Signaling Role of Patenting Decisions

by

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Signaling Role of Patenting Decisions

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[To my dear family]

ABSTRACT

Signaling Role of Patenting Decisions
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This thesis analyzes a strategic environment in which firms compete under simultaneous innovation and choose between filing a patent and relying on secrecy to protect their intellectual property. We build a theoretical model in which an inventor is essential to production and the inventor's ability is the key determinant of his or her productivity. Under full information, in which firms observe each other's innovation output and the inventor's ability, they opt for patenting and there is turnover only when the inventor has low ability. Incorporating informational asymmetry when firms have simultaneous innovation with certainty leads to an equilibrium in which the incumbent has incentives to distort optimal patent filing decision. The incumbent firm does not file a patent to avoid losing the inventor to the competitor and paying higher retention wages, whereas the competitor is granted a patent but cannot transfer knowledge. Our results indicate that under asymmetric information firms are more likely to patent their innovation under strong property rights, weaker rivalry, and higher monopoly profit. By contrast, higher ability difference between the inventor types is more important on turnover and choosing secrecy as the protection mechanism. When simultaneous innovation is possible but not definite, we find a threshold of simultaneous innovation probability over which firms choose to file a patent. This threshold increases with stronger property rights, higher monopoly profits and lower duopoly profits. Also, assuming a 0.5 ratio between duopoly and monopoly profits, we show that firms file a patent when simultaneous innovation occurs at a rate that is higher than the lost profit due to revealing information with patents.

ÖZETÇE

Patent Kararlarının İşaret Etme Rolü
A.Burak Küçük
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Bu tez, firmaların eş zamanlı yenilik altında rekabet ettiği ve sınai mülkiyetini korumak için patent başvurusu yapma veya gizliliğe güvenme arasında seçim yaptığı stratejik bir ortamı analiz etmektedir. Bir mucitin üretim için esas olduğu ve mucitin yeteneğinin üretimin ana belirleyeni olan teorik bir model oluşturuyoruz. Firmaların birbirlerinin yenilik çıktılarını ve mucidin yeteneğini gözlemlediği tam bilgi altında, firmalar dengede patent başvurusu yapmaya karar verirler ve mucitin rakip firmaya geçmesi yalnızca düşük yeteneğe sahip olduğu durumda meydana gelir. Firmaların eşzamanlı yenilik yapması mutlak olduğu durumda bilgi asimetrisini dahil etmek, mucitin çalıştığı firmanın optimal patent başvurusu yapma kararını bozmasına sebep olacak teşviklere sahip olduğu bir dengeye yol açar. Bu firma, mucidi rakibe kaybetmemek ve daha yüksek işte tutma ücretleri ödememek için bir patent başvurusu yapmazken, rakip firma bir patente sahip olur ancak bilgi transferini sağlayamaz. Sonuçlarımız, asimetrik bilgi altında firmaların güçlü mülkiyet hakları, zayıf rekabet ve yüksek tekelleşme kârları ile inovasyonlarını daha olası bir şekilde patentlemeye eğilimli olduğunu göstermektedir. Buna karşılık, mucid türleri arasındaki yüksek yetenek farkının iş değişikliği ve koruma mekanizması olarak gizliliği seçmede daha önemli olduğunu belirtiyoruz. Eş zamanlı yenilik mümkün ancak kesin olmadığında, firmaların bir patent başvurusu yapmayı tercih ettiği eş zamanlı yenilik olasılığı için bir eşik belirliyoruz. Bu eşik, güçlü mülkiyet hakları, yüksek tekelleşme karları ve düşük tekel karları ile artıyor. Ayrıca, tekel ve ikili tekel karları arasındaki oranın 0.5 olduğunu varsayarak, her ne zaman firmaların patent başvurusu yapma eşiği patentler aracılığıyla açığa çıkan bilgiden kaynaklanan kayıp karın üzerindeyse, firmaların bu durumda patent başvurusu yaptığını gösteriyoruz.

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Chapter 1

INTRODUCTION

This paper examines the incentives of firms to distort their intellectual property (IP) protection choices by focusing on certain characteristics of patents. First, patents provide valuable information about the inventors, acting as signals of their abilities. Second, patents reveal information about the innovation itself, giving firms a competitive advantage by impeding others from using the same advancements. Based on legal grounds, patents are public information, which makes them easily (and to some extent freely) accessible. Following this, patents can as well be used as a source of information about the inventor. We exploit this characteristic of patents as signals about the inventors. Moreover, patents reveal information about the innovation by outlining the key advancements that are to be legally protected. Firms in a market that can produce similar (or same) innovations have an additional incentive for patenting since other parties are impeded from using the same advancements, at least to some extent, when a firm is granted a patent. In this context, we focus on two sides of patents. On one hand, patents are informative about their inventors, and this is not always favored by firms since they risk losing their human capital, in other words, inventors. On the other hand, patents provide legal protection in case of simultaneous innovation. We focus on this trade-off faced by innovative firms.

Our approach coincides with some of those in the labor economics literature examining promotions. Specifically, we use the idea that job allocations and promotions act as signals of workers' abilities. In his seminal work, Waldman (1984) builds a model in which firms are allowed to assign their workers to jobs; and rival firms use those job allocations as signals about the workers. The paper also shows under certain assumptions, firms have incentives to inefficiently assign workers to jobs so that they do not have to pay higher wages to a worker whenever turnover is costly. Similarly, we focus on the signaling role of patents and build a model which shows that firms do not always file a patent since patents reveal the ability level of the inventor and may require higher wages, especially when turnover is costly.

On the other hand, patents provide a precautionary guard to firms in case their rivals produce a similar innovation. Our understanding here coincides with that of Kultti et al. (2007) in the sense that firms believe that there is simultaneous innovation at a certain rate, and in such a case, at most one firm is granted a patent. Therefore, firms are encouraged to protect their intellectual property by filing a patent before their rivals do so, whereas being granted a patent is a threat to firms since patents (possibly) reveal valuable information about inventors.

Focusing on this trade-off, we first build a benchmark model in which there is simultaneous innovation by two firms;and there is no information asymmetry. As expected, this benchmark model illustrates the positive sides of filing a patent since firms cannot reveal additional information by filing a patent. Hence, filing a patent is a dominant strategy for firms in the benchmark. Second, we add asymmetric information to the model and let the incumbent firm send a signal of the inventor ability by choosing whether to file a patent or not. In this case, we find equilibrium conditions that lead to different results; some assumptions lead to the results where firms have incentives to distort their patent filing decisions compared to the benchmark. Following this, we shortly explore the benchmark model when simultaneous innovation is possible but not definite. Our results from this model suggests that strong property rights, more likely simultaneous innovation, and higher monopoly profits are associated with filing a patent, whereas weaker property rights and greater loss on profits by revealing information are associated with firms' choosing to rely on secrecy to protect their intellectual property. We also show that, by assuming a 0.5 profit ratio between duopoly and monopoly profits, firms file a patent whenever simultaneous innovation occurs at a rate that is higher than the lost profit due to revealing information with patents. We discuss the limitations of the paper and propose implications to test our model with real data. Finally, we build an extension of the model in which the incumbent ex ante commits to file a patent and its production depends on the effort level chosen by the inventor. We show that under some assumptions, ex ante commitment to patents leads to inefficient results due to turnover. We conclude the paper by outlining the key results, future research directions, and some unaddressed questions.

The rest of the paper is organized as follows. In section 2, we discuss the related literature. In section 3, we present and analyze our main model. In section 4, we discuss the limitations of our model and propose some implications to test it. In section 5, we build an extension of the model with ex ante commitment to filing a patent. In section 6, we conclude the paper.

Chapter 2

RELATED LITERATURE

Property rights apply to a large set of properties, including any type of “formal” intellectual property (IP) which can be summarized under trade secrets, copyrights, and patents. Unlike physical properties, IPs are quite sensitive to the limits of their use and the extent of protection defined by law, as this type of properties mainly consist of breakthrough information, valuable knowledge; thus, it is harder to protect an IP without depending on court action. Therefore, it is inevitable that law has a critical role when IP owners choose a type of protection. Hypothetically, the boundaries defined by law is a result of a joint agreement; hence, it must be for the good of the society, or at least for the good of the majority who came to agreement for the rule of law. However, it is open to debate that the extent of IP rights brought with patents, and similarly copyrights, grant a legal monopoly to the owner. While this gives incentives for the future inventions, it may be detrimental for the competition. Once a firm is granted a patent, other firms may be further discouraged from competition and hence they may draw back from investing in R&D.

When firms decide on how to protect their IP, their priority is to maximize the benefit from a given innovation. Hence, they choose the protection mechanism that makes them more appropriative considering the legal environment, the extent of the innovation, competition in the market and many other factors that may directly or indirectly affect their profits. In such an environment, firms commonly have two choices; they either protect the innovation through patents or choose to rely on secrecy.

Anton and Yao (2004) model the choice between secrecy and patents with a trade-off in which firms must disclose some information about their innovation to signal their competitiveness while disclosing information leads to an imitation threat. Their model leads to a result in which the size of an innovation has an impact on which protection mechanism is chosen. More specifically, small and medium size innovations are patented whereas larger innovations are mostly protected by secrecy. A key part of their model is the level of property rights which represent the legal protection provided by patents, as expected, stronger property rights are associated with higher incentives for patenting. This result is consistent with the work by Horstman et al. (1985), who show that patenting occurs when the imitation is not profitable or when the imitation is profitable but product differentiation is not likely.

Another investigation on why firms do not always patent their innovations is conducted by Kwon (2012), in which they show stronger protection can still decrease firms' incentive to innovate, even when stronger protection makes firms more likely to patent their innovations. This result is consistent with some empirical evidence. For example, Arundel and Kabla (1998) find that two out of three firms rely on secrecy among 604 European firms. In addition, Cohen et al. (2000) report that regardless of the innovation type, firms' propensity to patent an innovation is not greater than 50%. This evidence is counterintuitive in the sense that legal monopoly granted by patents and protected by courts must be less attractive to firms than relying on secrecy in which case almost no court action is possible in case the of infringement. However, this supports the consensus in the literature that secrecy usually provides more protection than patents, as patents disclose information about an innovation and makes imitation more feasible. This is especially important for the future of patent policy, some explanation may lie in understanding the required time for detecting and punishing infringement as it may be costlier for firms than the expected protection provided by patents, the patent policy may not be strict enough for infringement and reverse engineering always remains as a threat.

Following the statements above, a counter argument could be why firms patent their innovation when secrecy provides more protection. As in Anton and Yao (2004), the explanation can be the positive signaling impact of patents, by which firms can threat their competitors, make them produce less and increase their market share. However, it may not always be the case in which firms choose production levels with respect to their competitors' cost.

Another explanation by Kultti et al. (2007) touches on simultaneous innovations. In such a setup, firms are likely to end up with the same innovation and there is a competition over patents. Their model is intuitive and follows the tradeoff that multiple innovators of the same innovation is possible and if a firm does not patent an innovation, it takes the risk that another competitor can patent it, whereas the firm discloses information with patents and usually bear weaker protection under patents compared to secrecy. Assuming the simultaneous innovations are likely to occur, their model clearly shows why firms choose patents even when secrecy provides more protection.

While the simultaneous innovations may be counterintuitive for most firms or industries, a similar argument can be made by relying on complementary innovations. Such a setup exists in Bessen and Maskin (2009) and by Hall and Ziedonis (2001). The basic intuition is that with complementary or cumulative innovations, a firm's patent can create a hold-up effect by substantially deterring the value of the complementary patents granted to other firms. Hence, this may be another reason why firms choose patents over secrecy, by which they can secure their competitive advantage over the competitors. However, this intuition combined with weaker patent protection also features decreasing level of R&D investment since firms are discouraged from investing more easily.

Another perspective to IP protection mechanism choice relates to knowledge transfer and efficiency problem. When firms patent their innovation, they bear a cost due to disclosing information. However, in a way, they make sure that their knowledge is not directly transferable due to legal barriers. A related work by Kim and Marschke (2005) investigates how firms' patenting decisions can be explained with a risk of departure by their scientists. In their work, they model firms' patenting decision as a protection mechanism towards their own employees, patents decrease the value of the innovation outside of the innovator firm, hence, patents decrease the inventor's incentive to move to a competitor by limiting the total value of knowledge transfer thanks to legal protection. This setup is especially important for understanding how more efficient IP choice could be without loyalty problems and how departure threat of inventors may deter the total exploitation from an innovation. A similar work by Agarwal et al. (2009) shows that when firms have higher reputation for being tough towards litigation, the departure of inventors create less spillovers for other firms as well. Hence, firms' standing towards their own innovation may also be determining how feasible knowledge transfer within firms due to departure of inventors can be. Schneider (2008) argues that patents discloses information which makes it feasible for other firms to patent a sequential innovation, hence, make a profit, however, similar to Anton and Yao (2004), they also argue that patents add value to the firm by signaling competitiveness. Therefore, innovation being more likely to be sequential is also another important aspect of firms' IP protection mechanism choice.

