Licensing Patent Rights and Trade Secrets

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Abstract

The purpose of this study is to examine the strategic interactions between two innovating firms that aim at maximising their profits. Of the two firms, one is endowed with a process invention and has to decide whether to file for a patent or rely on secrecy, and the other is a competing firm that can enter the market through technology transfer or imitation. The model considers that imitation is uncertain, costly, and takes time to materialize, as well as that trade secrets can accidentally leak to the public according to a Poisson process. The analysis suggests that patenting might be more or less preferable than secrecy, depending on the efficiency of the imitation technology and the strength of intellectual property protection. We also show that if the technological efficiency to imitate a patented invention and imitate a secret are sufficiently low, then a technology transfer would always occur, regardless of the protection choice of the inventor. Conversely, highly efficient imitation technologies lead to imitation instead of licensing. Acknowledging that, a trade secret might accidentally leak to the public and thus lose its economic value, thereby rendering secrecy less preferable to patenting. Additionally, the risk of leakage might also lead to more imitation than licensing. Finally, considering that the probability of leakage might increase with the number of firms practising a secret, the study expects an increase in the attractiveness of the patent system.

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1 Introduction

This study aims to examine the licensing behaviour of an innovating firm that has developed a technology and should decide the type of intellectual property protection upon which it can rely. We focus on the most common means of protection, enforceable in a court of law, namely patenting and secrecy. The economic literature suggests that, in some technology areas, patents provide better protection than secrets, while, in the other areas, firms favour secrecy over patents to protect their inventions. However, firms use a combination of patent rights and trade secrets (Cohen et al., 2000; Arundel, 2001; Kultti et al., 2007; Hall et al., 2014). Intellectual property or intangible assets, particularly, patents and trade secrets, have become increasingly crucial to businesses and the market economy over the last decade. Ocean Tomo, a firm providing an industry leading array of financial products and services related to intangible assets, estimates that intangibles have emerged as the leading asset class, growing from around 17 per cent of the entire market value of the S&P 500 in 1975 to approximately 87 per cent in 2015.[1] This increased importance of intangible assets and the evolution of business environment during the past decade have, in turn, led to the significant growth of licensing activities by firms, which are aiming to gain a comparative advantage and maximise their profits (Baldi and Trigeorgis, 2014). Prior literature on intellectual property rights (IPRs) has enriched our knowledge on optimal patent design and the choice of intellectual property protection, optimal level of protection and investment in research and development (R&D), patent licensing, and technology transfer; this literature has also explored the effects of IPRs on the incentive to innovate and welfare (Kamien and Tauman, 1984, 1986; Katz and Shapiro, 1985, 1986, 1987; Kamien et al., 1988; Kamien, 1992; Kamien et al., 1992; Gallini and Scotchmer, 2002; Lemley and Shapiro, 2005, 2007, 2013). In this study, we focus on how imitation and the type of intellectual property protection affect technology transfer. This is an important question with a broad impact, also comprising the common appropriability problem discussed widely in the economics of innovation literature.[2]

On the one hand, patenting a process invention enables the public to freely observe and study the protected technology during the patent term without wasting time and effort to rediscover it. Additionally, the patent act permits the public, and, particularly, competitors, to freely use the protected technology after expiration. Furthermore, patent rights are imperfect means of protection, in that others can invent around patented innovative efforts. Prior empirical literature focused on the imperfections of intellectual

[1] For more information regarding the growth of intangible assets, see www.oceantomo.com.

[2] The appropriability problem arises when firms investing in innovation have difficulty securing returns on that investment due to imitation by competing firms.

property protection for successful process inventions, has found that technological advances are typically imitated with a probability of 34 per cent within the first year after its introduction (Levin et al., 1987) and with a probability of almost 60 per cent within the fourth year (Mansfield et al., 1981). On the other hand, a trade secret derives its economic value from not being publicly available. A trade secret is attractive and valuable because it prevents information disclosure and has an indefinite economic life in the absence of an accidental disclosure and independent rediscovery. However, a trade secret typically changes hands among various locations and employees, thereby giving rise to a positive probability of the public disclosure of the secret (Epstein, 2003). This might lead to a loss of the secret's status and its commercial value. Other causes that might diminish the value of a trade secret are weak enforcement of property rights and misappropriation or theft.[3] Cohen et al. (2000) surveyed research laboratories in the US manufacturing sector and found that patenting is the least used protection type of intellectual property. Moreover, Arundel (2001) studied innovative manufacturing firms in the US and showed that secrecy is potentially a more effective means of appropriation than patents. Arora and Ceccagnoli (2006) and Arora et al. (2008) found that licensing through trade secrets occurs less often than licensing through patent rights. Hall et al. (2014) conducted a survey of the economic literature on intellectual property protection and showed that only ten per cent of a sample of innovating firms in the UK rate patent protection as important, around fifteen per cent rate secrecy as important, and more than half of them do not use intellectual property protection.

Previous literature related to licensing of IPRs has widely explored the positive effects of licensing on technology transfer, investment in the subsequent innovation, prevention of socially wasteful investment in R&D, and support for large-scale commercialization. However, licensing of IPRs can also lead to collusion between competing firms, less market competition, less investment in innovation, and hold-up problems on cumulative innovation in certain markets such as telecommunications (Bogers et al., 2012). The aforementioned factors have led policy-makers, practitioners, and scholars to take a strong interest in developing, monitoring, and studying the licensing conduct of innovating firms. Evidently, licensing of IPRs is a very broad topic, and hence, in this study, we focus on technology transfer through patent rights and trade secrets. This is achieved by comparing the profit of a firm that has a new patented technology with that of the profits earned when the same technology is protected by secrecy. The protection of IPRs is imperfect,

[3]One example of trade secret theft is the illegal transfer of Ford Motor Company's documents, which contained trade secrets about design specifications of engines and electric power supply systems, from an ex-Ford project engineer to China, particularly to Ford's rival Foxconn PCE Industry (Almeling, 2012). Additionally, Almeling (2012) argued that countries such as China, Pakistan, and Russia have weak enforcement of trade secrets.

and thus imitation can occur, irrespective of the type of intellectual property protection. Generally, the patent system can be seen as both complementary and a substitute to secrecy (Denicolo and Franzoni, 2008). However, in this study, we consider patenting to be a mutually exclusive alternative to secrecy.[4] We assume that imitation does not lead to potential infringement of patent rights or misappropriation of trade secrecy and that property rights of the new technology cannot be invalidated in a court of law. Additionally, imitation is uncertain, costly, and takes time to materialize. Moreover, the patent term is set to be finite, whereas the length of secrecy protection is meant to be indefinite. However, we assume that secrets can be leaked to the public, as revealed through a Poisson process. Finally, we consider that the ease and time to imitate are dependent on the type of protection employed by the inventor. This framework allows a non-trivial analysis of firms' strategic interactions and their implications for the diffusion of technology.

Consider the following two-stage game. In the first stage, Firm 1 has developed a technology and should decide whether to patent it or keep it a secret. In the second stage, after the type of intellectual property protection has been chosen, Firm 1 and a single potential entrant, Firm 2, should decide whether to enter a licensing agreement regarding the use of the new technology. When the new technology is patented, we assume that Firm 1 has full negotiation power regarding the transfer of the technology rights. Conversely, when the new technology is protected by means of secrecy, we assume that Firm 2 has the complete advantage in the bargaining process. Using Nash bargaining, we also extend the baseline model to allow for all possible combinations of firms' bargaining shares. If technology transfer does not occur, Firm 2 can opt for imitation, regardless of the type of proprietary protection adopted in the first stage of the game. The probability of successful imitation is chosen by Firm 2, which like Firm 1 aims at maximising its expected profit. Evidently, the profit of each firm does not depend only on its individual decisions but also on the actions of the other firm, and thus the equilibrium of the game is determined from the strategic interactions between the two competing firms.

