + c)$$
$$= P(\epsilon_e - \gamma\epsilon_i \leq \gamma\bar{\rho}_i - \bar{\rho}_e) - P(\epsilon_e < -\bar{\rho}_e + c)$$
$$= \Phi\left(\frac{\gamma\bar{\rho}_i - \bar{\rho}_e}{\sqrt{\sigma_e^2 + \gamma^2\sigma_i^2}}\right) - \Phi\left(\frac{c - \bar{\rho}_e}{\sigma_e}\right)$$

Differentiating $P_{N2}$ with respect to $\gamma$ yields:

$$\frac{\partial P_{N2}}{\partial \gamma} = \phi(.).\left[\frac{\sqrt{\sigma_e^2 + \gamma^2\sigma_i^2}.(\bar{\rho}_i - (\gamma\bar{\rho}_i - \bar{\rho}_e).\frac{1}{2}(\sigma_e^2 + \gamma^2\sigma_i^2)^{-\frac{1}{2}}.\sigma_i^2.2\gamma}{\sigma_e^2 + \gamma^2\sigma_i^2}\right] - \phi(.).[0]$$
$$= \phi(.).\left[\frac{\sigma_e^2\bar{\rho}_i + \sigma_i^2\gamma\bar{\rho}_e}{(\sigma_e^2 + \gamma^2\sigma_i^2)^{\frac{3}{2}}}\right] > 0 \qquad \texttt{(i.c)}$$

Denominator, $P_{D2} = P(-\bar{\rho}_e < \epsilon_e \leq \gamma\bar{\rho}_i + \gamma\epsilon_i - \bar{\rho}_e)$

$$= P(\epsilon_e - \gamma\epsilon_i \leq \gamma\bar{\rho}_i - \bar{\rho}_e) - P(\epsilon_e \leq -\bar{\rho}_e)$$
$$= \Phi\left(\frac{\gamma\bar{\rho}_i - \bar{\rho}_e}{\sqrt{\sigma_e^2 + \gamma^2\sigma_i^2}}\right) - \Phi\left(\frac{-\bar{\rho}_e}{\sigma_e}\right)$$

Differentiating $P_{D2}$ with respect to $\gamma$ yields:

$$\frac{\partial P_{D2}}{\partial \gamma} = \phi(.).\left[\frac{\sigma_e^2\bar{\rho}_i + \sigma_i^2\gamma\bar{\rho}_e}{(\sigma_e^2 + \gamma^2\sigma_i^2)^{\frac{3}{2}}}\right] > 0 \qquad \texttt{(i.d)}$$

Now, differentiating $T_2$ with respect to $\gamma$ yields:

$$\frac{\partial T_2}{\partial \gamma} = \frac{P_{D2}.\frac{\partial P_{N2}}{\partial \gamma} - P_{N2}.\frac{\partial P_{D2}}{\partial \gamma}}{(P_{D2})^2}$$

From `(i.c)` and `(i.d)`, we see that $\frac{\partial P_{N2}}{\partial \gamma} = \frac{\partial P_{D2}}{\partial \gamma}$. Further, notice that the range of $\epsilon_e$ implied in $P_{N2}$ is a subset of the range of $\epsilon_e$ implied in $P_{D2}$. $\therefore P_{N2} < P_{D2}$. Thus,

$$P_{N2}.\frac{\partial P_{D2}}{\partial \gamma} < P_{D2}.\frac{\partial P_{N2}}{\partial \gamma}$$
$$\implies P_{D2}.\frac{\partial P_{N2}}{\partial \gamma} - P_{N2}.\frac{\partial P_{D2}}{\partial \gamma} > 0$$
$$\therefore \frac{\partial T_2}{\partial \gamma} > 0 \qquad \texttt{(iii)}$$

Consolidating, we have:

$$P(p=1) = T_1 + T_2 \qquad \text{by } \texttt{(i)}$$
$$\frac{\partial P(p=1)}{\partial \gamma} = \frac{\partial T_1}{\partial \gamma} + \frac{\partial T_2}{\partial \gamma} > 0 \qquad \text{by } \texttt{(ii)} \text{ and } \texttt{(iii)}$$

Hence, the proof. ■

**(ii) Effect of a Stricter Patent Regime on Movement Behavior**

Movement occurs when $\rho_e > \lambda\rho_i \implies \epsilon_e > \lambda\bar{\rho}_i - \bar{\rho}_e + \lambda\epsilon_i$. Accordingly, the probability of movement is:

$$\begin{aligned} P(M) &= P(\epsilon_e - \lambda\epsilon_i > \lambda\bar{\rho}_i - \bar{\rho}_e) \\ &= P\left(\frac{\epsilon_e - \lambda\epsilon_i}{\sqrt{\sigma_e^2 + \lambda^2\sigma_i^2}} > \frac{\lambda\bar{\rho}_i - \bar{\rho}_e}{\sqrt{\sigma_e^2 + \lambda^2\sigma_i^2}}\right) \\ &= \Phi\left(-\frac{\lambda\bar{\rho}_i - \bar{\rho}_e}{\sqrt{\sigma_e^2 + \lambda^2\sigma_i^2}}\right) \end{aligned}$$

An increase in patent strength ($\sigma$), induced by an increase in litigation success probability ($r$) or recovery proportion ($\delta$) or both, implies an increase in the recovery coefficient ($\gamma$). It is evident that $\frac{\partial P(M)}{\partial \gamma} = 0$. Hence, the proof. ■

## Proof of Corollary 1

Let $p$ be the exogenously given probability with which the innovating entrepreneur patents the innovation.