Even though the contractual problems are hard to overcome as non compete agreements are usually seen as a barrier for an employee to secure a job, and trade secret laws are hard to implement, patents remain as the strongest formal IP choice of firms other than relying on secrecy. Works by Scotchmer and Green (1990) and Gallini (1992) are also cited in patent vs secrecy articles, however, these works lack incomplete information as a patent discloses the information fully, and the authors mainly look for implications of the patent policy on incentives to file a patent. Survey by Hall et al. (2014) supports the claims that secrecy is preferred more often by firms by showing evidence that only a small fraction of innovative companies use formal IP protection mechanisms, and they mostly rely on secrecy instead of patents.

In summary, firms' IP protection mechanism choice is an outcome of many variables such as the extent of property rights and legal protection, type of an innovation in the sense that whether it being simultaneous/complementary/sequential or a single innovation, possibility of knowledge transfer and imitation threat, the extent of positive impact of patents by signaling the competitiveness of a firm (especially by signaling very low cost of production to other firms which mainly gives the inventor firm a competitive advantage over the rivals), the relative cost of patenting/secrecy. While the patenting decision is not limited to these factors mentioned above, they are the main ones investigated in the related articles. In the literature, there is almost an unarguable consensus that patents disclose information and secrecy provides more protection compared to patents, however, some papers explain partially why firms still choose to disclose information by choosing a weaker protection with patents. While disclosing information may be beneficial to the society along the lines of some related articles investigating Open Science, it may not be favorable by firms, especially in the short run. Hence, applying the Open Science to firms' IP protection choice may provide only limited interpretation as the incentives to disclose differ significantly between firms and individuals.

Although some papers explain why firms choose patents, the arguments can still not be generalized and apply to all firms. While some firms choose to file a patent due to sequential innovation or the value created by the signaling impact of patents, some other firms may still favor patents for unexplained reasons. Hence, in this paper, we try to bring a new perspective to why firms may not always favor patents, focusing on the importance of an inventor's ability and the possibility of simultaneous innovation. For the base of the model, we slightly borrow from Kultti et al. (2007), disregarding the partial protection of IP protection mechanisms, and we believe the rest is original work.

Chapter 3

MODEL

In this section, we build a theoretical framework in which patents reveal information about an inventor's ability. Then, we present the model and analyze it under full information (benchmark model) and under asymmetric information. We propose our solution concepts and assumptions separately in each subsection.

3.1 General Setup

We consider a two-period model with one inventor and many firms, with our primary focus on firms A and B. Firm A is unique in that its production is endogenous, while firm B represents the rest of the market where production is drawn from a set with respect to a function g (further assumptions on this will be made later). In other words, the market consists of firms A, B, and infinitely many other firms that are identical to firm B. The competition in this market is centered around the production of an innovation, which carries a certain value impacting their sales in the first period (product market) and its implementation in the second period (innovation market). The details of the innovation market will be discussed in the subsequent paragraphs.

Firms A and B produce the same innovation with probability $\beta \in [0, 1]$. In this scenario, simultaneous innovation refers to only one party (one firm in this case) being legally entitled to claim an innovation as their intellectual property, as firms' innovations are not distinct enough to be granted separate legal entitlements.

Firm A employs an inventor at the beginning of period 1. The inventor can be of type H or of type L, where type H represents an inventor with the ability level θ_H and type L represents an inventor with the ability level θ_L. We assume 1 >

$\theta_H > \theta_L > 0$ and we treat ability as a normalized probability that an inventor successfully implements a project in the second period. The project in the second period is related to the innovation produced in the first period.

In period 1 both firms produce an innovation which has a value. Firm A produces $V_i \in \{V_L, V_H\}$, where i is the ability level of the inventor. Firm B's production is denoted by $\bar{V}$ which is exogenous and drawn from $\bar{V} \in [V_L, V_H]$. V_i is the value of the innovation and determines the size of the market; hence, all profits are multiplied by this.

After this, firms choose to rely on secrecy or file a patent, where secrecy is denoted by $s_j = 1$ and patening by $s_j = 0$. In case both firms file a patent, each is granted a patent with equal probabilities. A patent grants a monopoly at the rate $\alpha \in (0, 1)$. Consistent with the literature patents do not provide full protection, thus, we restrict α to be strictly between 0 and 1. For instance, even when a firm is granted a patent, it receives monopoly profit at the rate α and duopoly profit at the remaining rate $1 - \alpha$. A firm receives duopoly profit at the rate $1 - \alpha$ if the rival is granted a patent. If neither is granted a patent, they share duopoly profits. We provide net payoffs for all possible cases on the next page.

Observing the patent realizations, firms have the option to extend an offer to the inventor. The offer of firm j to the inventor with ability level i is denoted by w_i^j. The firm who employs the inventor in the second period receives an additional profit equal to the ability level of the inventor; this is due to capturing human capital. Firms are risk neutral. See Appendix B for a detailed discussion on this.

In the subsequent subsections, we provide details for the timing, information structure, and other assumptions for the full information benchmark and asymmetric information cases.

3.2 *Simultaneous Innovation with* $\beta = 1$

3.2.1 Full Information Benchmark

We begin by analyzing the model under full information. In this setup, we assume that the type of the inventor and the innovation value of firms A and B are common knowledge. As a result, wages will be type-specific, where firm j extends a wage offer w_i^j to inventor i. However, to be consistent with the asymmetric information setup, we will still assume a common prior p , such that the probability of the inventor being of type H is denoted by $\Pr\{\theta_i = \theta_H\} = p$. Under the full information benchmark, $p = 1$ if the inventor is of type H and $p = 0$ otherwise.

Definition 1. An equilibrium for the full information benchmark game under simultaneous innovation with $\beta = 1$ is the tuple $(w_H^A, w_L^A, w_H^B, w_L^B, s_H^A, s_L^A, s^B(\bar{V}))$ where

i. $(w_H^A, w_L^A, w_H^B, w_L^B) \in R_+^4$ is the set of wages extended to inventor $i \in \{H, L\}$ by firm $j \in \{A, B\}$,

ii. $(s_H^A, s_L^A) \in \{0,1\}^2$ is the of patenting decision of firm A with the inventor i of type H and L respectively, where $s_i^A = 0$ means that firm A files a patent and $s_i^A = 1$ means that firm A relies on secrecy when when the inventor's type is $i \in \{H, L\}$,

iii. $s^B(\bar{V}) : [V_L, V_H] \mapsto \{0,1\}$ is a mapping representing the patenting decision of firm B (when mixed strategies are not allowed). Specifically, $s^B(\bar{V}) = 0$ when firm B with the production value $\bar{V}$ files a patent and $s^B(\bar{V}) = 1$ otherwise,

such that the following conditions are simultaneously satisfied for $j \in \{H, L\}$:

$$w_j^A \in \underset{x \in R_+}{\arg\max} \quad \Pr\left\{x \geq w_j^B\right\} \cdot [V_j \theta_j - x] \tag{3.1}$$

$$w_j^B \in \underset{x \in R_+}{\arg\max} \quad \Pr\left\{x > w_j^A\right\} \cdot [\bar{V}\theta_j - x] \tag{3.2}$$

$$\begin{aligned} s_j^A \in \underset{x\in\{0,1\}}{\arg\max} \Bigg[& \mathbb{1}(x=1)(s^B V_j \pi_d + (1-s^B)V_j(1-\alpha)\pi_d) + \mathbb{1}(x=0) \\ & [\frac{s^B+1}{2}V_j(\alpha\pi_m+(1-\alpha)\pi_d)+\frac{1-s^B}{2}V_j(1-\alpha)\pi_d)]+(V_j\theta_j-w_j^B)\mathbb{1}(w_j^A \geq w_j^B) \Bigg] \end{aligned} \tag{3.3}$$

$$\begin{aligned} s^B(\bar{V}) \in \underset{x\in\{0,1\}}{\arg\max}\, p \cdot & \Bigg[\mathbb{1}(x=1)(s_H^A \bar{V}\pi_d + (1-s_H^A)\bar{V}(1-\alpha)\pi_d) + \mathbb{1}(x=0) \\ & (\frac{s_H^A+1}{2}\bar{V}(\alpha\pi_m+(1-\alpha)\pi_d)+\frac{1-s_H^A}{2}\bar{V}(1-\alpha)\pi_d)+(\bar{V}\theta_H-w_H^B)\mathbb{1}(w_H^B > w_H^A) \Bigg] \\ + (1-p) \cdot & \Bigg[\mathbb{1}(x=1)(s_L^A \bar{V}\pi_d + (1-s_L^A)\bar{V}(1-\alpha)\pi_d) + \mathbb{1}(x=0) \\ & (\frac{s_L^A+1}{2}\bar{V}(\alpha\pi_m+(1-\alpha)\pi_d)+\frac{1-s_L^A}{2}\bar{V}(1-\alpha)\pi_d)+(\bar{V}\theta_L-w_L^B)\mathbb{1}(w_L^B > w_L^A) \Bigg] \end{aligned} \tag{3.4}$$

The definition described above can be used to solve for an equilibrium and analyze a candidate equilibrium by checking whether all of the equations in the definition are satisfied. Equations 3.1 and 3.2 show that maximization problems for wage offers extended after the patent filing decisions of the firms. Equations 3.3 and 3.4 deal with the maximization problems for optimal patent filing of firms using backward induction, as the turnover depends on wage offers, and firm A's decision is type specific for $j \in \{H, L\}$. However, under full information, the equations 3.1 and 3.2 do not need to be case-specific since there is only one information node to be reached before extending wage offers. Below we explain these equations in more detail.

i. Regardless of the patent filing decision, firms perfectly observe the inventor's type and the value of innovation produced by the other firm under full information. Hence, wage offers aim to maximize the payoff from implementing the project in the second period, considering the competition among firms to hire the inventor. Thus, equations 3.1 and 3.2 do not consider the patent filing decision.

ii. Firm A solves equation 3.3 to determine its optimal patent filing strategy.

- If A chooses secrecy, $x = 1$ in 3.3, then A receives either a duopoly profit from the product market when B also chooses secrecy ($s^B = 1$), or $(1 - \alpha)$ of the duopoly profit when B chooses to file a patent ($s^B = 0$). The latter reflects that even though B has the legal monopoly in the market when granted a patent, this is only to the extent α is close to 1; hence, A may still earn a share of the duopoly profit. Also, the product market is captured at the rate V_j for $j \in \{H, L\}$, resulting in the multiplication with V_j.

- If A chooses to file a patent, $x = 0$ in 3.3, then A is granted a patent with probability $\frac{s^B+1}{2}$. Since we do not allow for mixed strategies, this is either 0.5 if $s^B = 0$, or equal to 1 if $s^B = 1$. If $s^B = 0$, then A is granted the patent with a probability of 0.5; receiving a monopoly at the rate α and a duopoly at the rate $1 - \alpha$. With the remaining 0.5 probability, B is granted the patent, and A receives only a duopoly at the rate $1 - \alpha$. Again, the product market is captured at the rate V_j for $j \in \{H, L\}$, resulting in the multiplication with V_j. Finally, if the wage offer extended by A is greater than or equal to the wage offer extended by firm B, then A retains the inventor at the cost w_j^B, implements the project with probability θ_j and receives a payoff of V_j

iii. Firm B solves equation 3.4 to determine its optimal patent filing strategy. Under full information, either $p = 1$ or $p = 0$, thus, B knows whether the inventor is type H or L and solves one part of the equation. The rest of the equation is similar to what is explained above for equation 3.3.

Proposition 1. *Since firm B is the representative of the rest of the market, B's wage offer equals the (expected) marginal product of the inventor in any equilib-*

rium. This wage offer is characterized by the function f, where $f(V, \theta_i; s^A, s^B) = \mathbb{E}[\theta_i \mid s^A, s^B]V$. With this, we will restrict the domain of the maximizers in 3.1 and 3.2 to the set wages that are in the co-domain of the function f for any equilibrium candidates.

Proof. Suppose for contradiction that firm B offers $w_j^B < \mathbb{E}[\theta_i \mid s^A, s^B]\bar{V}$. Then, since there are infinitely many firms identical to firm B, say firm B' would offer $w_j^B + \epsilon < \mathbb{E}[\theta_i \mid s^A, s^B]\bar{V}$ for some small $\epsilon > 0$ and has a higher probability of hiring inventor i and still makes a positive profit in the amount equal to $\mathbb{E}[\theta_i \mid s^A, s^B]\bar{V} - w_j^B - \epsilon$, then firm B has a profitable deviation by offering $w_j^B + \epsilon + \frac{\mathbb{E}[\theta_i|s^A,s^B]\bar{V} - w_j^B - \epsilon}{2} < \mathbb{E}[\theta_i \mid s^A, s^B]\bar{V}$. However, the same argument can be sustained infinitely many times until one of the outside firms extends a wage offer equal to $\mathbb{E}[\theta_i \mid s^A, s^B]\bar{V}$. This is because (expected) marginal product of the inventor for the rival firms are equal and this leads to a standard Bertrand competition result. □

Proposition 2. *Under the full information benchmark, in equilibrium, there is turnover only if the inventor is of type L. The inventor's wage offer is determined by the outside option with respect to the function f. Specifically, $w_H^A = \bar{V}\theta_H$ and $w_L^A \in [0, \bar{V}\theta_L)$.*

Proof. Suppose there is no turnover when the inventor is type L. Then, it must be that $w_L^A = f(\bar{V}, \theta_L) = \bar{V}\theta_H$, so that A matches B's offer. Then since $V_L \leq \bar{V}$, by hiring type L, firm A makes a loss equal to $(\bar{V} - V_L) \cdot \theta_L > 0$ for any $\bar{V} > 0$. However, firm A would make zero profit by deviating to wage offer $w_L^A = 0$, which strictly dominates $w_L^A = \bar{V}\theta_L$ for any $\bar{V} > 0$, and gives the same payoff for $\bar{V} = 0$. Hence, firm A has a weakly dominant strategy to extend a wage offer $w_L^A = 0$. From Proposition 1, firm B extends $w_L^B = \bar{V}\theta_L$, thus, there is turnover as long as $\bar{V} > 0$. Now suppose there is turnover when the inventor is is type H. Then, it must be that $w_H^A < f(\bar{V}, \theta_H) = \bar{V}\theta_H \leq V_H\theta_H$ the last inequality follows from $\bar{V} \in [V_L, V_H]$. However, A has a weakly dominant strategy to extend a wage offer

$w_H^A = \bar{V}\theta_H$, which gives a positive profit as long as $\bar{V} < V_H$, and yields zero profit when $\bar{V} = V_H$. Hence, there cannot be turnover when the inventor is type H. $\square$

Proposition 3. *Patent filing decision. Under the full information benchmark, firms always choose to file a patent in equilibrium. Hence,* $s_H^A = s_L^A = s^B = 0$.