The main findings of the paper are as follows. First, the analysis suggests that the equilibrium protection choice depends on the efficiency of the imitation technology and the strength of intellectual property protection. Furthermore, patent protection might be more or less preferable to secrecy depending on whether certain conditions are satisfied. Second, a technology transfer always occurs if the efficiency to imitate a patented technology and to imitate a secret are sufficiently low. Conversely, if both the imitation technologies are highly efficient, then the imitation would dominate. Third, we

[4] In order for confidential information to be considered a trade secret, it must comply with certain conditions and general standards, which are specified in the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS Agreement).

demonstrate that the risk of accidental leakage lessens the attractiveness of trade secret protection, whereas it might encourage imitation. Fourth, the incentives to patent are fostered based on considering a probability of leakage that depends on the number of firms practising a trade secret.

Section 2 reviews the literature that focuses on the effects of patenting and secrecy on the investment in R&D and the licensing behaviour of innovating firms. Sections 3 presents the model and focuses on technology transfer through patenting and secrecy, whereas Section 4 determines the equilibrium outcomes of the game and discusses the main economic implications of the analysis. Section 5 extends the analysis, relaxing some limitations of the basic model. Section 6 presents reflections and conclusions.

2 Literature Review

This section reviews the literature on innovation and intellectual property that emphasised the imperfect protection and weak enforcement of IPRs, and thus partially addresses the problem of imperfect appropriability. Particularly, the review focuses on the theoretical research that concerns technology transfer and imitation of technological inventions. Additionally, it discusses selected empirical literature that addresses the decision of firms about the type of intellectual property protection upon which it can rely.

2.1 Theoretical Literature

Most of the early theoretical literature in this area focuses on the factors that determine the optimal licensing behaviour of innovating firms and, in turn, the effects of licensing on the diffusion of technology, incentives to innovate, investment in imitation, and social welfare.[5] For example, Friedman et al. (1991) studied the loss of secrecy by accidental leakage and rediscovery considering the lack of protection that characterises the trade secret law. The authors suggest that relying on secrecy might reflect the fact that patenting is unified instead of technology-specific, and thus secrecy might be more beneficial in terms of economic reward and protection time. Likewise, we show that the strength of intellectual property protection affects the strategic conduct of innovating firms and the type of inventions licensed in equilibrium. Gallini (1992) also studied the protection choices of firms by incorporating in the analysis optimal patent design and

[5]For prominent early research on patent races and patent licensing, refer to Gilbert and Newbery (1982), Reinganum (1983), Rostoker (1983), Gallini (1984), and Scotchmer (1991); additionally, refer to the references cited in these studies.

costly endogenous imitation. The author found that short-term patents are socially optimal when the patent length is the only available policy instrument, while broad patents with an adjusted patent length become optimal with an option to choose the patent breadth (scope). Gallini (1992)'s analysis contributes to a better understanding of optimal patent policy. Following Gallini (1992), we consider imitation to be endogenously determined and perfect.[6] Takalo (1998) extended Gallini (1992)'s model by accounting for the spillover of R&D that arises due to a rational imitation by a competitor. His analysis confirms Gallini (1992)'s social optimality of short patents; however, Takalo (1998)'s study found that broad patents are not always optimal when imitation is costly, especially when associated with large spillovers. In an effort to study optimal licensing when an inventor has protection choices, we assume that both innovation and imitation determine the diffusion of new technology, similar to the consideration in Takalo (1998).

Maurer and Scotchmer (2002) suggested that licensing can serve as a managerial tool to deter duplication (perfect imitation) even when independent invention serves as a defence against infringement. The authors found that the threat of duplication by an unlimited number of entrants induces the diffusion of new technology because it lowers licensing fees and reduces entry to patent races, which, in turn, mitigates wasteful, duplicative effort. Additionally, they found that a new entry does not undermine investment in innovation when rediscovery does not lead to infringement and is not less than half the cost of invention. Ottoz and Cugno (2004) extended Maurer and Scotchmer (2002)'s analysis to consider the case of a single potential entry in the face of legal restriction on licensing contracts, that is, no negative fixed licensing fees. Building on the earlier literature described above, Anton and Yao (2004) examined the problem of how much knowledge should an innovating firm disclose, and how much it should conceal. The authors assumed Cournot competition characterised by asymmetric information about the extent of innovation and limited protection of property rights from imitation. Their analysis suggests that, in equilibrium, small inventions are patented free of imitation threat, larger inventions are protected through both patents and secrets in the face of imitation, and large inventions are protected by trade secrecy. The main reflection that comes from these findings is that when property rights are weak, technological information about smaller inventions is typically disclosed, whereas information about larger inventions is mostly concealed. Although we do not consider innovation size and a specific industry structure in our study, these assumptions can be suitable extensions of our basic model.

Denicolo and Franzoni (2003), while also studying imitation and market size of innovation, explored the contract theory of patents assuming that patenting is a substitute

[6] Gallini (1992) extended the analysis to additionally consider imperfect imitation.

to secrecy. Their analysis suggests that secrecy is typically the least socially preferable choice. Additionally, they found that an inventor's defence against infringement strengthens incentives to innovate, but lessens patenting and social welfare. In a companion paper, Denicolo and Franzoni (2004) studied how changes in the scope of patent rights granted to the first and second inventors affect the first inventor's propensity to patent and incentives to innovate. The authors assumed a game of complete information in which patent protection is perfect, but secrecy does not prevent imitation and leakage. Additionally, they compared the main policy options about the first and second inventors' patent rights.[7] Their economic analysis shows that the introduction of prior-user rights stimulates investment in innovation, reduces first inventor's propensity to patent, and produces an uncertain effect on social welfare, which depends on whether or not the patent term is set optimally.[8] Our economic analysis follows Denicolo and Franzoni (2003, 2004) in that we also compare patents versus secrets incorporating imperfect intellectual property protection and assuming that the ease to imitate depends on the type of protection adopted by the first inventor.

Kultti et al. (2006) compared the choice of an inventor between patenting and secrecy when innovation is simultaneous, that is, a patent race. Their analysis suggests that the first inventor typically patents to prevent others from patenting even when secrecy offers better protection. Particularly, the first inventor's propensity to patent increases with the likelihood of the second inventor to successfully innovate. Their study also contributes to the debate described above about whether introducing prior-user rights is socially beneficial. In Kultti et al. (2007), the authors extended their previous work to a more comprehensive model that included a continuum of inventors and inventions. They found similar results, thereby suggesting that an effective patent system is more important for disclosing information than for rewarding innovative effort. They show that firms engage in costly patenting to prevent others from patenting the same invention; in this case, the first inventor risks both infringement and return appropriation. Being the first inventor is not always a defence against infringement. Unlike the study by Kultti et al. (2007), which considered patents and trade secrets to be mutually exclusive protection choices, Ottoz and Cugno (2011) developed a model where both patents and secrets can be used to protect different aspects of the same invention (see, also, Garvey and Baluch, 2007). Particularly, they assume that only the component of the technology that relies on secrecy can be duplicated with a success probability; this probability depends on the duplication effort and scope of the trade secret law, that is, the level of concealed information that

[7]In Europe, being the first inventor is a defence against infringement, whereas, in the United States, second inventors can exclude first inventors from the invention.

[8]For a cost benefit analysis of prior-user rights, refer to Shapiro (2006).

is spilled out. The authors determined conditions wherein secrecy can enable the society to save on wasteful imitation expenditure, and thereby become socially beneficial; this analysis was supported by prior empirical evidence, such as Cohen et al. (2000) and Arundel (2001), but opposed by Denicolo and Franzoni (2004) and several other studies. Yeh (2016) provided a more recent overview of the purpose, enforcement, limitation, and misappropriation of the trade secret law.[9]

2.2 Empirical Literature

The available empirical evidence about the means of appropriating returns from investment in R&D shows that firms rely more on secrecy and lead time than on the patent system (Levin et al., 1987; Cohen et al., 2000; Arundel, 2001; Anton and Yao, 2004; Hall et al., 2014). Most of this evidence is based on surveys that focus on firms' choice of intellectual property protection in the face of imitation. These survey-based studies also show that patent effectiveness varies significantly across industries and judicial systems. In this study, we examine how the legal regime, ease to imitate, and strength of intellectual property protection affect firms' strategic behaviour and technology transfer.