Entrepreneur's expected loss from movement:

$$\bar{w} + \lambda\rho_i - p.(\sigma\lambda\rho_i) + p.c$$

where $\lambda\rho_i$ is the total loss if movement occurs and $\sigma\lambda\rho_i$ is the recovery from patenting. $c$ is the cost of patenting.

Scientist's expected return from movement:

$$\bar{w} + \rho_e - p.(\sigma\lambda\rho_i)$$

where $\rho_e$ is the return at a rival and $\sigma\lambda\rho_i$ is the damage cost borne in case the innovation is patented.

Movement occurs when scientist's expected gain from movement exceeds entrepreneur's potential loss due to movement:

$$\bar{w} + \rho_e - p.(\sigma\lambda\rho_i) > \bar{w} + \lambda\rho_i - p.(\sigma\lambda\rho_i) + p.c$$
$$\implies \rho_e > \lambda\rho_i + p.c$$
$$\implies \epsilon_e > \lambda\bar{\rho_i} + \lambda\epsilon_i + p.c - \bar{\rho_e} \qquad \texttt{(iv)}$$

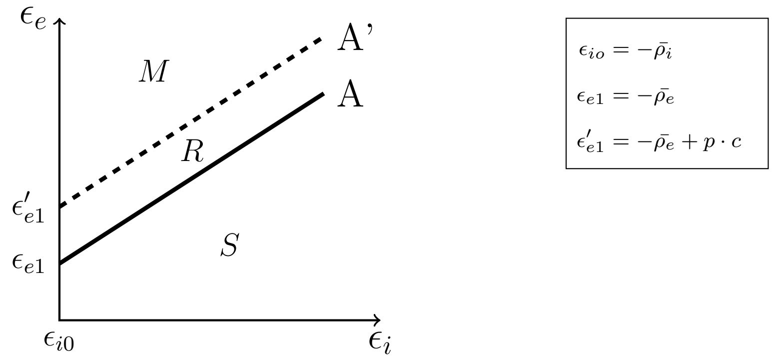


Figure A.1: Movement Decision under Exogenous Patenting Propensity

In Figure A.1, line A defines the boundary for movement decision in `(iv)` at $p = 0$. This corresponds to line A in Figure 1, which determines movement behavior under endogenous patenting decision. Increase in $p$ shifts line A in Figure A.1 up, to line A', say, thereby reversing movement decision in region $R$. Therefore, an exogenous increase in patenting propensity deters scientist mobility in region $R$. Hence, the proof. ■

## Proof of Corollary 2

It directly follows from the determining condition for mobility in `(iv)` that an increase in patent strength ($\sigma$), induced by an increase in litigation success probability ($r$) or recovery proportion ($\delta$) or both does not alter mobility when patenting propensity is exogenously given. ■

## 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 $\gamma$ yields:

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

Differentiating the second term with respect to $\gamma$ yields:

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

Similarly, differentiating the third term with respect to $\gamma$ yields:

$$\frac{c}{\gamma^2}\int_{-\infty}^{c-\bar{\rho}_e}\frac{c}{\gamma}g(\epsilon_e,\frac{c}{\gamma}-\bar{\rho}_i)\,d\epsilon_e \tag{vii}$$

Differentiating the fourth term with respect to $\gamma$ yields:

$$\frac{c}{\gamma^2}\int_{c-\bar{\rho}_e}^{\frac{c}{\sigma}-\bar{\rho}_e}\frac{c}{\gamma}g(\epsilon_e,\frac{c}{\gamma}-\bar{\rho}_i)\,d\epsilon_e \tag{viii}$$

Differentiating the fifth term with respect to $\gamma$ yields:

$$-\frac{c}{\gamma^2}\int_{\frac{c}{\sigma}-\bar{\rho}_e}^{\infty}[\bar{\rho}_e+(1-\lambda)\frac{c}{\gamma}+\epsilon_e]g(\epsilon_e,\frac{c}{\gamma}-\bar{\rho}_i)\,d\epsilon_e \tag{ix}$$

Differentiating the sixth term with respect to $\gamma$ yields:

$$\frac{c}{\gamma^2}\int_{\frac{c}{\sigma}-\bar{\rho}_e}^{\infty}[\bar{\rho}_e+(1-\lambda)\frac{c}{\gamma}+\epsilon_e]g(\epsilon_e,\frac{c}{\gamma}-\bar{\rho}_i)\,d\epsilon_e \tag{x}$$

Differentiating the seventh term with respect to $\gamma$ yields:

$$-\frac{c}{\gamma^2}\int_{c-\bar{\rho}_e}^{\infty}cg(\epsilon_e,\frac{c}{\gamma}-\bar{\rho}_i)\,d\epsilon_e \tag{xi}$$

It can be easily seen that (v) + (vi) + (vii) + (viii) + (ix) + (x) = 0 and (xi) < 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 $\gamma$ yields:

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

Differentiating the second term with respect to $\gamma$ yields:

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

Similarly, differentiating the third term with respect to $\gamma$ yields:

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

Combining `(xii)`, `(xiii)` and `(xiv)`:

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

The above expression is positive. Hence the proof. ■