Proof. The proof is intuitive. Filing a patent possibly yields a monopoly profit to a firm, whereas not filing gives a duopoly profit at its best. Formal proof follows from equation (3) and (4). Suppose firm A with inventor type H finds it optimal to not file a patent ($s_H^A = 1$). Then, equation (3) is satisfied if and only if $s^B V_H \pi_d + (1-s^B)V_H(1-\alpha)\pi_d \geq \frac{s^B+1}{2}V_H(\alpha\pi_m + (1-\alpha)\pi_d) + \frac{1-s^B}{2}V_H(1-\alpha)\pi_d)$ which holds true if and only if $V_H\pi_d(s^B + \frac{1-s^B}{2}(1-\alpha) \geq V_H\pi_d(\frac{s^B+1}{2}(1-\alpha)) + \frac{s^B+1}{2}V_H\alpha\pi_m$ which is a contradiction since $\frac{s^B+1}{2}V_H\alpha\pi_m > 0$ for any s^B. The other case for firm A is symmetric. Finally, for firm B, let $s^B(\bar{V}) = 1$ for some $\bar{V} \in [V_L, V_H]$. Using $s_H^A = s_L^A = 0$ in equilibrium, then it must be $\bar{V}(1-\alpha)\pi_d \geq \frac{1}{2}\bar{V}(\alpha\pi_m + (1-\alpha)\pi_d) + \frac{1}{2}\bar{V}(1-\alpha)\pi_d$, which holds true if and only if $(1-\alpha)\pi_d \geq \alpha\pi_m + (1-\alpha)\pi_d$, which is a contradiction for any $\alpha \in (0,1)$. Hence, $s^B = s_H^A = s_L^A = 0$ in equilibrium. $\square$

The benchmark provides the following results. Firstly, when types are fully observed, firms' optimal choice is to file a patent since it has no impact on the second period wages. In other words, whenever $\beta = 1$ and there is perfect information, then firms face no trade-off regarding patent filing decisions. Hence, in the benchmark, firms always choose to file a patent. Secondly, there is no turnover when firm A starts with a high type inventor, and there is always turnover when A starts with a low type inventor[1]

The results from the benchmark are rather simple. However, we will point out to these results and make comparisons after introducing the model with asymmetric

[1] This is because $\bar{V} \in [V_L, V_H]$. While this assumption determines when there is turnover, if we instead assumed another set $[0, \hat{V}]$ such that $\bar{V}, V_H, V_L \in [0, \hat{V}]$, we could show that there is turnover whenever $\bar{V} > V_L$ and $\bar{V} > V_H$, and these would occur with a certain probability depending on the distribution of $\bar{V}$. However, this would not change our main results whenever $\bar{V} \in [V_L, V_H]$ and we would observe different results when it does not hold. Therefore, for simplicity and to focus on the patent filing decision of firms, we will maintain our assumption that $\bar{V} \in [V_L, V_H]$.

information.

3.2.2 Asymmetric Information

This section introduces and analyzes the main model of the paper. We first describe the environment and then solve for an equilibrium. Our solution follows a certain path. First, we introduce the solution concept. Then, we analyze firms' profits in each possible case, establish how the posterior belief is updated, pin down the wage offers and determine when there is turnover. Using our deductions, we give a formal definition of the equilibrium and solve for patent filing decisions. Finally, we analyze the equilibrium strategies and the conditions to sustain them.

Different from the benchmark, now firms A and B observe each other's innovation value only when the rival firm files a patent. We remind ourselves that a firm cannot guarantee a patent by filing it since only one firm can be granted it under simultaneous innovation. However, even when the firm who files a patent is not granted a patent, the innovation value is revealed to the other firm due to filing. In addition, the inventor's type is initially unobserved by both firms and there is a common prior probability p that the inventor is of type H; hence; $\Pr\{\theta_i = \theta_H\} = p$. Under asymmetric information, we assume $p \in (0,1)$. Firm A privately observes the value V_i after the production and this reveals the type of the inventor to A; similarly firm B privately observes the value $\bar{V}$. This is before firms make their patenting decisions. Therefore, firm j's innovation value is its private information unless it files a patent for $j \in \{H, L\}$.

Asymmetric information adds the following trade-offs to the model.

1- From firm A's perspective, filing a patent possibly yields a monopoly profit. However, it may lead to turnover or possibly a higher retention wage since the inventor's type is revealed to firm B. Given that firm A's payoff depends on both being granted a patent and employing the inventor in the second period, A's optimal decision reflects this trade-off.

2- From firm B's perspective, whenever firm B files a patent, it reveals its production value, hence, this reveals the wage offer made by firm B. As otherwise, if B does not file a patent, B's true wage offer is its private information and A decides what wage to offer given the *expected* wage offer of B[2]. When B files a patent, this makes it easier for firm A since A can then correctly anticipate the outside option of the inventor and may as well prevent any turnover by matching this offer. However, similar to firm A, firm B also needs a patent to (possibly) enjoy a monopoly profit. Hence, firm B's decision reflect this trade-off between revealing its wage offer and risking monopoly profit.

Additionally, firm A's decision to file a patent will be used as signals by firm B to form rational beliefs about the type of the inventor employed by firm A [3]. To clarify, when firm A files a patent, it directly reveals the type of the inventor; however, when A does not file a patent, the inventor's type is known to firm A only. Hence, B will assess when firm A is likely to file a patent and when it is not. Since mixed strategies are not allowed here and types are binary, A's equilibrium patent filing strategy will either perfectly reveal types under a separating equilibrium, or will leave B's posterior same as its prior belief under a pooling equilibrium. However, off-the-equilibrium path beliefs will play a critical role and determine how the asymmetric information equilibrium differs from the benchmark equilibria . We will establish that there is a set of equilibria with optimal strategies different from those in the full information benchmark.

We will use Perfect Bayesian Equilibrium as a solution concept and solve for an equilibrium using backward induction. Beliefs will be updated according to Bayes' Rule whenever possible (whenever a decision node is reached with a positive probability). However, as mentioned before, beliefs in equilibrium will be correct and firm B will either perfectly anticipate types, or B's posterior will remain the same

[2] In an alternative mechanism, A can first observe B's wage offer and then decide whether to match it or not. However, in this section, we will assume that A observes the true value of the wage offer extended by B only when B files a patent. This is rather more complicated since now A's optimal strategy depends on the expected wage offer extended by B.

[3] Rationality is only to the extent B's posterior belief can be updated with respect to Bayes' Rule. Therefore, off-the-equilibrium path beliefs will play a crucial role while determining the set of equilibria that can be sustained.

as its prior.

For each proposition, we will indicate the necessary restrictions on the off-the-equilibrium path beliefs. Since we use backward induction to solve for an equilibrium, we start by examining the turnover in all possible cases before giving the formal definition of an equilibrium.

From Proposition 1, firm B's wage offer will be characterized by the function f. Hence $w^B = f(\theta, \bar{V}; s^A, s^B) = \mathbb{E}[\theta_i \mid s^A, s^B] \cdot \bar{V}$. One important distinction here is that although firm A decides whether to file a patent or not both when the inventor is of type H and L, firm B observes only one decision made by A. Hence, s^A indicates what firm B observes. When we apply backward induction, we start from the last decision node, which is when firms decide what wage to offer given the patent filing decision of the other firm (and whether one of the firms is granted a patent as a result). At this stage, firms already know their own innovation values, V_i for firm A and $\bar{V}$ for firm B. In addition, each firm observes whether the other firm filed a patent, and if a patent is granted to one of the firms. Therefore, there are 6 cases; A or B or neither is granted a patent, and there is turnover or no turnover for each of these. For convenience, we summarize the firms' payoffs for each case below.

Case 1: A is granted a patent and there is no turnover

Payoff of A: $V_i(\alpha\pi_m + (1-\alpha)\pi_d) + V_i\theta_i - w_i^A$

Payoff of B: $\bar{V}(1-\alpha)\pi_d$

Case 2: A is granted a patent and there is turnover

Payoff of A: $V_i(\alpha\pi_m + (1-\alpha)\pi_d)$

Payoff of B: $\bar{V}(1-\alpha)\pi_d + \bar{V}\theta_i - w_i^B$

Case 3: B is granted a patent and there is no turnover

Payoff of A: $V_i(1-\alpha)\pi_d + V_i\theta_i - w^B$

Payoff of B: $\bar{V}(\alpha\pi_m + (1-\alpha)\pi_d)$

Case 4: B is granted a patent and there is turnover

Payoff of A: $V_i(1-\alpha)\pi_d$

Payoff of B: $\bar{V}(\alpha\pi_m + (1-\alpha)\pi_d) + \bar{V}\theta_i - w^B$

Case 5: Neither firm is granted a patent and there is no turnover

Payoff of A: $V_i\pi_d + V_i\theta_i - w_i^A$

Payoff of B: $\bar{V}\pi_d$

Case 6: Neither firm is granted a patent and there is turnover

Payoff of A: $V_i\pi_d$

Payoff of B: $\bar{V}\pi_d + \bar{V}\theta_i - w^B$

Notice that above payoffs are not given in the simplest way; we would like to show the distinction between firms' payoff from the product market and innovation market. Hence, we do not use a common parenthesis with $\bar{V}$ or V_i. In addition, B's wage offer is type specific whenever A is granted a patent, this is because a patent reveals the inventor's type[4].

For convenience, let $\bar{\theta} = p \cdot \theta_H + (1-p) \cdot \theta_L$ and let $\bar{\pi} = \alpha\pi_m + (1-\alpha)\pi_d$. From Proposition 1, B's wage offer is characterized by the function f and A's wage offer is always type specific[5]. Since we assume $\bar{V} \in [V_L, V_H]$, there will be turnover whenever the inventor is of type L. Hence, A (as in the benchmark) has a weakly dominant strategy to extend a wage offer $w_L^A = 0$. Therefore, for any $\bar{V} > 0$, there will be turnover if the inventor is of type L.

Firm B will form a belief $\mu \in [0,1]$ denoting the probability firm B attaches to that the inventor is of type H whenever A does not file a patent. Formally, $\mu = \Pr\left\{\theta_i = \theta_H \mid s^A = 1\right\}$. We will make some deductions regarding μ for possible strategies of firm A.

[4] B's wage offer will also be type specific under a separating equilibrium even if A does not file a patent. This is because B will perfectly distinguish types in any separating equilibrium.

[5] A's wage offer will be $\mathbb{E}[f(.)]$ if A wants to retain the inventor by matching B's offer, otherwise it can be anything in the set $[0, \mathbb{E}[f(.)])$. In the latter case, extending a wage offer equal to zero is a dominant strategy for A.

Suppose that in equilibrium firm A always files a patent when the inventor is of type H, and never files a patent when the inventor is of type L. Then, B's belief will represent this separation in A's strategies with different types of the inventor. In this case, B believes the inventor is of type L whenever firm A does not file a patent, i.e. $\mu = 0$.

Suppose that in equilibrium firm A always chooses to file a patent regardless of the inventor's type. Then, Bayes' Rule does not imply anything about B's posterior belief since we cannot reach a case in which A does not file a patent. In this case, B's belief will be free, i.e., $\mu \in [0, 1]$ will represent off-the-equilibrium path beliefs.

Suppose that in equilibrium firm A always files a patent when the inventor is of type L, and A never files a patent when the inventor is of type H. Then, B's belief will represent this separation in A's strategies. Firm B will believe the inventor is of type H whenever A does not file a patent, i.e., $\mu = 1$.

Finally, suppose that in equilibrium firm A never files a patent both when the inventor is of type H and of type L. Then, B's posterior is the same as its prior since there is no separation in A's strategies, and no additional information is revealed because A never files a patent. Hence, $\mu = p$.

To summarize, under a separating equilibrium, B's posterior is either equal to 1 or 0. Under a pooling equilibrium, if A files a patent regardless of the inventor's type, then B's posterior belief is free. If A never files a patent, then B's posterior is the same as the prior belief.