Horstmann et al. (1985) developed a model of patenting behaviour in which the disclosure of technical information might lead to imitation. The authors aimed to explain the decision of firms to patent only a proportion of their intellectual property.[10] They found that patent disclosing makes imitation easier, which reduces firms' propensity to patent and, in turn, increases firms' reliance on trade secrecy. In this study, we also consider the signalling effect of the patent act by assuming that the efficiency of the imitation technology is dependent on the protection choice of the inventor. Levin et al. (1987) analysed firms' protection choices in different industries in an effort to study the effectiveness of available protection mechanisms in appropriating returns from investment in R&D. The authors found that, on an average, patent protection is not the most important protection choice, except in a few industries such as pharmaceuticals and chemicals.

Cohen et al. (2000) conducted another influential and a relatively recent study in this area. The authors used the Carnegie Mellon Survey (CMS) on Industrial R&D in the US manufacturing sector in 1994 and found that firms typically employ a variety of mechanisms to protect their inventions; additionally, they found that although patent protection is among the main protection mechanisms in numerous industries, it is not the

[9]For other relatively recent theoretical contributions on IPRs, refer to Denicolo and Zanchettin (2002), Denicolo (2007), Bessen and Maskin (2009), and Hall et al. (2014).

[10]For initial empirical studies on firms' propensity to patent, refer to Scherer (1967, 1983) and Pakes (1985, 1986).

most important mechanism. Particularly, they suggest that firms benefit from patenting in ways other than the protection of property rights. For instance, patent rights can be used to prevent new entry, block competitors, mitigate infringement risk, and increase bargaining power in technology transfer. One of the objectives of our study is to determine the optimal licensing behaviour or the strategic use of IPRs by first inventors. Arundel (2001), using data from the European Community Innovation Survey (CIS) on R&D-performing firms in 1993, studied which protection choice between patent rights and trade secrecy is more effective as an appropriation mechanism. His analysis suggests that secrecy prevails as an effective appropriation method for both process and product inventions, which confirms Cohen et al. (2000). Another interesting result of Arundel (2001) is the relevance of firm size on the effectiveness of intellectual property protection choice. The author found that the value of secrecy increases with firm size; however, the relative value of secrecy, when compared to patents, declines with firm size. Although we do not take into account firm size in our study, extending the analysis to the case with small and big types of firms might lead to useful insights about current problems with the patent act and trade secret law. Hussinger (2006) examined the influence of patents and secrecy on a firm's profits as indexed by sale figures. She pointed out that firms tend to apply for both protection mechanisms; however, there are prominent industry preferences for the use of one mode over the other. Moreover, other industry-related features and employed innovation strategies have a limited impact on the propensity to file for a patent or opt for secrecy. Conversely, firm size, but not R&D intensity, has a strong positive impact on patent desirability.[11]

Layne-Farrar (2014) argued that, generally, patents that are a part of standards are more valuable than patents that are not included in standards. In turn, Layne-Farrar (2016) reviewed the literature on fair, reasonable, and non-discriminatory (FRAND) licensing and indirectly implied the strong impact of IPR protection on firms' competitive advantage. The trade-off among available intellectual property protection choices has been a challenging area in theoretical and empirical economics. Particularly, economists have sought to measure the value of patents and licences, and although much progress has been achieved, a conclusive answer remains to be seen. There are various ways and approaches proposed in the literature to examine product and process inventions that involve a sizeable investment in R&D.[12]

[11] For additional information about patents, refer to Hall (2007); this study surveyed the theoretical and empirical literature on the effectiveness of patent protection and its incentives to spur innovation. However, for a thorough review of the theory of trade secrets, refer to Dreyfuss and Strandburg (2011) and the literature cited therein.

[12] The following literature serve as useful studies related to intellectual property protection. Schwartz (2004) addressed the question of patent valuation by implementing a simulation approach based on real options. Bulut and Moschini (2006) studied the strategic interaction between innovative firms that have

3 The Model

Let Firm i for $i = \{1, 2\}$ denote the firms in a single market of a standard good. Assume that Firm 1, which invested in innovation in the past, has developed a technology for the production of a certain product. Let the initial investment of Firm 1 in R&D be a sunk cost, and thus be irrelevant for decision-making purposes. Additionally, consider that a single potential rival, Firm 2, can enter the market through licensing or imitation.

In the first stage of the game, Firm 1 should choose the type of intellectual property protection upon which it can rely. Particularly, Firm 1 should decide whether to patent ($Patent$) the technology or rely on trade secrecy ($Secret$) to protect the technology. In the second stage, the two competing firms should decide whether to enter into a licensing agreement on the rights to use the technology. By licensing ($License$), Firm 1 transfers the technology to Firm 2 in return for a fixed licence fee and the firms compete in quantities, according to Cournot competition, which yields a symmetric duopoly payoff π^d for each firm (Cournot and Fisher, 1929). Let the fixed licensing fee of a patented technology be F_P, and that of a trade secret be F_S.

Alternatively, Firm 2 can try to imitate the proprietary technology ($Imitate$). We assume that patent rights and trade secrecy are imperfect means of protection; however, the ease and time involved in imitating differ under each protection choice. This, in turn, implies that the expected profits in equilibrium are dependent on the type of protection that is adopted in the first stage of the game. If imitation is successful, then the firms will engage again in a Cournot competition. Additionally, each firm would earn π^d; otherwise, Firm 1 will earn the monopoly rent π^m where $\pi^m > \pi^d$, whereas Firm 2 will earn no profit.[13] Each firm aims at maximising its profit, and the game is one of perfect information. Principally, each firm anticipates the sequence of actions and the optimal actions of the other firm and includes this information in its decision-making to maximise its profit. The game with payoffs is summarised in Figure 3.1.[14] Let us first describe the sequence of actions and firms' payoffs when Firm 1 decides to patent, and subsequently

a protection choice and showed that the availability of multiple protection mechanisms might lead to the selection of R&D projects that are closer to the socially desirable magnitude of correlation. Bessen and Maskin (2009) introduced a sequential model of innovation and found that, in a static world, patents help inventors to cover the R&D costs and encourage innovative activity, but, in a sequential setting, the importance of patents is undermined. Baldi and Trigeorgis (2014) valued optimal intellectual property licensing in the light of a real options lens, by focusing in a case study from biotechnology.

[13]In general, $\pi^m > 2\pi^d > 0$ (the efficiency effect) should hold to prevent anticompetitive conduct (collusion) (Gilbert and Newbery, 1982; Aoki and Hu, 2003).

[14]Figure 3.1 summarises the payoffs of all possible outcomes of the game without discounting, that is, assuming a discounting rate equal to zero. However, we relax this assumption later in the analysis by discounting all payoffs at the time zero with a positive rate.

consider trade secrecy.

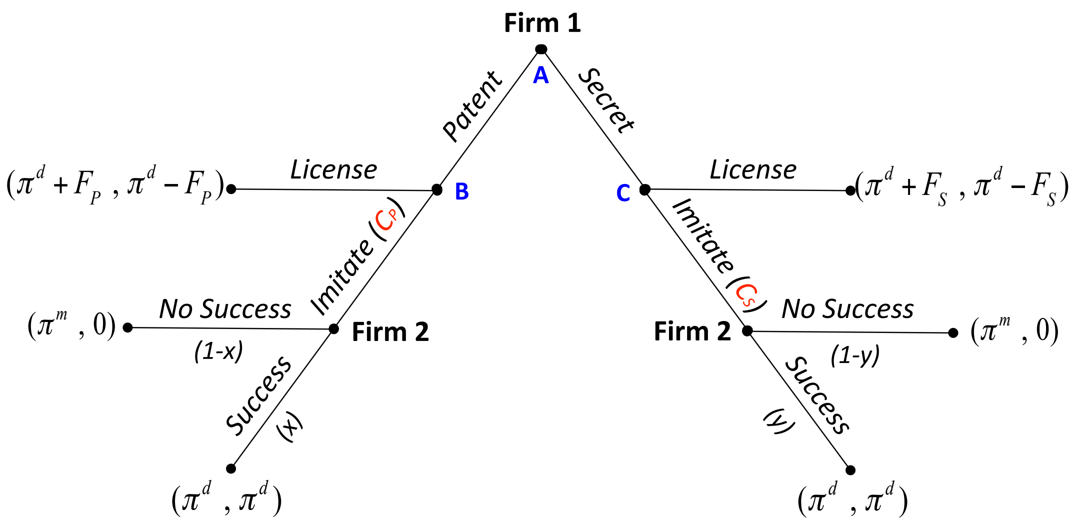

Figure 3.1: The decision tree with payoffs.

3.1 The Decision to Patent

Consider that Firm 1 relies on patent protection (*Patent*) in the first stage of the game (decision node A in Figure 3.1). Patenting is accompanied by information disclosure; it does not prevent imitation. Additionally, upon expiry, which is assumed to be in time T, the invention becomes freely available to the public. When patent protection expires, the profits of the technology holders are driven to zero. Once the decision about the protection choice has been made, Firm 1 should decide whether to transfer the technology in return for an upfront fixed payment F_P, where $F_P > 0$. In fact, technology transfer is an agreement that must be accepted by both parties (decision node B in Figure 3.1); technology transfer occurs if each firm is better off accepting the agreement than rejecting it. Nevertheless, let us assume that Firm 1 has full negotiation power regarding the transfer of the patent rights to Firm 2. When a licensing agreement occurs (*License*), each firm begins production at time 0 and receives a symmetric duopoly payoff π^d from time 0 to time T. Additionally, Firm 2 pays a fixed fee F_P to Firm 1 at time 0 in return for the technology transfer. Let an ordered pair of entries denote the distribution of payoffs for each outcome of the game, where the first entry corresponds to the payoff of Firm 1 and the second entry to the payoff of Firm 2. Then, the payoff outcome of this case, without discounting, is $(\pi^d + F_P, \pi^d - F_P)$.

If technology transfer does not occur, then Firm 2 would opt for a costly imitation

($Imitate$). Let Firm 2 incur an imitation cost $C_P = \frac{1}{2}\alpha_P x^2$ at time zero, where α_P measures the efficiency of the technology to imitate a patent, and x denotes the probability of successful imitation. Additionally, let α_P be a sufficiently large positive number to ensure that $x \leq 1$ (see, Takalo, 1998). Clearly, Firm 2 successfully imitates the patented technology with a probability x ($Success$) and fails to imitate with a probability $1 - x$ ($No\ Success$). Imitation is not instantaneous; thus, let T_P be the length of time required to imitate the patented technology. Given that the invention becomes freely available to the public when the patent expires, it implies that imitation is valuable only if it occurs earlier than the patent expiration, that is, $T_P < T$. If imitation is successful, then each firm would earn the duopoly payoff π^d from the time T_P that Firm 2 enters the market until time T that the patent expires. In this case, the payoff outcome without discounting will be (π^d, π^d). If imitation is unsuccessful, then Firm 1 would earn the monopoly rent π^m until time T, whereas Firm 1 will not enter the market, and thus receive nothing. As a result, the payoff outcome of this event, without discounting, will be $(\pi^m, 0)$.

3.1.1 Patent Licensing in Equilibrium

Let us now consider the case described above, where Firm 1 relies on patent protection in the first stage of the game, and characterise the equilibrium. All profits are discounted at a continuously compounded common rate r ($r > 0$). Additionally, it is helpful to define the discounted value of a unit flow earned from time t_1 to time t_2, where $t_1 < t_2$:

$$\delta_{t_1}^{t_2} \equiv \int_{t_1}^{t_2} e^{-rt} dt = \frac{e^{-rt_1} - e^{-rt_2}}{r}. \tag{3.1}$$

The measure $\delta_{t_1}^{t_2}$ is convenient for computational purposes and can also be seen as a discounted-adjusted intellectual property protection length (see, Aoki and Hu, 2003; Denicolo and Franzoni, 2003, 2004).

First, consider that Firm 1 patents and offers a licence to transfer the technology. Clearly, licensing occurs if each firm is better off with the agreement than without it. Let π_i^L for $i = \{1, 2\}$ be the profit of Firm i when the technology is patented, and a licensing agreement is established (*License*). Then, the profits of Firms 1 and 2 are:

$$\begin{aligned}
\pi_1^L &= \int_0^T \pi^d e^{-rt} dt + F_P, \\
&= \pi^d \delta_0^T + F_P, \\
\\
\pi_2^L &= \int_0^T \pi^d e^{-rt} dt - F_P, \\
&= \pi^d \delta_0^T - F_P.
\end{aligned} \tag{3.2}$$

Second, consider that technology transfer does not occur. In this case, Firm 2 opts for imitation incurring a cost equal to $C_P = \frac{1}{2}\alpha_P x^2$. Imitation occurs with probability x, which is chosen by Firm 2 that aims at maximising its expected profit. Let π_i^I for $i = \{1, 2\}$ be the profit of Firm i when Firm 2 tries to imitate the patented technology of Firm 1 (*Imitate*). Then, the expected profits of Firms 1 and 2 are:

$$\begin{aligned}
\pi_1^I &= \int_0^{T_P} \pi^m e^{-rt} dt + \left[x \int_{T_P}^T \pi^d e^{-rt} dt + (1-x) \int_{T_P}^T \pi^m e^{-rt} dt\right] \\
&= \pi^m \delta_0^T - x(\pi^m - \pi^d)\delta_{T_P}^T, \\
\\
\pi_2^I &= x \int_{T_P}^T \pi^d e^{-rt} dt - C_P \\
&= x\pi^d \delta_{T_P}^T - \frac{1}{2}\alpha_P x^2.
\end{aligned} \tag{3.3}$$

Let us now consider the optimal imitation effort of Firm 2. The optimal probability of imitation can be determined from the first-order condition of the following maximisation problem:

$$\max_x \quad x\pi^d \delta_{T_P}^T - \frac{1}{2}\alpha_P x^2, \tag{3.4}$$

that gives a probability of imitation in equilibrium equal to $\frac{1}{\alpha_P}\pi^d \delta_{T_P}^T$.[15]

Let the superscript $*$ denote the value of a variable in equilibrium, then the expected

[15]The optimal imitation effort is more accurately given by the following equation:

$$x = \begin{cases} \frac{1}{\alpha_P}\pi^d \delta_{T_P}^T & \text{for } \frac{1}{\alpha_P}\pi^d \delta_{T_P}^T \leq 1, \\ 1 & \text{for } \frac{1}{\alpha_P}\pi^d \delta_{T_P}^T > 1. \end{cases}$$

However, we have already assumed that the parameter α_P is large enough to ensure that $x \leq 1$; in this case, we need to consider only the first line of the above system of equations.

profits in equilibrium of Firms 1 and 2 are:

$$\begin{aligned} \pi_1^I(x^*) &= \pi^m \delta_0^T - \frac{1}{\alpha_P}\pi^d(\pi^m - \pi^d)(\delta_{T_P}^T)^2, \\ \pi_2^I(x^*) &= \frac{1}{2\alpha_P}(\pi^d \delta_{T_P}^T)^2. \end{aligned} \tag{3.5}$$

We can now consider the optimal fee to transfer the technology. It is evident that a licensing agreement occurs if each firm is better off with a licence than without it. Particularly, the technology is transferred if $(\pi^m - 2\pi^d)\delta_0^T \leq \frac{1}{\alpha_P}\pi^d(\pi^m - \pi^d)(\delta_{T_P}^T)^2 - \frac{1}{2\alpha_P}(\pi^d \delta_{T_P}^T)^2$. We have assumed above that Firm 1 has the full negotiation power when the new technology is patented, which implies that Firm 1 charges the maximum price to receive all the benefits from a potential licensing agreement. Essentially, Firm 1 transfers the technology rights only at a price that makes Firm 2 indifferent between becoming a licensee and opting for imitation. Precisely, the optimal licensing fee that induces a technology transfer is:

$$F_P^* = \pi^d \delta_0^T - \frac{1}{2\alpha_P}(\pi^d \delta_{T_P}^T)^2. \tag{3.6}$$