Using our simplifications regarding firm B's posterior belief, we now derive if and when there is turnover. We start from Proposition 1. Since firm B's wage offer is $w^B = f(\theta, \bar{V}; s^A, s^B) = \mathbb{E}[\theta_i \mid s^A, s^B] \cdot \bar{V}$, using our rationale for μ, we derive the following wages for each case.

If A files a patent both when the inventor is of type L and of type H (meaning $s^A_H = 0 = s^A_L$; pooling equilibrium), B will perfectly observe the types, hence will extend two different wage offers depending on the inventor's type; $w^B_H = \bar{V}\theta_H$ and

$w_L^B = \bar{V}\theta_L$ respectively. These are exactly the same wages as in the full information benchmark.

However, whenever A's equilibrium strategy is the pooling with $s_H^A = 1 = s_L^A$ so that A never files a patent, then B's wage offer will reflect the information asymmetry; B's best guess will be the prior. Hence, $w^B = \mathbb{E}[\theta_i \mid s^A = 1, s^B] \cdot \bar{V} = (p \cdot \theta_H + (1-p) \cdot \theta_L)\bar{V} = \bar{\theta}\bar{V}$. From A's perspective, $w_L^A = 0$ still remains as the weakly dominant wage offer for type L as in the benchmark. However, A's wage offer for type H will reflect its best guess for the outside option of type H inventor and it will be equal to $\mathbb{E}[f(.)]$.

Whenever both A and B file a patent, $w_H^A = \bar{V}\theta_H$ since $\bar{V}$ is known to A and θ_H is revealed to B.

When A is the only firm that files a patent, A's wage offer for type H will be $w_H^A = \theta_H \cdot \mathbb{E}[\bar{V} \mid s^A = 0, s^B = 1]$ since filing a patent by firm A will reveal the inventor's type but $\bar{V}$ is not revealed to A.

On the other hand, whenever firm B is the only firm that files a patent, A's wage offer for type H will be $w_H^A = \bar{V} \cdot \mathbb{E}[\theta_i \mid s^A = 1, s^B = 0]$, this will depend on $\mathbb{E}[\theta_i \mid s^A = 1, s^B = 0]$; which is either θ_H in a separating equilibrium ($s_H^A = 1$ and $s_L^A = 0$) or will be equal to $\bar{\theta}$ in a pooling equilibrium ($s_H^A = 1$ and $s_L^A = 1$).

Finally, when neither firm files a patent, $w_H^A = \mathbb{E}[\theta_i \mid s^A = 1, s^B = 1] \cdot \mathbb{E}[\bar{V} \mid s^A = 1, s^B = 1]$, which will either be equal to $\theta_H \cdot \mathbb{E}[\bar{V} \mid s^A = 1, s^B = 1]$ in a separating equilibrium ($s_H^A = 1$ and $s_L^A = 0$), or it will be equal to $\bar{\theta} \cdot \mathbb{E}[\bar{V} \mid s^A = 1, s^B = 1]$ in a pooling equilibrium ($s_H^A = 1$ and $s_L^A = 1$).

Therefore, turnover is summarized below:

1.If the inventor is of type L, there is always turnover and the inventor moves to B.

2.If the inventor is of type H, there is turnover if $\mathbb{E}[\bar{V} \mid s^A, s^B] < \bar{V}$.

Assumption 1. *Uniform distribution of $\bar{V}$. Let $\bar{V}$ be drawn from the interval*

$[V_L, V_H]$ *with respect to the function* g*. Let* g *be the pdf representing the uniform distribution:*

$$g(\bar{V}) = \begin{cases} \frac{1}{V_H - V_L} & \textit{if } \bar{V} \in [V_L, V_H], \\ 0 & \textit{otherwise} \end{cases}$$

Observation 1. Whenever types are revealed to or observed by firm B, hiring the inventor will bring a net profit of zero to firm B from Proposition 1. However, if types are not perfectly observed by or revealed to B, then B will make a net loss of $(\bar{\theta} - \theta_L) \cdot \bar{V}$ by hiring type L; and will make a net profit of $(\theta_H - \bar{\theta}) \cdot \bar{V}$ by hiring type H. On the other hand, whenever types are revealed to or observed by firm B and B files a patent, firm A will make a net profit of $(V_H - \bar{V})\theta_H$ by retaining type H, and in case types are revealed to or observed by firm B but B does not file a patent; firm A will make a net profit of $(V_H - \mathbb{E}[\bar{V} \mid s^A, s^B]) \cdot \theta_H$ by retaining type H, and finally, if types are not observed by or revealed to B, then A will make a net profit of $(V_H - \mathbb{E}[\bar{V} \mid s^A, s^B]) \cdot (\theta_H - \bar{\theta})$ in case B does not file a patent and will make a net profit of $(V_H - \bar{V}) \cdot (\theta_H - \bar{\theta})$ in case B files a patent by retaining the inventor.

Now we are ready to give a formal definition of the equilibrium. We use the results from Observation 1 to simplify the maximization problems; such as; we pinned down the wage offers by using our rationale for μ and the turnover in each case. We derived that firm B makes a net profit of zero by hiring the inventor whenever types are revealed to (or observed by) B. Therefore, instead of writing the formal maximization problems for wage offers, we simply write the expressions found using backward induction.

Definition 2. An equilibrium for the asymmetric information game with $\beta = 1$ is the tuple $(w_H^A, w_L^A, w^B, s_H^A, s_L^A, s^B(\bar{V}), \mu)$ where:

i. $(w_H^A, w_L^A, w^B) \in R_+^3$ is the set of wages extended to inventor $i \in \{H, L\}$ by firm A and B respectively,

ii. $(s_H^A, s_L^A) \in \{0,1\}^2$ denote the patenting decision of firm A with the inventor of type H and L respectively, where $s_i^A = 0$ means that firm A files a patent, and $s_i^A = 1$ means that firm A does not file a patent (relies on secrecy) when it employs type $i \in \{H, L\}$,

iii. $s^B(\bar{V}) : [V_L, V_H] \mapsto \{0,1\}$ is a mapping denoting the patenting decision of firm B (when mixed strategies are not allowed), where $s^B(\bar{V}) = 0$ when firm B with the production value $\bar{V}$ files a patent and $s^B(\bar{V}) = 1$ otherwise,

iv. $\mu \in [0,1]$ denotes the belief of firm B that the inventor is of type H whenever a patent is not filed by firm A,

such that the following conditions are satisfied:

$$w_H^A = \mathbb{E}[\bar{V} \mid s_H^A, s^B] \cdot \mathbb{E}[\theta \mid s_H^A, s^B] \tag{3.5}$$

$$w_L^A \in \Big[0, (\mathbb{E}[\bar{V} \mid s_L^A, s^B] \cdot \mathbb{E}[\theta \mid s_H^A, s^B])\Big) \tag{3.6}$$

$$w^B \in f(\theta, \bar{V}; s^A, s^B) = \bar{V} \cdot \mathbb{E}[\theta \mid s^A, s^B] \tag{3.7}$$

$$\begin{aligned} s_H^A \in \arg\max_{x \in \{0,1\}} \Bigg[& \mathbb{1}(x=1) \Bigg(s^B(\bar{V}) \cdot \big[V_H \pi_d + \Pr\left\{ \bar{V} \le \mathbb{E}[\bar{V} \mid s_H^A = 1, s^B = 1] \right\} \cdot (V_H \theta_H - w_H^A) \big] \\ & + (1 - s^B(\bar{V})) \cdot V_H (1-\alpha) \pi_d + V_H \theta_H - w_H^A \Bigg) + \mathbb{1}(x=0) \\ & \Bigg(\frac{s^B(\bar{V}) + 1}{2} \cdot V_H \cdot (\alpha \pi_m + (1-\alpha)\pi_d) + \frac{1 - s^B(\bar{V})}{2} \cdot V_H \cdot (1-\alpha) \pi_d \\ & + s^B(\bar{V}) \cdot \Pr\left\{ \bar{V} \le \mathbb{E}[\bar{V} \mid s_H^A = 0, s^B = 1] \right\} \cdot (V_H \theta_H - w_H^A) + (1 - s^B(\bar{V})) \cdot (V_H \theta_H - \bar{V} \theta_H) \Bigg) \Bigg] \end{aligned} \tag{3.8}$$

$$s_L^A \in \underset{x\in\{0,1\}}{\arg\max}\Bigg[\mathbb{1}(x=1)\Big(s^B(\bar{V})\cdot V_L\cdot\pi_d+(1-s^B(\bar{V}))\cdot V_L\cdot(1-\alpha)\pi_d\Big)$$
$$+\mathbb{1}(x=0)\Big(\frac{s^B(\bar{V})+1}{2}\cdot V_L\cdot(\alpha\pi_m+(1-\alpha)\pi_d)+\frac{1-s^B(\bar{V})}{2}\cdot V_L\cdot(1-\alpha)\pi_d\Big)\Bigg] \tag{3.9}$$

$$s^B(\bar{V}) \in \underset{x\in\{0,1\}}{\arg\max}\Bigg\{p\cdot\Bigg[\mathbb{1}(x=1)\Big(s_H^A\bar{V}\pi_d+(1-s_H^A)\bar{V}(1-\alpha)\pi_d$$
$$+s_H^A\cdot\mathbb{1}(\bar{V}>\mathbb{E}[\bar{V}\mid s_H^A=1,s^B=1])\cdot\big(\bar{V}\theta_H-\bar{V}\cdot\mathbb{E}[\theta\mid s_H^A=1,s^B=1]\big)\Big)$$
$$+\mathbb{1}(x=0)\Big(\frac{s_H^A+1}{2}\bar{V}(\alpha\pi_m+(1-\alpha)\pi_d)+\frac{1-s_H^A}{2}\bar{V}(1-\alpha)\pi_d\Big)\Bigg]$$
$$+(1-p)\cdot\Bigg[\mathbb{1}(x=1)\Big(s_L^A\bar{V}\pi_d+(1-s_L^A)\bar{V}(1-\alpha)\pi_d\Big)+\mathbb{1}(x=0)$$
$$\Big(\frac{s_L^A+1}{2}\bar{V}(\alpha\pi_m+(1-\alpha)\pi_d)+\frac{1-s_L^A}{2}\bar{V}(1-\alpha)\pi_d\Big)-s_L^A(\bar{V}\theta_L-w^B)\Bigg]\Bigg\} \tag{3.10}$$

$$\mu=\frac{p\cdot s_H^A}{p\cdot s_H^A+(1-p)\cdot s_L^A}\quad\text{if}\quad[p\cdot s_H^A+(1-p)\cdot s_L^A]\neq 0 \tag{3.11}$$

Let us first describe the above equations in words.

a. Equations 3.5, 3.6 and 3.7 represent the pinned down wage offers we derived from backward induction.

b. Equation 3.8 gives the formal expression firm A solves for the optimal patent filing decision when the inventor is of type H.

i. The indicator function for $x = 1$ represents the case when A chooses to rely on secrecy. In such a case, A's payoff depends on the patent filing decision of B.

- If B does not file a patent so that $s^B = 1$, then they share the market and A receives a duopoly profit, which is captured at the rate V_H. Further, since B does not file a patent, A retains the high type inventor with the probability that $\bar{V}$ is less than or equal to $\mathbb{E}[\bar{V} \mid s_H^A = 1, s^B = 1]$, since otherwise A's wage offer is strictly less than B's offer. Therefore, with this probability A retains the inventor of type H and receives a payoff equal to $V_H\theta_H$ and pays w_H^A to the inventor.

- If B files a patent so that $s^B = 0$, then B is granted a patent and a monopoly at the rate α. Thus, A receives a duopoly profit at the rate $(1-\alpha)$ and this is captured at the rate V_H. However, since B files a patent, then there is no turnover anymore; A retains the inventor of type H and receives a payoff equal to $V_H\theta_H$ and pays w_H^A to the inventor.

ii. The indicator function for $x = 0$ represents the case when A files a patent. Similar to above arguments, A's payoff depends on the patent filing decision of B.

- If B does not file a patent so that $s^B = 1$, then A is granted a monopoly at the rate α and captures the market at the rate V_H. However, since $\bar{V}$ is not revealed to A, type H inventor is retained by firm A with the probability $\bar{V}$ is less than or equal to $\mathbb{E}[\bar{V} \mid s_H^A = 0, s^B = 1]$. With this probability, A retains type H, earns $V_H\theta_H$ and pays w_H^A.

- If B files a patent so that $s^B = 0$, then each firm is granted a patent with probability

$$0.5$$

. Hence, with

$$0.5$$

probability A is granted a monopoly at the rate α and with the remaining

$$0.5$$

probability firm B is granted a monopoly at the rate α. In the former, A receives a convex combination of monopoly and duopoly profits, whereas in the latter A receives a duopoly at the rate $(1-\alpha)$. Both profits are captured at the rate V_H. However, since B files a patent, then there is no turnover. Hence, A retains type

H, earns $V_H\theta_H$ and pays w_H^A.

c. Equations 3.9 and 3.10 essentially follow the same intuition as explained for Equation 3.8. Two points differ here.

i. As discussed before, there is turnover whenever the inventor is of type L. Hence, A's maximization problem in 3.9 does not involve the profits from the innovation market by retaining type L.

ii. B's problem in 3.10 represents its ex-ante expectation. Firm B will maximize an expectation of both cases, when the inventor is of type H and L, since B does not know anything related to this while deciding whether to file a patent or rely on secrecy. However, wage offers and turnover are pinned down from backward induction; there is always turnover when the inventor is of type L, and there is turnover if the inventor is of type H and $\bar{V}$ is greater than $\mathbb{E}[\bar{V} \mid s_H^A = 1, s^B = 1]$. Hence, B's patent filing decision will take this into account using its private information about $\bar{V}$.

Finally, we will simplify Equation 3.11 into the following three equations for simplicity:

$$\mu = p \quad \text{if} \quad s_H^A = s_L^A = 1 \tag{3.12}$$

$$\mu = 1 \quad \text{if} \quad s_H^A = 1 \quad \text{and} \quad s_L^A = 0 \tag{3.13}$$

$$\mu = 0 \quad \text{if} \quad s_H^A = 0 \quad \text{and} \quad s_L^A = 1 \tag{3.14}$$

Proposition 4. *(Benchmark Pooling) Restricting off-the-equilibrium path beliefs to* $\mu = 1$; $s_H^A = s_L^A = s^B = 0$ *along with the wage offers* $w_H^A = w_H^B = \bar{V}\theta_H$ *when the inventor is of type* H*, and* $w_L^A \in [0, \bar{V}\theta_L)$ *and* $w_L^B = \bar{V}\theta_L$ *when the inventor is of type* L *constitute a continuum of equilibria. Firm* B*'s wage offer is type specific* *since types are fully observed in equilibrium.*

Proof. In such an equilibrium, types are fully revealed and we restrict off-the-equilibrium path belief to $\mu = 1$. Hence, whenever firm A does not file a patent, firm B will believe for sure that the inventor is of type H. Secondly, we observe that there is no turnover when the inventor is of type H, and there is turnover when the inventor is of type L. Suppose for contradiction that firm A has a unilateral profitable deviation to $s_H^A = 1$, then from equation (3.8), it must be that $V_H(1-\alpha)\pi_d + V_H\theta_H - w_H^A \geq \frac{1}{2}V_H\bar{\pi} + \frac{1}{2}V_H(1-\alpha)\pi_d + V_H\theta_H - \bar{V}\theta_H$ which simplifies to $\bar{V}\theta_H - w_H^A \geq V_H(\frac{\bar{\pi}-(1-\alpha)\pi_d}{2})$. However, from 3.5, $w_H^A = \mathbb{E}[\bar{V} \mid s_H^A, s^B] \cdot \mathbb{E}[\theta \mid s_H^A, s^B] = \bar{V}\theta_H$ since $\mu = 1$, which implies that $w_H^A = \bar{V}\theta_H$. Hence the deviation condition simplifies to $0 \geq V_H(\frac{\bar{\pi}-(1-\alpha)\pi_d}{2})$ which is a contradiction since $\bar{\pi} - (1-\alpha)\pi_d > 0$ for any $\alpha \in (0,1)$ and $\pi_m > \pi_d \geq 0$. Therefore, A cannot deviate to $s_H^A = 1$. Moreover, this is incentive compatible for A since not filing sends the same signal as if revealing type H with a patent (by assumption $\mu = 1$). Now let us suppose for contradiction that A has a unilateral deviation to $s_L^A = 1$. Then, it must be $V_L(1-\alpha)\pi_d \geq \frac{1}{2}V_L(\bar{\pi} + (1-\alpha)\pi_d)$ which simplifies to $V_L(1-\alpha)\pi_d \geq V_L\bar{\pi}$ which is a contradiction since $\bar{\pi} = \alpha\pi_m + (1-\alpha)\pi_d \geq (1-\alpha)\pi_d$ for any $\alpha \in (0,1)$. Thus, $s_L^A = 0$ is also a best response to $s^B(\bar{V}) = 0$. Finally, suppose that firm B has an incentive to deviate to $s^B(\bar{V}) = 1$ for some $\bar{V} \in [V_L, V_H]$. Then from 3.10, it must be $\bar{V}(1-\alpha)\pi_d \geq \frac{1}{2}V_L(\bar{\pi} + (1-\alpha)\pi_d)$ which simplifies to $\bar{V}(1-\alpha)\pi_d \geq \bar{V}\bar{\pi}$ which is a contradiction since $\bar{\pi} = \alpha\pi_m + (1-\alpha)\pi_d \geq (1-\alpha)\pi_d$ for any $\alpha \in (0,1)$. Thus, $s^B(\bar{V}) = 0$ is also a best response for any $\bar{V} \in [V_L, V_H]$ since we initially pick an arbitrary one. □

Observation 2. Filing a patent is a weakly dominant strategy for firm A whenever the inventor is of type L, and benchmark equilibrium can be sustained as long as we restrict off the equilibrium path belief to $\mu = 1$ (pooling equilibrium with $s_H^A = s_L^A = 0$). However, we believe this is a strong assumption. Since a more natural guess for off-the-equilibrium path belief would be the prior (or a more cautious guess would be assuming the inventor is of type L whenever A does not file a patent). We will argue the required conditions for the benchmark equilibrium when off-the-equilibrium path belief is not $\mu = 1$ in the following propositions.

Proposition 5. *If we restrict off-the-equilibrium path belief to $\mu = p$ (prior) or $\mu = 0$ (cautious belief); then the benchmark equilibrium is sustained only if $\frac{\bar{V}}{V_H} \leq \frac{\bar{\pi}-(1-\alpha)\pi_d}{2(\theta_H-\bar{\theta})}$ for $\mu = p$; and $\frac{\bar{V}}{V_H} \leq \frac{\bar{\pi}-(1-\alpha)\pi_d}{2(\theta_H-\theta_L)}$ for $\mu = 0$. The general condition is $\frac{\bar{V}}{V_H} \leq \frac{\bar{\pi}-(1-\alpha)\pi_d}{2(\theta_H-(\mu\theta_H+(1-\mu)\theta_L)}$. Using $\bar{\pi} = \alpha\pi_m + (1-\alpha)\pi_d$ and manipulating the expression in the denominator, the general condition simplifies to $\frac{\bar{V}}{V_H} \leq \frac{\alpha\pi_m}{2(1-\mu)(\theta_H-\theta_L)}$.*

Proof. From Proposition 4, we deduce that firm A that employs the inventor of type H has an incentive to deviate from $s_H^A = 0$ to $s_H^A = 1$ if $\bar{V}\theta_H - w_H^A \geq V_H(\frac{\bar{\pi}-(1-\alpha)\pi_d}{2})$. Since the candidate equilibrium is the one in which $s^B(\bar{V}) = 0$, then $w_H^A = \bar{V} \cdot \mathbb{E}[\theta \mid s_H^A, s^B]$. Assuming off-the-equilibrium path belief that the inventor is of type H is $\mu \in [0,1]$, then the signal A sends is incentive compatible if and only if $\bar{V}(\theta_H - (\mu\theta_H + (1-\mu)\theta_L)) \leq V_H(\frac{\bar{\pi}-(1-\alpha)\pi_d}{2})$ which simplifies to $\frac{\bar{V}}{V_H} \leq \frac{\alpha\pi_m}{2(1-\mu)(\theta_H-\theta_L)}$. In case we assume $\mu = p$, then the condition is $\frac{\bar{V}}{V_H} \leq \frac{\bar{\pi}-(1-\alpha)\pi_d}{2(\theta_H-\bar{\theta})}$ since $\mathbb{E}[\theta_i \mid s_H^A, s^B] = \bar{\theta}$, and the condition is $\frac{\bar{V}}{V_H} \leq \frac{\bar{\pi}-(1-\alpha)\pi_d}{2(\theta_H-\theta_L)}$ when $\mu = 0$ since $\mathbb{E}[\theta_i \mid s_H^A, s^B] = \theta_L$. □

Observation 3. We derived the general required condition for the benchmark pooling as $\frac{\bar{V}}{V_H} \leq \frac{\alpha\pi_m}{2(1-\mu)(\theta_H-\theta_L)}$. We observe that an increase in α, π_m, V_H, θ_L and μ makes the benchmark equilibrium more likely; whereas an increase in $\bar{V}$ or θ_H makes it less likely. Therefore, we relate strong property rights (higher α), higher monopoly profits (π_m), and lower (ability) difference between types ($\theta_H - \theta_L$) with a more likely benchmark equilibrium. However, the benchmark equilibrium fails under strong rivalry $\bar{V}$ and/or higher (ability) difference between types. Therefore, we relate these with a distortion in patent filing decision of firm A caused by information asymmetry. To clarify, firm A's trade-off between guaranteeing no turnover at lower wages and possibly enjoying monopoly profits characterize the equilibrium conditions which lead to a distortion in optimal patent filing decision by firm A.

Proposition 6. *No separating equilibrium. There is no equilibrium in which $s^A_H = 1$ and $s^A_L = 0$ or one in which $s^A_H = 0$ and $s^A_L = 1$, regardless of $s^B(\bar{V})$. The latter is because filing a patent is dominant for A when it employs the inventor of type L, and the former is simply because types are fully revealed in any separating equilibrium. Hence, A has no incentive to risk the monopoly profit by not filing a patent when it employs the inventor of type H.*

Proof. Suppose for contradiction that there exists an equilibrium in which $s^A_H = 1$ and $s^A_L = 0$. Then, Bayes' Rule implies that $\mu = 1$. Hence, B's wage offer is type specific; whenever A does not file a patent $w^B_H = \bar{V} \cdot \theta_H$ since types are perfectly revealed to B. Following this, hiring the inventor brings a net profit of zero to B. Then B's patent filing strategy for some $\bar{V} \in [V_L, V_H]$ is derived from comparing the expected payoffs; filing a patent brings a payoff of $p \cdot \bar{V}\bar{\pi} + \frac{1}{2}\bar{V}((1-p)\bar{\pi} + (1-\alpha)\pi_d)$ whereas not filing a patent brings $p \cdot [\bar{V}\pi_d + \mathbb{1}(\bar{V} > \mathbb{E}[\bar{V} \mid s^A_H = 1, s^B = 1])(\bar{V}\theta_H - \bar{V}\mathbb{E}[\theta \mid s^A_H = 1, s^B = 1] + (1-p) \cdot \bar{V}(1-\alpha)\pi_d)$. Since $\mathbb{E}[\theta \mid s^A_H = 1, s^B = 1] = \theta_H$ under separating equilibrium. Then B compares $p \cdot \bar{V}\bar{\pi} + (1-p)\frac{\bar{V}\bar{\pi}}{2} + \frac{\bar{V}(1-\alpha)\pi_d}{2}$ to the expression $p \cdot \bar{V}\pi_d + (1-p)\bar{V}(1-\alpha)\pi_d$. If $p \cdot \bar{V}\bar{\pi} + (1-p)\frac{\bar{v}\bar{\pi}}{2} + \frac{\bar{V}(1-\alpha)\pi_d}{2} \geq p \cdot \bar{V}\pi_d + (1-p)\bar{V}(1-\alpha)\pi_d$, and, thus, B's optimal strategy is to file a patent. Notice that $p \cdot \bar{V}\bar{\pi} + (1-p)\frac{\bar{V}\bar{\pi}}{2} + \frac{\bar{V}(1-\alpha)\pi_d}{2} > p \cdot \bar{V}\bar{\pi} + (1-p)\frac{\bar{V}(1-\alpha)\pi_d}{2} + \frac{\bar{V}(1-\alpha)\pi_d}{2} \geq p \cdot \bar{V}\pi_d + (1-p)\bar{V}(1-\alpha)\pi_d$; where the strict inequality follows from the fact that $\bar{\pi} > (1-\alpha)\pi_d$. Hence, B would then choose to file a patent regardless of the value of $\bar{V}$. We had already established that $s^A_L = 0$ is a weakly dominant strategy. Hence, our contradiction will come from showing that firm A has an incentive to deviate from $s^A_H = 1$ to $s^A_H = 0$. Given $s^B(\bar{V}) = 0$ and $\mu = 1$ (from Bayes' Rule since we are in a separating equilibrium environment), then we deduce that there is no turnover when the inventor is of type H. Suppose for contradiction that A cannot deviate to a higher profit by changing its patent filing strategy from $s^A_H = 1$ to $s^A_H = 0$. Then it must be $\frac{1}{2}V_H(\bar{\pi} + (1-\alpha)\pi_d) + (V_H - \bar{V}) \cdot \theta_H < V_H(1-\alpha)\pi_d + V_H\theta_H - \bar{V}\mathbb{E}[\theta \mid s^A_H = 1, s^B = 0]$. Realize that given $s^B(\bar{V}) = 0$ and $\mu = 1$, $\mathbb{E}[\theta \mid s^A_H = 1, s^B = 0] = \theta_H$ which implies the condition is satisfied if and only if $\frac{1}{2}V_H(\bar{\pi} + (1-\alpha)\pi_d) < V_H(1-\alpha)\pi_d$ which is a contradiction since $\bar{\pi} + (1-\alpha)\pi_d > 2 \cdot (1-\alpha)\pi_d$. Thus, A has an incentive to deviate to $s^A_H = 0$ whenever $s^B(\bar{V}) = 0$ in a separating equilibrium environment. Hence there is no separating equilibrium. □