As a result, the profits of Firms 1 and 2 in equilibrium are:

$$\begin{aligned} \pi_1^L(F_P^*) &= 2\pi^d \delta_0^T - \frac{1}{2\alpha_P}(\pi^d \delta_{T_P}^T)^2, \\ \pi_2^L(F_P^*) &= \frac{1}{2\alpha_P}(\pi^d \delta_{T_P}^T)^2. \end{aligned} \tag{3.7}$$

We also establish the following corollary:

Corollary 1 *The equilibrium licensing fee given by Equation 3.6 has the following properties:* $\partial F_P^*/\partial \pi^d > 0$*,* $\partial F_P^*/\partial \alpha_P > 0$*,* $\partial F_P^*/\partial T \geq 0$*,* $\partial F_P^*/\partial T_P > 0$*, and the sign of* $\partial F_P^*/\partial r$ *is ambiguous.*

Proof *See Appendix.*

Corollary 1 suggests that—everything else being equal—the optimal, technology transfer fee is increasing in the duopoly profit, the efficiency of the imitation technology, the patent term, and the length of time required to achieve imitation. Additionally, a change in the discount rate might have an ambiguous impact on the equilibrium licensing fee.

When Firm 2 is indifferent, let us assume that the firms prefer a technology transfer more than imitation.[16] An extension of the basic model, which follows later, applies Nash bargaining to determine the licensing fee in equilibrium. Nash bargaining is a more suitable way to analyse licensing agreements when the negotiation shares of the counterparties are unspecified.

Let us now consider the optimal licensing fee for different efficiency levels of the imitation technology. Although we have assumed that the efficiency of the imitation technology (α_P) is sufficiently high, theoretically, when α_P tends to zero ($\alpha_P \to 0$), imitation becomes costless ($C_P \to 0$), and thus the optimal imitation effort tends to unity ($x^* \to 1$), and, in turn, the licensing fee in equilibrium falls to zero ($F_P^* \to 0$). In other words, when the efficiency of the imitation technology is sufficiently low, the cost of imitation is also trivial, which implies that imitation occurs almost with certainty. Thus, both firms begin production simultaneously. As a result, only a trivial licensing fee makes Firm 2 indifferent between technology transfer and imitation. Conversely, when α_P tends to infinity ($\alpha_P \to \infty$), the cost of imitation becomes sufficiently large ($C_P \to \infty$), and thus the occurrence of successful imitation becomes unlikely ($x^* \to 0$); consequently, this leads Firm 1 to charge the maximum possible licensing fee that initiates a technology transfer ($F_P^* \to \pi^d \delta_0^T$). Nevertheless, a technology transfer does not occur in this case because the profit of Firm 1 as a monopolist is higher than its profit as a licensor, that is, $\pi^m > 2\pi^d$. This result suggests that both technology transfer and imitation might not occur when the efficiency of the imitation technology is sufficiently high.

Moving back, let us now consider the condition that provides a technology transfer. We have already shown that technology transfer occurs if $(\pi^m - 2\pi^d)\delta_0^T \leq \frac{1}{\alpha_P}\pi^d(\pi^m - \pi^d)(\delta_{T_P}^T)^2 - \frac{1}{2\alpha_P}(\pi^d \delta_{T_P}^T)^2$, which can be used to establish the following result:

Theorem 1 *A transfer of a patented technology, between Firms 1 and 2, occurs if and only if $\alpha_P \leq \hat{\alpha}_P$, where the threshold $\hat{\alpha}_P$ is defined to be:*

$$\hat{\alpha}_P \equiv \left[\frac{(\pi^m - \frac{3}{2}\pi^d)\delta_{T_P}^T}{(\pi^m - 2\pi^d)\delta_0^T}\right]\pi^d \delta_{T_P}^T. \tag{3.8}$$

Theorem 1 suggests that the technology transfer depends primarily on the efficiency of the imitation technology (α_P) and the time to imitate (T_P); it also depends on the relative magnitudes of the monopoly and duopoly profits, the patent lifetime, and the discount rate (r). Additionally, we establish the following corollary:

[16] In another context, there could be many plausible reasons that might lead firms to avoid imitation, such as the probabilistic nature of imitation, the rapid progress of technology, or a lengthy imitation time lag.

Corollary 2 *The patent licensing threshold given by Equation 3.8 has the following properties:* $\partial\hat{\alpha}_P/\partial\pi^m < 0$, $\partial\hat{\alpha}_P/\partial\pi^d > 0$, $\partial\hat{\alpha}_P/\partial T > 0$, $\partial\hat{\alpha}_P/\partial T_P < 0$, *and the sign of* $\partial\hat{\alpha}_P/\partial r$ *is ambiguous.*

Proof *See Appendix.*

Corollary 2 suggests that—everything else being equal—increasing the duopoly profit (π^d) or the patent lifetime (T) encourages a technology transfer, whereas increasing the monopoly profit (π^m) or the time to imitate (T_P) discourages licensing. Finally, it shows that the effect of a change in the discount rate on technology transfer cannot be, in fact, determined.

3.2 The Decision to Rely on Secrecy

Consider that Firm 1 keeps the invention secret (*Secret*) in the first stage of the game (decision node A in Figure 3.1). A trade secret presumes that reasonable measures have been taken to maintain the secrecy of the scientifically and commercially valuable information by its rightful holder. This information concealment might, in turn, render imitation more difficult than when valuable information is publicly disclosed. However, it cannot prevent independent rediscovery or accidental disclosure. Particularly, the protection of a trade secret can last for an unlimited period of time unless the secret is independently discovered, legally acquired by others, or unintentionally leaked to the public. When the information becomes freely available to the public, a trade secret loses its commercial value, and thus the profits of the technology holders are driven to zero. Nevertheless, let us for now set the probability that the confidential information might accidentally leak out equal to zero.

In the second stage of the game, Firm 1 should decide whether to transfer the rights of the trade secret to Firm 2 in return for a fixed licensing fee F_S, where $F_S > 0$. Although we have already mentioned that technology transfer is an agreement that has to be accepted by both parties (decision node C in Figure 3.1), let us for now assume that Firm 2 has the full bargaining power. Firm 1 decides to keep the technology secret because it, clearly, regards secrecy as better protection choice than patenting. Secrecy is characterised from the perspective of an indefinite term and the transmission of less valuable information to Firm 2 when compared to a patent system, which might potentially lessen the incentives of Firm 2 to imitate. Essentially, we assume that Firm 2 is more inclined to propose a licensing agreement. If technology transfer occurs (*License*), then each firm will earn π^d from time 0 to perpetuity, unless the secret is rediscovered by Firm 2. Additionally, Firm

2 transfers a one-time licensing fee F_S to Firm 1 at time 0 to legally use the technology. In this case, the payoff outcome, without discounting, is $(\pi^d + F_S, \pi^d - F_S)$.

However, if technology transfer does not occur, then Firm 2 will opt for imitation and incur a cost $C_S = \frac{1}{2}\alpha_S y^2$ at time zero, where α_S reflects the efficiency of the technology to imitate a trade secret, and y can be seen as the likelihood of a successful imitation. Similar to the patent protection case, α_S is assumed to be sufficiently large to ensure that $y \leq 1$. If imitation is successful, which occurs with a probability y (*Success*), then each firm would receive π^d from time T_S to an unlimited period of time. In this case, the payoff outcome without discounting is (π^d, π^d). If Firm 2 fails to imitate, which has a probability $1 - y$ to occur (*No Success*), then Firm 1 would get the monopoly profit π^m forever, whereas Firm 2 would not earn any profit. The payoff outcome is $(\pi^m, 0)$.