Assumption 2. *Let $V_L = 0$. We make this assumption to simplify the algebra and focus on firm A's optimal patent filing strategy when the inventor is of type H.*

Proposition 7. *Asymmetric information pooling. Under assumption 1 and 2; if $\bar{\pi} - \pi_d \geq \frac{\theta_H - \bar{\theta}}{2}$ and $\frac{\alpha \pi_m}{2(\theta_H - \theta)} \leq \frac{\bar{V}}{V_H}$, then $s^A_H = 1 = s^A_L$ and $s^B(\bar{V}) = 0$ along with the wage offers $w^A_H = \bar{V}\bar{\theta} = w^B$ and $w^A_L \in [0, \bar{V}\bar{\theta})$ constitute a continuum of equilibria.*

Proof. Under assumption 2, $s^A_L \in \{0,1\}$ and $w^A_L \in [0, \bar{V}\bar{\theta})$ as established previously. Given that $s^A_L = s^A_H = 1$, Bayes' Rule implies that posterior expectation must be equal to prior expectation, thus, $\mu = p$. Following this, $\mathbb{E}[\theta_i \mid s^A = 1, s^B = 0] = \bar{\theta}$. Hence, B extends a wage offer $w^B = \bar{V}\bar{\theta}$. Let us focus on when B files a patent. Whenever B files a patent, there is no turnover, and in case B does not file a patent, there is turnover with probability $(1 - \Pr\left\{\bar{V} \leq \mathbb{E}[\bar{V} \mid s^A = 1, s^B = 1]\right\})$. In such a case, since $\bar{V}$ is uniformly distributed on the interval $[0, V_H]$, A will take the expectation of the set of $\bar{V}$ after which B files a patent. Hence, $(1 - \Pr\left\{\bar{V} \leq \mathbb{E}[\bar{V} \mid s^A = 1, s^B = 1]\right\}) = \frac{1}{2}$. Using this, B's expected payoff from filing a patent is $p \cdot \bar{V}\bar{\pi} + (1-p) \cdot (\bar{V}\bar{\pi} + \bar{V}\theta_L - \bar{V}\mathbb{E}[\theta_i \mid s^A = 1, s^B = 0])$. Since $\mu = p$, we derive $\mathbb{E}[\theta_i \mid s^A = 1, s^B] = \bar{\theta}$. If B does not file a patent, its expected payoff is $p \cdot \bar{V}\pi_d + \frac{1}{2}\bar{V}(\theta_H - \bar{\theta}) + (1-p)\bar{V}\pi_d + (1-p)\bar{V}(\theta_L - \bar{\theta})$. Then, $s^B(\bar{V}) = 0$ is a best response if and only if $p \cdot \bar{V}\bar{\pi} + (1-p) \cdot \bar{V}\bar{\pi} + (1-p)\bar{V}(\theta_L - \bar{\theta}) \geq p \cdot \bar{V}\pi_d + \frac{1}{2}\bar{V}(\theta_H - \bar{\theta}) + (1-p)\bar{V}\pi_d + (1-p)\bar{V}(\theta_L - \bar{\theta})$ which holds true if and only if $\bar{\pi} \geq \pi_d + \frac{1}{2}(\theta_H - \bar{\theta})$ which simplifies to $\bar{\pi} - \pi_d \geq \frac{\theta_H - \bar{\theta}}{2}$, which is exactly the condition established in the Proposition 7. Then, we established that $s^B(\bar{V}) = 0$ assuming $\bar{\pi} - \pi_d \geq \frac{\theta_H - \bar{\theta}}{2}$. Let us now check if A has a profitable deviation from $s^A_H = 1$ to $s^A_H = 0$. In such a case, A's expected payoff from filing a patent is $\frac{1}{2}V_H(\bar{\pi} + (1-\alpha)\pi_d) + V_H\theta_H - \bar{V}\theta_H$, and its expected payoff from not filing is $V_H(1-\alpha)\pi_d + V_H\theta_H - \bar{V}\bar{\theta}$. Then, A finds it optimal to not file a patent whenever

$\frac{1}{2}V_H(\bar{\pi}+(1-\alpha)\pi_d)+V_H\theta_H-\bar{V}\theta_H \leq V_H(1-\alpha)\pi_d+V_H\theta_H-\bar{V}\bar{\theta}$ which simplifies to $\frac{\bar{\pi}-(1-\alpha)\pi_d}{2(\theta_H-\bar{\theta})} \leq \frac{\bar{V}}{V_H}$ which is $\frac{\alpha\pi_m}{2(\theta_H-\bar{\theta})} \leq \frac{\bar{V}}{V_H}$. □

Observation 4. The conditions for the asymmetric information pooling equilibria are $\frac{\alpha\pi_m}{2(\theta_H-\bar{\theta})} \leq \frac{\bar{V}}{V_H}$ and $\bar{\pi}-\pi_d \geq \frac{\theta_H-\bar{\theta}}{2}$. Realize that the second expression can be rewritten as $\alpha(\pi_m-\pi_d) \geq \frac{\theta_H-\bar{\theta}}{2}$. Hence, this condition will reflect the trade-off faced by firm B while deciding between filing a patent to (possibly) enjoy a monopoly profit (in which case firm B cannot hire type H) and being unknown by not filing a patent to hire type H (in which case it risks overpaying type L and losing monopoly profit but turnover is possible). Hence, the condition reflects this trade-off faced by firm B; an increase in property rights or the difference between monopoly and duopoly profits will give firm B incentives to file a patent whereas a smaller prior probability or a higher ability difference between types will discourage firm B to file a patent. On the other hand, the second condition $\frac{\alpha\pi_m}{2(\theta_H-\bar{\theta})} \leq \frac{\bar{V}}{V_H}$ reflects the trade-off faced by firm A, in which A decides between filing a patent for monopoly profit by risking turnover and not filing a patent to guarantee no turnover at lower wages by sacrificing possible monopoly profit. Notice that an increase in $\bar{V}$ makes firm A less likely to file a patent since with higher $\bar{V}$, revealing type H inventor will cost more to firm A, and a lower production by type H meaning a lower value for V_H will make A more likely to file a patent. Finally, a greater ability difference between inventor types will also push A to rely on secrecy. On the other hand, increased monopoly profit or stronger property rights will give A incentives to file a patent. Combining the two expressions, we derive the following condition to sustain the equilibrium proposed in proposition 7; $\frac{\theta_H-\bar{\theta}}{2}+\alpha\pi_d \leq \alpha\pi_m \leq 2\cdot\frac{\bar{V}}{V_H}(\theta_H-\bar{\theta})$. If we further assume that $\pi_d=0$ we derive another necessary condition which is $\frac{\bar{V}}{V_H} \geq \frac{1}{4}$. Finally, if we let $\pi_m=1$ and $\pi_d=0$, the condition simplifies to $\frac{\theta_H-\bar{\theta}}{2} \leq \alpha \leq 2\cdot\frac{\bar{V}}{V_H}(\theta_H-\bar{\theta})$ which can further be simplified to $\frac{1}{2} \leq \frac{\alpha}{\theta_H-\bar{\theta}} \leq 2\cdot\frac{\bar{V}}{V_H}$.

Observation 5. Under the condition that $\frac{\theta_H-\bar{\theta}}{2}+\alpha\pi_d \leq \alpha\pi_m \leq 2\cdot\frac{\bar{V}}{V_H}(\theta_H-\bar{\theta})$, we established there is a pooling equilibrium in which firm A does not file a patent both when the inventor is of type H and L, and B always files a patent. Hence, this condition represents the impact of information asymmetry between firms on optimal patent filing decision. This supports that firm A has an incentive to distort optimal patenting decisions; the distortion is stronger under weak property rights and "relatively higher competition", by the former we mean a lower value of α and by the latter we mean the condition based on $\frac{\bar{V}}{V_H}$.

While there are other (possible) equilibria depending on the restriction on off-the-equilibrium path beliefs and whether mixed strategies are allowed, we conclude the analysis of our main model here. In the following subsection, we shortly discuss the case when firms believe that they possibly but not definitely produce the same innovation. In other words, when $\beta \in (0, 1)$.

We will touch on the results, shortcomings and possible extensions of the model in Section 4.

3.2.3 Simultaneous Innovation with Exogeneous Belief $\beta \in (0, 1)$

In this section we will shortly discuss the case when $\beta \in (0, 1)$. First, let us make some simplifications in the equations and show our aim in a simpler way. We remind ourselves that $\bar{\pi} = \alpha\pi_m + (1 - \alpha)\pi_d$ as before. Under the full information and from Proposition 1, wage offers are as follows: $w_H^A = w_H^B = \beta \cdot \bar{V}\theta_H$ as discussed while introducing the model. Here, the outside option of type H is determined at the rate β since now knowledge transfer is costlier for firm B under the assumption that firms do not definitely produce the same innovation. However, assuming full information; whenever firm A files a patent, firm B observes whether they produce the same innovation and extends the wage offer after this decision. We represent our thoughts in two different ways here. In case β is just similarity between the innovations produced at two firms, then, we argue that the wage offer is still characterized by the function f as before, hence; $w_H^A = w_H^B = \beta \cdot \bar{V}\theta_H$, $w_L^A \in [0, \beta \cdot \bar{V}\theta_L)$, and $w_L^B = \beta \cdot \bar{V}\theta_L$. In case we treat β as the probability that firms A and B produce the same innovation, and we assume that knowledge transfer is possible only when A and B have exactly the same innovation; then we must treat this as there is no outside option for the inventor regardless of his type in our model. However, we treat β as the former and argue that β represents the similarity between the projects held at the two firms, and β is common knowledge among them. Therefore, wage offers are are characterized as we discussed before. Moreover, there is turnover only when the inventor is of type L, since we assume $\bar{V} \in [V_L, V_H]$ which implies that type H's outside option can never exceed his marginal value to A. Therefore, filing a patent is not a decision related to turnover under full information. For that reason, we disregard the wage offers and turnover in the maximization problem regarding the optimal patent filing decision. Secondly; as opposed to the case when $\beta = 1$, now even under full information benchmark, firms face a trade-off while choosing between patents and secrecy for the following reason. Under our initial assumption that property rights yield monopoly profit at the rate $\alpha \in (0, 1)$, firms face a possible loss of profit when they file a patent; however, they can enjoy a monopoly profit by relying on secrecy as long as the innovation produced at A and B are not the same. To clarify, if A and B produce the same innovation and they both rely on secrecy, they only get duopoly profit $\pi_d < \pi_m$ since they share the market. However, if they do not produce the same innovation, they can either rely on secrecy and fully enjoy monopoly profit π_m or they can file a patent and earn $\alpha\pi_m + (1-\alpha)\pi_d = \bar{\pi} < \pi_m$. To summarize, firms optimal strategy is to file a patent only when they produce the same innovation; they would like to rely on secrecy when there is no simultaneous innovation. This is the trade-off faced by two firms. Finally, the threshold condition to file a patent or to rely on secrecy will be the same for A and B regardless of the type of the inventor. This is because the trade-off is only to the extent they produce the same innovation, hence, they face the same exogenous risk.

Below we give the maximization problems to choose optimal s^A_H s^A_L and s^B. Since $s^A_H = s^A = L$ under full information, denote this with s^A in B's problem so that we do not have to write an expected maximization problem for B with respect to the prior $p \in (0,1)$.

$$s^A = s^A_H = s^A_L \in \underset{x\in\{0,1\}}{\arg\max} \quad \beta \cdot \Bigg[x \cdot \big(s^B \pi_d + (1-s^B)(1-\alpha)\pi_d\big) \\ + (1-x)\big(\frac{s^B+1}{2}\bar{\pi} + \frac{1-s^B}{2}(1-\alpha)\pi_d\big)\Bigg] \\ + (1-\beta) \cdot \Big[x \cdot \pi_m + (1-x) \cdot \bar{\pi} \Big] \tag{3.15}$$

$$s^B \in \underset{x\in\{0,1\}}{\arg\max} \quad \beta \cdot \Bigg[x \cdot \big(s^A \pi_d + (1-s^A)(1-\alpha)\pi_d\big) + (1-x)\big(\frac{s^A+1}{2}\bar{\pi} + \frac{1-s^A}{2}(1-\alpha)\pi_d\big)\Bigg] \\ + (1-\beta) \cdot \Big[x \cdot \pi_m + (1-x) \cdot \bar{\pi} \Big] \tag{3.16}$$

Proposition 8. *Under full information, firms A (both when the inventor is of type H and L) and B file a patent if the following condition is satisfied. In other words, $s^A_H = s^A_L = s^B = 0$ in equilibrium if:*

$$\big(\textit{Patent filing threshold for} \quad \beta \in (0,1)\big) : \quad \frac{\beta}{1-\beta} \geq \frac{2 \cdot (1-\alpha)(\pi_m - \pi_d)}{\alpha \pi_m} \tag{3.17}$$

Which can be rewritten as

$$\frac{\beta \cdot \alpha}{(1-\beta)\cdot(1-\alpha)} \geq \frac{2\cdot(\pi_m - \pi_d)}{\pi_m} = 2 \cdot \left(1 - \frac{\pi_d}{\pi_m}\right) \tag{3.18}$$

Otherwise, firms choose to rely on secrecy in equilibrium and $s^A_H = s^A_L = s^B = 1$.

Proof. First, let us assume $s^A_H = s^A_L = s^B = 0$. Since the maximization problem is the same for all of them, let us consider $s^A_H = 0$. Suppose for contradiction that A has a profitable deviation to $s^A_L = 1$. Then, from equation 3.15, it must be true that

$$\beta \cdot \big(\frac{\bar{\pi} + (1-\alpha)\pi_d}{2}\big) + (1-\beta)\cdot \pi_d < \beta \cdot (1-\alpha)\pi_d + (1-\beta)\cdot \pi_m$$

Rewriting $\bar{\pi} = \alpha\pi_m + (1-\alpha)\pi_d$, the inequality simplifies to $\beta \cdot (\frac{\alpha\pi_m}{2} + (1-\beta) \cdot \bar{\pi} < \beta \cdot (1-\alpha)\pi_d + (1-\beta) \cdot \pi_m$, which further simplifies to $\frac{\beta \cdot \alpha \cdot \pi_m}{2} < (1-\beta) \cdot (\pi_m - \bar{\pi}) = (1-\beta) \cdot (1-\alpha) \cdot (\pi_m - \pi_d)$. This gives the final condition $\frac{\beta \cdot \alpha}{(1-\beta) \cdot (1-\alpha)} < \frac{2 \cdot (\pi_m - \pi_d)}{\pi_m}$ which contradicts 3.18. Hence, the patent filing threshold for $\beta \in (0,1)$ is given in equation 3.17 and is simplified in 3.18. □

Observation 6. Here we discuss the full information results from the previous proposition. We found the threshold to file a patent as $\frac{\beta \cdot \alpha}{(1-\beta) \cdot (1-\alpha)} \geq \frac{2 \cdot (\pi_m - \pi_d)}{\pi_m}$. First, we observe that the first derivative of the left hand side with respect to β is

$$\frac{\alpha}{(1-\beta)^2 \cdot (1-\alpha)} > 0 \quad \forall \alpha \in (0,1)$$

and the first derivative with respect to α is

$$\frac{\beta}{(1-\alpha)^2 \cdot (1-\beta)} > 0 \quad \forall \beta \in (0,1)$$

Therefore, for given values of π_m and π_d; firms are more likely to file a patent whenever there is an increase in α or β or both. Secondly, observe that for any profit ratio $\frac{\pi_d}{\pi_m}$; strong property rights ($\uparrow \alpha$) and more similar (more likely simultaneous) innovation ($\uparrow \beta$) are associated with more likely patent filing and less likely relying on secrecy. Finally, an increase in π_m or a decrease in π_d or both at the same time leads to less patents for given values of α and β. The intuition here follows that a greater monopoly profit leaves less room for a firm to take the risk of imitation (since a patent grants a monopoly at the rate α only), thus, the firm is less likely to file a patent; whereas a smaller duopoly profit discourages the firm to file a patent by the same arguments. Since what matters for the condition is the relative profit ratio $\frac{\pi_d}{\pi_m}$, an increase (decrease) in π_m (π_d) is cancelled with the exact same decrease (increase) in π_d (π_m). Finally, let us assume $\frac{\pi_d}{\pi_m} = \frac{1}{2}$. Then; the condition to file a patent simplifies to

$$\beta \geq (1-\alpha)$$

which reflects the trade-off between filing a patent under simultaneous innovation and losing some profit under patents due to weaker property rights compared to relying on secrecy. Ultimately, it becomes a decision of whether the rival firm is likely to take the lead in an innovation or not, and whether it is worth revealing important information with patents.

Chapter 4

DISCUSSION & IMPLICATIONS

In this section, we briefly discuss the paper, propose alternative mechanisms to explain our initial hypothesis, and finally address the limitations. First, throughout the paper, we focus on the decisions made by firms and the inventor plays a role only when firms extend a wage offer. We simply assume the inventor accepts the highest wage offer and remains at the incumbent in case of a tie. The latter argument follows the idea that turnover must be costly for an inventor, especially when the outside offer is exactly the same as his or her current wage. However, an inventor's decision to a job offer may include other important aspects of a job; location, prestige, job security, firm culture and more. Therefore, although we disregard these in this paper, we believe they are important factors. More specifically, inventors are of high importance to R&D firms, (or firms' R&D department), but we also expect them to demand higher job security compared to other type of corporate workers, since innovations take longer than usual production.

We assume exogenous production made by firm B, whereas A's production was simply restricted to exogenous values produced by types. This is indeed another restriction we are aware of that is not very realistic. In a more complicated setup, an inventor can exert effort to produce a value which gives the inventor another strategic decision. While this feature is reasonable and would bring a higher credit to our model, it is not at the reach of this paper. In such a setup though, we would expect the inventor to strategically evaluate the patent filing decision of the incumbent and change their level of effort accordingly. Simply then information asymmetry moves into another dimension; incumbent receives a signal about the ability of the inventor by observing the effort exerted by the inventor and the rival firm receives another signal from the incumbent about the ability of the inventor through observing the patent filing decision of the incumbent firm. This sounds as exciting as it is challenging, however, we still expect to see a distortion in patent filing decision by the incumbent depending primarily on the exogenous values.

Finally, another limitation from the inventor's perspective, a continuum of types would bring a higher level of discussion to the model, and the equilibria would not be limited as in our binary types model. However, this paper aims to simply show that information asymmetry and signaling role of patents can distort optimal patent filing decision of a firm that is in an industry where simultaneous innovations are (highly) possible. We believe in a setup where types are defined on a continuum, the results would somehow coincide with the ones proposed in this paper; a threshold ability would determine the types for whom the incumbent firm files a patent, and the rest of the types for whom the incumbent chooses to rely on secrecy and does not file a patent.

We also like to shortly discuss some implications. First, our focus is on simultaneous innovation, thus, implications should be investigated in industries where this is likely. One way to explore this could be by going over Court Cases in which intellectual property disputes are resolved. While going over these cases, especially those in which one party claims to be the legal owner of an innovation while the other party is granted a patent; one might have a clue about the industries in which firms are more likely to experience such legal cases. Secondly, after narrowing down the industries and even the firms that are at an intense rivalry, one can investigate the turnover of top scientists/inventors among those firms. If turnovers can be explained by being granted patents and listing the inventor as the contributor, one can then compile a list of the firms and inventors that fit these criteria.

When turnovers are explained at a lower rate by patents, then it might support our hypothesis; incumbent distorts the optimal patent filing whenever turnover of a top scientist is highly costly. This distortion in reality may not go as far as relying on trade secrecy rather than filing a patent but also may remain as simply giving less credit to the scientist as a contributor on a patent. Distortion might be by attributing the work to other people and to the help/fund of other organizations, or simply by listing the whole team as the contributor rather than the top inventor/scientist. Finally, use and removal of non-compete agreements can provide help for an empirical setup by addressing some of the critics related to endogenous decision variables.

Lastly, even though we use ability as a top indicator of productivity in our model, measuring this in real life is not quite likely, whether it is the ability of a top scientist or any non-science person. However, other measures related to productivity such as number of patents, citations, highest academic degree, salary increase in the years of experience, move-up in the industry (one way to consider this is a promotion to a higher title and/or to another firm that is larger in the market") and by larger it could be in research budget rather than firms' market cap. One final suggestion to measure an inventor's promotion in an industry is by analyzing the research budget the inventor manages throughout years, of course controlling for inflation, economic booms/recessions, industry and research trends. While the budget a scientist at a corporate R&D manages may be classified information, information of who gets which funds and grants are mostly (if not completely) accessible for those working in academia.

Chapter 5

EXTENSION: A SIMPLE MODEL OF EFFORT

In this section, our aim is to build a simple model to show that ex ante commitment to filing a patent by the incumbent firm may lead to inefficient results. In this setup, firm A commits to filing a patent whenever the production is higher than a threshold. A employs an inventor that is type H with a common prior $p \in (0,1)$ and type L with the remaining probability $(1-p)$. Types have the ability $\theta_H > \theta_L > 0$; notice that ability is no more restricted to the set $(0,1)$. Firm A's production is determined by the effort level chosen by i. Formally, i chooses an effort level $e \in [0,1]$ and A's production is denoted by $V^A = e$. Borrowing from the singaling literature, effort is costlier for type L; more specifically, exerting effort level $e > 0$ costs $\frac{e}{\theta_i}$ to inventor $i \in \{H, L\}$, and exerting effort level $e = 0$ costs zero to both types. Firm B's production level $\bar{V}$ is exogenous with $\bar{V} \in [0,1]$. In addition, same as in the main model, $\bar{V}$ is uniformly distributed on the interval $[0,1]$, thus, $\mathbb{E}[\bar{V}] = \frac{1}{2}$. Firm A ex ante commits to filing a patent whenever the production level of A is (weakly) greater than the production level at firm B. More formally, A's filing a patent decision $s^A = 0$ whenever $V^A \geq \bar{V}$. Therefore, effort level chosen by inventor i determines whether a patent is filed or not. In case a patent is filed by A, then i's true type is no more revealed to firm B since even A may not fully observe the type. However, B forms a belief about i's type in the following way: If A files a patent, then B believes i is type H, if A does not file a patent then B's belief is the prior. Let $\mu(e) \in [0,1]$ be the function denoting the belief firm A forms that i is type H whenever the effort level e is chosen by i. Let e_i denote the effort level chosen by type $i \in \{H, L\}$. Then, we derive the following conditions from Bayes' Rule:

- $\mu(e) = 1$ if $e_H = e \neq e_L$

- $\mu(e) = 0$ if $e_H \neq e = e_L$

- $\mu(e) = p$ if $e_H = e = e_L$

- $\mu(e) \in [0,1]$ if $e_H \neq e$ and $e_L \neq e$ (off-the-equilibrium path belief)

Following this, similar to the main model, i's outside option is determined by the function f, where f simply yields B's expected profit from hiring i. Hence, whenever A files a patent, B extends a wage offer $\bar{V} \cdot \mathbb{E}[\theta_i \mid s^A = 0]$ to inventor i which is denoted by $w^B(s^A = 0)$ and is equal to $\bar{V} \cdot \theta_H$, and if A does not file a patent, B extends a wage offer $\bar{V} \cdot \mathbb{E}[\theta_i \mid s^A = 1]$ to inventor i which is denoted by $w^B(s^A = 1)$ and is equal to $\bar{V} \cdot \bar{\theta}$ where $\bar{\theta} = p \cdot \theta_L + (1-p) \cdot \theta_H$. Finally, A's wage offer is characterized by this expectation; if A believes i is type H, then A extends a wage offer

$$w^A(e) = \begin{cases} \theta_H \bar{V} & \text{if} \quad \mathbb{E}[\bar{V}] \leq e \\ \bar{\theta}\bar{V} & \text{otherwise.} \end{cases}$$

Assumption 3. *Let* $\frac{2}{\theta_H} \leq (\theta_H - \bar{\theta}) \leq \frac{2}{\theta_L}$ *be true.*

Replacing $\mathbb{E}[\bar{V}] = \frac{1}{2}$; observe that type H maximizes the following problem to choose optimal e_H.

$$\begin{aligned} &\max_{e \in [0,1]} \quad e \cdot \frac{\theta_H}{2} + (1-e) \cdot \frac{\bar{\theta}}{2} - \frac{e}{\theta_H} \\ &\text{s.t.} \quad e \leq 1 \\ &e \geq 0 \end{aligned} \tag{5.1}$$

Proposition 9. *Under assumption 3,* $e_H = 1$, $e_L = 0$, $\mu(e = 1) = 1$, $\mu(e = 0) = 0$ *paired with off the equilibrium path belief* $\mu(e) = 0$ *if* $e \neq 1$ *along with the wage offers* $w^A(e = 1) = \frac{\theta_H}{2}$, $w^A(e) = \frac{\theta_L}{2}$ *if* $e \neq 1$, $w^B(s^A) = \bar{V}\theta_H$ *if* $e = 1$ *and* $w^B(s^A) = \bar{V}\bar{\theta}$ *if* $e \neq 1$ *constitute a separating equilibrium in which types are fully distinguished by firm A.*

Proof. We will check whether $e_H = 1$ maximizes the expression in (18), and incentive compatibility constraints for the low and high type, so that no type has an incentive to imitate the other. First, in any separating equilibrium $e_L = 0$, as otherwise effort is costly for the low type. Hence, if type L's incentive compatibility is satisfied, then L's expected profit from exerting zero effort is equal to $\frac{\bar{\theta}}{2}$. This is because firm B cannot distinguish between types and B's belief is prior. Since we restrict off-the-equilibrium path belief $m(e) = 0$ for any $e \in [0, 1)$, then e cannot make better by deviating to any other $e \neq 1$. If L deviates to $e = 1$, then L's expected profit is $\frac{\theta_H}{2} - \frac{1}{\theta_L}$, since it is costlier for L to exert the same effort compared to type H. However, this is a profitable deviation if and only if $\frac{\theta_H}{2} - \frac{1}{\theta_L} > \frac{\bar{\theta}}{2}$, which simplifies to $(\theta_H - \bar{\theta}) > \frac{2}{\theta_L}$ and is false given assumption 4. Hence, $e_L = 0$ is incentive compatible for type L. Suppose H has a profitable deviation, then it must be to $e = 0$, as otherwise H exerts an effort level that is costlier but gives the same expected profit. However, H deviates from $e_H = 1$ to $e = 0$ if and only if $\frac{\theta_H}{2} - \frac{1}{\theta_H} < \frac{\bar{\theta}}{2}$, which simplifies to $(\theta_H - \bar{\theta}) < \frac{2}{\theta_H}$ and is false given assumption 4. Hence, under assumption 4 and the restriction on off-the-equilibrium path beliefs, $e_L = 0$ and $e_H = 1$ are part of an equilibrium. Finally, in any separating equilibrium, A perfectly distinguishes types and extends the outside option of outside H and L given their types; which are $w^A(e = 1) = \frac{\theta_H}{2}$, $w^A(e) = \frac{\theta_L}{2}$ for any $e \in [0, 1)$ respectively. Finally, B extends a wage offer $w^B(s^A) = \bar{V}\theta_H$ if $e = 1$ and $w^B(s^A) = \bar{V}\bar{\theta}$ if $e \neq 1$, since B believes i is type H whenever A files a patent, which happens when $e = 1$ under this equilibrium, and B believes i is type H with probability $p \in (0, 1)$ (common prior). □

Observation 7. Under assumption 3; notice that the above equilibrium will leave firm A with turnover whenever i is type L, and when i is type H and $\bar{V} > \frac{1}{2}$. Since B's production is uniformly distributed on $[0, 1]$, the latter happens with 0.5 probability. Therefore, ex ante commitment to filing a patent leaves firm A with possible turnover whenever production is a function of the effort exerted by i. In the main model, A never experiences turnover of type H under patents.