3.2.1 Trade Secret Licensing in Equilibrium

We can now solve the case described above and characterise the equilibrium when the Firm 1 chooses secrecy as its protection mechanism. Let all profits be discounted at the continuously compounded common rate r, and v_i^L be the profit of Firm i for $i = \{1, 2\}$, when Firm 1 keeps the technology secret and a licensing agreement occurs (*License*). In this case, the profits of Firms 1 and 2 are:

$$
\begin{aligned}
v_1^L &= \int_0^\infty \pi^d e^{-rt} dt + F_S, \\
&= \pi^d \delta_0^\infty + F_S, \\
\\
v_2^L &= \int_0^\infty \pi^d e^{-rt} dt - F_S, \\
&= \pi^d \delta_0^\infty - F_S,
\end{aligned}
\tag{3.9}
$$

where δ_0^∞ is equal to $\frac{1}{r}$. However, in order to be consistent throughout the analysis, we use the $\delta_{t_1}^{t_2}$ measure, which is defined in Equation 3.1 above.

Next, consider the case when technology transfer does not occur, and thus Firm 2 aims at independent rediscovery or imitation of the new technology. Similar to when the technology is patent-protected, Firm 2 chooses the optimal imitation effort to maximise its expected profit. Let v_i^I for $i = \{1, 2\}$ be the profit of Firm i when Firm 2 tries to legally rediscover the concealed invention (*Imitate*). Then, the expected profits of Firms

1 and 2 are:

$$
\begin{aligned}
v_1^I &= \int_0^{T_S} \pi^m e^{-rt} dt + \left[y \int_{T_S}^{\infty} \pi^d e^{-rt} dt + (1-y) \int_{T_S}^{\infty} \pi^m e^{-rt} dt \right], \\
&= \pi^m \delta_0^{\infty} - y(\pi^m - \pi^d)\delta_{T_S}^{\infty}, \\
v_2^I &= y \int_{T_S}^{\infty} \pi^d e^{-rt} dt - C_S, \\
&= y\pi^d \delta_{T_S}^{\infty} - \frac{1}{2}\alpha_S y^2.
\end{aligned}
\tag{3.10}
$$

Firm 2 solves the following problem to determine the optimal imitation effort:

$$
\max_y \quad y\pi^d \delta_{T_S}^{\infty} - \frac{1}{2}\alpha_S y^2, \tag{3.11}
$$

that gives an optimal effort $y^* = \frac{1}{\alpha_S}\pi^d \delta_{T_S}^{\infty}$.[17] As a result, the expected profits in equilibrium of Firms 1 and 2 are:

$$
\begin{aligned}
v_1^I(y^*) &= \pi^m \delta_0^{\infty} - \frac{1}{\alpha_S}\pi^d(\pi^m - \pi^d)(\delta_{T_S}^{\infty})^2, \\
v_2^I(y^*) &= \frac{1}{2\alpha_S}(\pi^d \delta_{T_S}^{\infty})^2.
\end{aligned}
\tag{3.12}
$$

We can now determine the optimal licensing fee that provides a technology transfer. Particularly, a technology transfer occurs if $(\pi^m - 2\pi^d)\delta_0^{\infty} \leq \frac{1}{\alpha_S}\pi^d(\pi^m - 2\pi^d)(\delta_{T_S}^{\infty})^2 - \frac{1}{2\alpha_S}(\pi^d \delta_{T_S}^{\infty})^2$. Firm 2 has the full negotiation power when the technology is protected by secrecy, which implies that a technology transfer occurs only at a price that makes Firm 1 indifferent between accepting and rejecting a licensing agreement. Essentially, the equilibrium licensing fee that provides a technology transfer is:

$$
F_S^* = (\pi^m - \pi^d)\delta_0^{\infty} - \frac{1}{\alpha_S}\pi^d(\pi^m - \pi^d)(\delta_{T_S}^{\infty})^2. \tag{3.13}
$$

[17]The optimal imitation effort, similar to the effort when the technology is patented, can be more accurately given by the following equation:

$$
y = \begin{cases} \frac{1}{\alpha_S}\pi^d \delta_{T_S}^{\infty} & \text{for } \frac{1}{\alpha_S}\pi^d \delta_{T_S}^{\infty} \leq 1, \\ 1 & \text{for } \frac{1}{\alpha_S}\pi^d \delta_{T_S}^{\infty} > 1. \end{cases}
$$

However, given the assumption that α_S is sufficiently large to ensure that $y \leq 1$, we need to consider only the first line of the above system of equations.

Consequently, the profits of Firms 1 and 2 in equilibrium are:

$$\begin{aligned} v_1^L(F_S^*) &= \pi^m \delta_0^\infty - \frac{1}{\alpha_S}\pi^d(\pi^m - \pi^d)(\delta_{T_S}^\infty)^2, \\ v_2^L(F_S^*) &= \frac{1}{\alpha_S}\pi^d(\pi^m - \pi^d)(\delta_{T_S}^\infty)^2 - (\pi^m - 2\pi^d)\delta_0^\infty. \end{aligned} \tag{3.14}$$

At the equilibrium licensing fee, Firm 1 is indifferent between the two available actions; in this case, we assume licensing to prevail. As already noted, later in the analysis, we relax the negotiation assumption using Nash bargaining to determine the optimal licensing fee. From Equation 3.13, we establish the following corollary:

Corollary 3 *The equilibrium licensing fee given by Equation 3.12 has the following properties:* $\partial F_S^*/\partial \pi^m > 0, \partial F_S^*/\partial \pi^d < 0$, $\partial F_S^*/\partial \alpha_S > 0$, $\partial F_S^*/\partial T_S > 0$, *and the sign of* $\partial F_S^*/\partial r$ *is ambiguous.*

Proof *See Appendix.*

Corollary 3 suggests that—everything else being equal— the equilibrium licensing fee is increasing in the monopoly profit, the efficiency of the imitation technology, and the time to imitate. It also implies that the effect of a change in the discount rate on the equilibrium licensing fee cannot be determined; importantly, it shows that the optimal licensing fee is decreasing in the duopoly profit. One reason for the latter result is that a higher duopoly profit increases the willingness of Firm 2 to imitate, and thus a technology transfer occurs if the equilibrium fee that Firm 2 has to pay is sufficiently small.

Finally, consider how the optimal licensing fee changes for different efficiency levels of the imitation technology. First, suppose that the efficiency is sufficiently low. Subsequently, the cost of imitation becomes sufficiently small, and the success probability of imitation tends to one. As a result, only a sufficiently small licensing fee triggers a technology transfer. Second, let α_S be sufficiently large. Subsequently, the imitation cost becomes sufficiently large, and the success probability tends to zero. In this case, the optimal licensing fee becomes larger than the maximum fee that Firm 2 is willing to pay to acquire a licence. Consequently, a technology transfer does not occur, and Firm 1 becomes a monopoly.

We have shown above that a technology transfer occurs when $(\pi^m - 2\pi^d)\delta_0^\infty \leq \frac{1}{\alpha_S}\pi^d(\pi^m - 2\pi^d)(\delta_{T_S}^\infty)^2 - \frac{1}{2\alpha_S}(\pi^d\delta_{T_S}^\infty)^2$, which is equivalent to the following result:

Theorem 2 *A transfer of a technology protected by secrecy, between Firms 1 and 2,* *occurs if and only if $\alpha_S \le \hat{\alpha}_S$, where the threshold $\hat{\alpha}_S$ is defined to be:*

$$\hat{\alpha}_S \equiv \left[\frac{(\pi^m - \frac{3}{2}\pi^d)\delta_{T_S}^{\infty}}{(\pi^m - 2\pi^d)\delta_0^{\infty}}\right]\pi^d\delta_{T_S}^{\infty}. \tag{3.15}$$

From Equation 3.15, we establish the following corollary:

Corollary 4 *The trade secret licensing threshold given by Equation 3.15 has the following properties: $\partial\hat{\alpha}_S/\partial\pi^m < 0$, $\partial\hat{\alpha}_S/\partial\pi^d > 0$, $\partial\hat{\alpha}_S/\partial T_S < 0$, and $\partial\hat{\alpha}_S/\partial r < 0$.*

Proof *See Appendix.*

Corollary 4 suggests that—everything else being equal— only increasing the duopoly profit (π^d) encourages licensing. Precisely, increasing the monopoly profit (π^m), the time required to achieve imitation (T_S), and the discount rate (r) have an adverse impact on technology transfer.