Proposition 10. *Suppose assumption 3 fails; then at least either type H or L has an incentive to deviate to the effort level chosen by the other type. Hence, a separating equilibrium cannot be sustained under such a case.*

Proof. Focus on $\frac{2}{\theta_H} \leq \frac{2}{\theta_L} \leq (\theta_H - \bar{\theta})$. Then, $e_H = e_L = 1$ along with the wage offers $w^A(e = 1) = \frac{\bar{\theta}}{2}$ and $w^A(e) = \left[\mu(e) \cdot \frac{\theta_H}{2} + (1 - \mu(e)) \cdot \frac{\bar{\theta}}{2}\right]$ if $e \neq 1$ where $\mu(e)$ denotes the off-the-equilibrium path belief of firm A for any $e \in [0, 1] \setminus \{1\}$. Hence, type L's optimal choice is to imitate type H, therefore, this leads to a pooling equilibrium in which types cannot be distinguished by A. Yet, since the optimal effort choice by both types are 1, which is greater than $\bar{V}$ with probability 1 (because $\bar{V} \in [0, 1]$; then A's ex ante commitment to filing a patent leaves A with patents under both cases. Moreover, since B believes i is type H when A files a patent, then $w^B(s^A = 0) = \bar{V}\theta_H$. Therefore, both types have no incentive to deviate whenever off-the-equilibrium path belief is $\mu(e) =$ for any $e \in [0, 1)$. Now $w^B(s^A = 0) = \bar{V}\theta_H$ which is greater than $w^A(e = 1) = \frac{\bar{\theta}}{2}$ whenever $\bar{V} > \frac{\bar{\theta}}{2 \cdot \theta_H}$. □

Observation 8. Whenever assumption 3 fails, and more specifically whenever $\frac{2}{\theta_H} \leq \frac{2}{\theta_L} \leq (\theta_H - \bar{\theta})$, type H and L moves to firm B with probability $(1 - \frac{\bar{\theta}}{2 \cdot \theta_H})$. Moreover, regardless of turnover, type L is overpaid with the amount equal to $\frac{\bar{\theta}}{2} - \frac{\theta_L}{2}$ in case of no turnover; and with the amount equal to $\bar{V}\theta_H - \frac{\theta_L}{2}$. However, type H is underpaid with the amount equal to $\frac{\theta_H}{2} - \frac{\bar{\theta}}{2}$ in case of no turnover; and is either underpaid with the amount equal to $\frac{\theta_H}{2} - \bar{V}\theta_H$ if $\bar{V} > \frac{1}{2}$, and otherwise H is overpaid equal to the same amount. The key observation is ex ante committing to file a patent leads to inefficient turnover. Let's suppose $V = 3/4$. Then, there is turnover under both types. However, by extending a wage offer $w^A \in [3/4, 1)$, A can make a positive profit from hiring H, whereas B makes a net profit of zero. This implies there is room for pareto improvement; information asymmetry combined with ex ante commitment leads to inefficiency.

Chapter 6

CONCLUSION

While the literature on patents is quite extensive and researchers in this field have made substantial contributions, signaling role of patents are mostly investigated from firms' perspective. Their contribution brought many explanations to and shed light on the phenomena of why firms file a patent to protect their intellectual property while relying on trade secrecy is more commonly preferred and is less costlier; the literature did not touch on the role of the patents and how they shape the career prospects of their contributors. From this perspective, we argue that a patent can also be informative about its inventor rather than the firm only; and can provide enough information (signal) to rival firms to assess the productivity of an inventor. Therefore, our aim throughout this paper is to show that filing a patent can as well send signals about an inventor.

In order to support our claim in a more formal way, we built a simple but reasonable model of competition between two firms. These firms were forced to file a patent in the full information benchmark of the main model since they compete with each other under simultaneous innovation. In this setup, firms aim to capture both the market profit and the worker so that they can earn more from their production. Our results from asymmetric information are based on the trade-off between revealing the innovation value, revealing the inventor type and risking the monopoly profit. The results under asymmetric information support our initial claim that firms have incentives to distort their optimal patent filing decisions whenever the inventor is essential to the firm compared to one period monopoly profit. These results also coincide with the understanding that strong property rights encourage firms to file a patent whereas weaker protection forces them to rely on secrecy while choosing how to protect their intellectual property.

We believe this paper contributes to the literature by building a rather simple but reasonable signaling model in which firms face a realistic trade-off between risking turnover and profits. Moreover, our model is consistent with the literature by featuring the claim that secrecy provides more protection than patents. To clarify, we assume a non-perfect protection from patents and a perfect protection from secrecy, though relying on secrecy possibly leaves the firm with partial duopoly profit due to simultaneous innovation. We reach a threshold to illustrate another trade-off firms can face in real life. This revolves around the risk of simultaneous innovation resulting in smaller profits due to not filing a patent, and being granted a partial monopoly due to revealing information through patents. Our rather implicit assumption here is patents make it easier for others to imitate even though there is legal protection. However, innovations that are kept as a secret cannot be imitated unless another firm produces a very similar (or the same) one. Finally, our extension model suggested that ex ante commitment to patents by the incumbent is detrimental to both profits and turnover. Indeed the results from the extension model suggest that under some assumptions the equilibrium we reach leads to inefficiency by turnover.

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Chapter 7

APPENDIX

Discussion of Profits

Firms A and B compete in two distinct markets; the product market and the innovation market. Let us describe the firms' profits from each market separately.

1- Product Market Profit: A firm's profit from the product market is determined beforehand and can take the form of a monopoly profit, a duopoly profit or a convex combination of both, depending on the firms' IP choice and the occurrence of simultaneous innovation. The IP choice and simultaneous innovation together determine whether a monopoly is (fully or partially) granted to a single firm. The value of the innovation further determines the portion of the market captured by the firm. For instance, if firm j is granted a monopoly in the product market and has produced an innovation valued at k, then its profit from the product market will be k times the monopoly profit. Hence, the innovation value has a direct impact on a firm's profit in the product market. Note that the innovation value is not restricted to be less than or equal to 1, meaning that high-value innovations can increase the size of the product market, whereas low-value innovations can decrease it.

2- Innovation Market Profit: A firm's profit from the innovation market depends on the successful implementation of a project related to the innovation produced in the first period. To clarify, in the first period, firms A and B invest in projects leading to innovations with specific values. For simplicity, we assume that the initial investment cost has already been incurred, making the investment decision non-strategic. The implementation of a project in the second period is successful only if firm j employs the inventor, and the ability level of the inventor determines the probability of successful implementation. The payoff for a firm from the implementation of a project in the second period is simply the value produced in the first period, denoted by V_i for $i \in \{H, L\}$ in the case of firm A where $V_H > V_L \geq 0$. For firm B, the payoff from implementing a project is represented by $\bar{V}$, which is drawn from $[V_L, V_H]$ according to the probability density function g. Consequently, the competition in the innovation market revolves around firms racing to hire the inventor in the second period so that they can assign the inventor to the implementation of their project.

To clarify, we assume firm A's innovation value produced in the first period depends on the type of the inventor initially employed by A, whereas B's production is drawn from a certain set. After the production phase of a project, at the end of period 1, firms A and B decide whether to file a patent or not. When a firm does not file a patent, it chooses to protect the innovation by relying on secrecy. The patenting decision of firm $j \in \{A, B\}$ is denoted by s^j, where $s^j = 1$ if the firm chooses to rely on secrecy, and $s^j = 0$ if it files a patent. In the case of both A and B producing the same innovation and filing a patent, each firm is granted the patent with probability 0.5. Otherwise, each firm is granted a patent with a probability of 1 whenever it files for one. Filing a patent is assumed to be free for both firms. A patent grants a monopoly to a firm at the rate $\alpha \in (0, 1)$. In the simplest understanding, α represents the strength of property rights in this industry, indicating the rate at which a patent holder is legally protected and obtains a monopoly profit. If a firm chooses to rely on secrecy, it either shares a duopoly profit under simultaneous innovation or receives a monopoly profit otherwise. This represents a perfect protection from relying on secrecy but also implies that firms have to share the profit in the market in the case of simultaneous innovation.

After the patenting decision and the grant of patents (if any), firms have the option to extend a wage offer to the inventor given the patent filing decision of the other firm. We denote the wage offer of firm j as w^j when the inventor's type is not observed by firm j and as w_i^j if it is observed by (or revealed to) j. The inventor's payoff is his wage, hence, he accepts the highest wage offer. In case of a tie, we assume that the inventor does not move to B.

In the second period, firm A or B employs the inventor $i \in \{H, L\}$ and assigns the inventor to implement the project related to the innovation produced in the first period. At the end the of the second period, firms realize their payoffs from two sources. Firstly, they receive payoffs from the product market based on their IP choices and innovation values. Secondly, firms (possibly) implement the project, and if the implementation is successful then firms receive payoffs equal to the value of the innovation produced in the first period. In summary, the first source of payoffs lie on the simple way of making sales and penetrating the market, whereas the second source comes from directly monetizing the value created from an innovation, such as franchising or follow-on innovations.

A patent reveals information about both the innovation value and the inventor, while relying on secrecy perfectly protects the firm from revealing its private information. The property rights under patents are not perfect, so a firm with a patent enjoys a monopoly profit at a rate $\alpha \in (0, 1)$ and earns duopoly profit with the remaining $(1 - \alpha)$ probability. Firms may also earn a portion of the duopoly profit when their rival is granted a patent due to the imperfect property rights.

Let us summarize firms' profits for each possible case.

If firms do not have the same innovation, each firm enjoys a monopoly profit π_m from the product market depending on the level of property rights. Under patents, they receive a monopoly profit π_m with probability $\alpha \in (0, 1)$ and earn a duopoly profit π_d with the remaining $(1 - \alpha)$ probability. Under secrecy they receive π_m.

If A and B produce the same innovation, the firm with the patent (if any) earns a monopoly profit π_m with probability α and earns duopoly profit π_d with the remaining probability $(1 - \alpha)$. In such a case, the other firm without a patent still receives π_d with $(1 - \alpha)$ probability. This is due to imperfect property rights under patents.

If neither firm is granted a patent, with probability 1, each firm earns a duopoly profit π_d under simultaneous innovation, and they earn π_m otherwise (when there is no simultaneous innovation). We assume that $\pi_m > \pi_d \geq 0$.

Firms' profits from the product market are captured at rates V_i for firm A and $\bar{V}$ for firm B, as discussed earlier. The innovation value determines the market size, but the values are not necessarily restricted to the interval $[0, 1]$ (this would rather be helpful for simplicity but does not change the equilibrium). Thus, high-value innovations can increase the market size.

The second part of firms' payoffs comes from the implementation of a project, which yields a payoff equal to the value of the innovation. The probability of implementation is θ_i for firm A when it employs the inventor, resulting in a payoff of V_i with probability θ_i. For firm B, the probability of implementation is $\theta_i\beta$ when it employs the inventor, resulting in a payoff of $\bar{V}$ with probability $\theta_i\beta$. The difference in probabilities is due to the familiarity of the inventor with the innovation produced at firm B to the extent β being close to 1. Our rationale here is as follows; whenever a firm employs an inventor who has previously worked on a related project and created a specific value, the inventor can monetize this value at a certain rate. This could be a follow-on innovation, implementation of a related project, or implementation of the project for franchise purposes. Hence, the implementation is not exactly the same for firm B as it is for firm A unless $\beta = 1$. Mostly in this section, we will focus on the case when $\beta = 1$. However, the difference is not a critical issue due to the (expected) zero-profit condition for the rival firm(s) from hiring the inventor.