4 The Equilibrium

We have defined a licensing threshold for each of the available protection choices of Firm 1, namely $\hat{\alpha}_P$ for patent protection and $\hat{\alpha}_S$ for secrecy protection. A technology transfer occurs if the efficiency of the imitation technology does not exceed the corresponding licensing threshold. Therefore, the strategic interaction between the firms depends on the efficiency of the imitation technology. Essentially, the protection choice is, in turn, dependent on the probabilistic outcome of imitation. Now, we can compare the two protection choices to determine the equilibrium outcomes of the game.

First, suppose that the efficiency of the technology to imitate a patented invention and to imitate a trade secret are sufficiently low, that is, $\alpha_P \le \hat{\alpha}_P$ and $\alpha_S \le \hat{\alpha}_S$. According to Equations 3.8 and 3.15, a technology transfer occurs, regardless of the protection decision of Firm 1 in the first stage of the game. Essentially, the profit of Firm 1 with a patented technology is $\pi_1^L(F_P^*)$ and that with a technology protected by secrecy is $v_1^L(F_S^*)$. The invention is thus patented if $\pi_1^L(F_P^*) \ge v_1^L(F_S^*)$, and this condition is equivalent to:

$$\begin{aligned} M &\equiv \frac{y^*(\pi^m - \pi^d)\delta_{T_S}^{\infty} - \frac{1}{2}x^*\pi^d\delta_{T_P}^{T}}{\pi^m\delta_0^{\infty} - 2\pi^d\delta_0^{T}} \\ &= \frac{\frac{1}{\alpha_S}\pi^d(\pi^m - \pi^d)(\delta_{T_S}^{\infty})^2 - \frac{1}{2\alpha_P}(\pi^d\delta_{T_P}^{T})^2}{\pi^m\delta_0^{\infty} - 2\pi^d\delta_0^{T}} \ge 1. \end{aligned} \tag{4.1}$$

The condition clearly shows that patent protection is optimal for Firm 1 when the patenting threshold M is equal to or higher than one. We further assume that patenting prevails when Firm 1 is indifferent between the two available protection choices. Similar to the case described above, when only the technological efficiency to imitate a patent is sufficiently low, whereas that for a trade secret is sufficiently high, that is, $\alpha_P \leq \hat{\alpha}_P$ and $\alpha_S > \hat{\alpha}_S$, patenting is optimal if $M \geq 1$. In other words, if the condition given by Equation 4.1 holds, then the profit of Firm 1 with a patent would be at least as large as the profit of Firm 1 with a trade secret, that is, $\pi_1^L(F_P^*) \geq v_1^I(y^*)$. The patenting threshold is the same in these first two cases because of the weak preferences that we have assumed when determining the optimal licensing fee F_S^*. If the preferences of the firms are strict, that is, $\pi_1^L(F_P^*) > v_1^I(y^*)$, which is similar to assuming that a technology transfer occurs only for a licensing fee that is ϵ-smaller than the optimal fee, then Firm 1 would benefit more from licensing a trade secret than from licensing a patented technology. Let us now consider some of the properties of the patenting threshold M.

Corollary 5 *The patenting threshold given by Equation 4.1 has the following properties:* $\partial M/\partial \alpha_P > 0$, $\partial M/\partial \alpha_S < 0$, $\partial M/\partial T_P > 0$, *and* $\partial M/\partial T_S < 0$. *Also, the signs of* $\partial M/\partial T$, $\partial M/\partial r$, $\partial M/\partial \pi^d$, *and* $\partial M/\pi^m$ *cannot be determined.*

Proof *See Appendix.*

Corollary 5 suggests that—everything else being equal— the incentives to patent are increasing in the efficiency of the technology and the time required to imitate a patented technology (α_P and T_P), unlike the efficiency and time to imitate a trade secret (α_S and T_S). Additionally, the effect of a change in the patent term (T) or in the discount rate (r) on the incentives to patent is ambiguous. Finally, the partial derivatives of M with respect to the monopoly and duopoly profits cannot be determined unless further assumptions are made, particularly, regarding the relative magnitudes of α_P and α_S.[18]

Second, let both the efficiency of the imitation technology of a patent and that of a secret be sufficiently high, that is, $\alpha_P > \hat{\alpha}_P$ and $\alpha_S > \hat{\alpha}_S$. Then, Equations 3.8 and 3.15 clearly show that a technology transfer does not occur, regardless of whether Firm 1 chooses to patent the invention or keep it a secret. If Firm 1 chooses to patent the technology, then it would receive $\pi_1^I(x^*)$; however, if it chooses to conceal the technology, then it would get $v_1^I(y^*)$. Evidently, patenting occurs if $\pi_1^I(x^*) \geq v_1^I(y^*)$, which can also

[18]For example, it can be assumed that the difficulty to imitate a technology protected by secrecy is not less than that the difficulty to imitate a patented technology. This might, in turn, imply that the length of time required to achieve imitation of a concealed invention is not shorter than the length of time required to imitate a patented invention; for instance, the information disclosed when patenting might facilitate the process of imitation. Additionally, the measures taken by the inventor to protect a trade secret might decelerate the process of reverse engineering.

be written as:

$$
\begin{aligned}
N &\equiv \frac{y^*(\pi^m - \pi^d)\delta_{T_S}^{\infty} - x^*(\pi^m - \pi^d)\delta_{T_P}^{T}}{\pi^m \delta_0^{\infty} - \pi^m \delta_0^{T}} \\
&= \frac{\pi^d(\pi^m - \pi^d)\left[\frac{1}{\alpha_S}(\delta_{T_S}^{\infty})^2 - \frac{1}{\alpha_P}(\delta_{T_P}^{T})^2\right]}{\pi^m \delta_T^{\infty}} \geq 1.
\end{aligned}
\tag{4.2}
$$

This means that patenting prevails in equilibrium when the patenting threshold N is equal to or larger than one. Finally, let us consider the case when the efficiency of the technology to imitate a patent and a trade secret are sufficiently high and low, respectively, that is, $\alpha_P > \hat{\alpha}_P$ and $\alpha_S \leq \hat{\alpha}_S$. If Firm 1 relies on patent protection in the first stage of the game, then it would earn $\pi_1^I(x^*)$; however, if Firm 1 keeps the technology a secret, then it would earn $v_1^L(F_S^*)$. A comparison of these profits yields a patenting threshold that is equal to N. Firm 1 is indifferent between accepting and rejecting an agreement to transfer a trade secret at the optimal licensing fee F_S^*, and hence the threshold does not change. The properties of N are the same as those of M, that is, N increases with the technological efficiency and the time to imitate a patented technology (α_P and T_P), whereas it decreases with the technological efficiency and the time required to imitate a trade secret (α_S and T_S). Ultimately, let us establish the following result about the equilibrium outcomes of the game:

Theorem 3 *The equilibrium outcomes of the game in Figure 3.1 are as follows:*

A. *Firm 1 relies on the patent system to protect a process invention if and only if conditions (5) or (6) are satisfied.*

   (1.) *A transfer of a patented technology occurs if and only if conditions (1) or (2) are satisfied.*

B. *Firm 1 relies on secrecy to protect a process invention if and only if conditions (5) or (6) are not satisfied.*

   (2.) *A transfer of a technology protected by secrecy occurs if and only if conditions (1) or (4) are satisfied.*

Where conditions (1) to (6) are defined to be:

(1) $\hat{\alpha}_P \leq \alpha_P$ *and* $\hat{\alpha}_S \leq \alpha_S$*,*

(2) $\hat{\alpha}_P \leq \alpha_P$ *and* $\hat{\alpha}_S > \alpha_S$*,*

(3) $\hat{\alpha}_P > \alpha_P$ *and* $\hat{\alpha}_S > \alpha_S$*,*

(4) $\hat{\alpha}_P > \alpha_P$ *and* $\hat{\alpha}_S \leq \alpha_S$*,*

(5) $M \geq 1$*,*

(6) $N \geq 1$*,*

and the patenting thresholds M *and* N *are defined by Equations 4.1 and 4.2, respectively.*

Theorem 3 suggests that both patenting and secrecy can characterise the equilibrium if certain conditions hold. Additionally, it suggests that a technology transfer always occurs in equilibrium, regardless of the protection decision of Firm 1, if both the technological efficiency to imitate a patent and that to imitate a secret are sufficiently low. However, if both the imitation technologies are sufficiently efficient, then imitation would always prevail in equilibrium.

5 Extensions of the Model

In this section, we introduce two extensions of the basic model—the undetermined bargaining shares instead of the one-sided full bargaining power, and a positive probability of the accidental disclosure of the trade secret to the public instead of the probability of a leakage that equals zero. First, we show that the equilibrium outcomes obtained until now correspond to specific situations of a Nash bargaining setup. Second, we find that the risk of accidental leakage weakens trade secret protection, which, in turn, increases the attractiveness of patenting and might also encourage imitation relatively more than transferring a trade secret.

5.1 Nash Bargaining

Clearly, the game depicted in Figure 3.1 characterises a conflict of interest between two innovating firms that can achieve a mutually beneficial outcome. This situation represents a common bargaining problem. These problems lead to the question associated with the distribution of profit from a potential agreement. In this section, we employ the Nash bargaining to determine the optimal fixed fee at which a licensing contract can be subscribed to transfer the technology. Let the bargaining power of Firm 1 be β, and that of Firm 2 be $1 - \beta$, where $0 \leq \beta \leq 1$.

To begin with, suppose that Firm 1 relies on patent protection in the first stage of the game. The bargaining problem is $\max_{F_P} \left(\pi_1^L - \pi_1^I(x^*)\right)^{\beta}\left(\pi_2^L - \pi_2^I(x^*)\right)^{1-\beta}$; by substituting the profit functions, the study shows that this is equivalent to:[19]

$$\max_{F_P}\left(\pi^d\delta_0^T + F_P - \pi^m\delta_0^T + \frac{1}{\alpha_P}\pi^d(\pi^m - \pi^d)(\delta_{T_P}^T)^2\right)^{\beta}\left(\pi^d\delta_0^T - F_P - \frac{1}{2\alpha_P}(\pi^d\delta_{T_P}^T)^2\right)^{1-\beta}. \quad (5.1)$$

Let F_P^{NB} be the optimal licensing fee determined using Nash bargaining at which a transfer of the patented technology occurs. Then, the first-order condition of Equation 5.1 yields:

$$F_P^{NB} = \left[(\pi^m - \pi^d) - \beta(\pi^m - 2\pi^d)\right]\delta_0^T - \frac{1}{\alpha_P}\pi^d\left[(\pi^m - \pi^d) - \beta(\pi^m - \frac{3}{2}\pi^d)\right](\delta_{T_P}^T)^2. \quad (5.2)$$

Differentiating the optimal licensing fee defined in Equation 5.2, we establish the following result:

Corollary 6 *The equilibrium licensing fee defined by Equation 5.2 has the following properties:* $\partial F_P^{NB}/\partial\pi^m \geq 0$, $\partial F_P^{NB}/\partial\alpha_P > 0$, *and* $\partial F_P^{NB}/\partial T_P > 0$. *Additionally, the signs of* $\partial F_P^{NB}/\partial\pi^d$, $\partial F_P^{NB}/\partial\beta$, *and* $\partial F_P^{NB}/\partial r$ *cannot be determined.*

Proof *See Appendix.*

Suppose now that Firm 1 has a maximum contractual advantage over Firm 2 ($\beta = 1$). Subsequently, the substitution for β equal to one, in Equation 5.2, gives the equilibrium licensing fee that corresponds to the case of a patented invention and is defined by Equation 3.6. This result implies that the case when Firm 1 has full bargaining power and relies on patent protection is only a specific situation of the Nash Bargaining solution. Next, suppose that Firm 2 has a maximum bargaining power ($\beta = 0$). In this case, a direct substitution for β equal to zero in Equation 5.2 yields an equilibrium licensing fee equal to $(\pi^m - \pi^d)\delta_0^T - \frac{1}{\alpha_P}\pi^d(\pi^m - \pi^d)(\delta_{T_P}^T)^2$. This is similar to the licensing fee defined in Equation 3.13, except that now the efficiency of the imitation technology and the length of protection time correspond to a patented technology instead of a trade secret. Another interesting case that can be considered is when both firms have equal bargaining shares ($\beta = \frac{1}{2}$), which is, in fact, closer to the real-world conflict of interest situation. In this

[19] It must be noted that the maximisation problem is subject to certain conditions, such as $\pi_1^L \geq \pi_1^I(x^*)$ and $\pi_2^L \geq \pi_2^I(x^*)$. Although we have omitted these conditions from Equation 5.1, we consider them to determine the optimal licensing fee defined by Equation 5.2.

case, the optimal licensing fee is equal to $\frac{1}{2}[\pi^m \delta_0^T - \frac{1}{\alpha_P}\pi^d(\pi^m - \frac{1}{2}\pi^d)(\delta_{T_P}^T)^2]$, which is larger than the equilibrium licensing fee when Firm 1 has a minimum bargaining power ($\beta = 0$), but smaller than the equilibrium fee when Firm 1 has a maximum bargain power ($\beta = 1$).

The last case that has to be considered is when Firm 1 resorts to secrecy instead of choosing patent protection. Similar to the patenting decision considered above, the bargaining problem is $\max_{F_S} \left(v_1^L - v_1^I(x^*)\right)^\beta \left(v_2^L - v_2^I(x^*)\right)^{1-\beta}$ or equivalently:

$$\max_{F_S} \left(\pi^d \delta_0^\infty + F_S - \pi^m \delta_0^\infty + \frac{1}{\alpha_S}\pi^d(\pi^m - \pi^d)(\delta_{T_S}^\infty)^2\right)^\beta \left(\pi^d \delta_0^\infty - F_S - \frac{1}{2\alpha_S}(\pi^d \delta_{T_S}^\infty)^2\right)^{1-\beta}. \quad (5.3)$$

Let F_S^{NB} denote the optimal licensing fee of a secret determined using Nash Bargaining. Then, the first-order condition of Equation 5.3 gives:

$$F_S^{NB} = \left[(\pi^m - \pi^d) - \beta(\pi^m - 2\pi^d)\right]\delta_0^\infty - \frac{1}{\alpha_S}\pi^d\left[(\pi^m - \pi^d) - \beta(\pi^m - \frac{3}{2}\pi^d)\right](\delta_{T_S}^\infty)^2. \quad (5.4)$$

Similar to the optimal licensing fee F_P^{NB} defined by Equation 5.2, the optimal licensing fee of a secret is increasing in the monopoly profit, the efficiency of the imitation technology, and the time required to achieve imitation. Additionally, the substitution for β equal to zero, in Equation 5.4, gives an equilibrium licensing fee equal to $(\pi^m - \pi^d)\delta_0^\infty - \frac{1}{\alpha_S}\pi^d(\pi^m - \pi^d)(\delta_{T_S}^\infty)^2$, which is exactly the result given by Equation 3.13. Thus, the case, in which the technology is protected through secrecy and Firm 2 has maximum bargaining power, corresponds to another specific situation of the Nash bargaining solution. If β equals one, then the optimal licensing fee will be $\pi^d\delta_0^\infty - \frac{1}{2\alpha_S}(\pi^d\delta_{T_S}^\infty)^2$, which is similar to the optimal fee given by Equation 3.6, except that the efficiency of the imitation technology and the protection lifetime correspond to a trade secret instead of a patent. Following the same arguments, the equilibrium licensing fee when Firms 1 and 2 have equal bargaining powers is $\frac{1}{2}[\pi^m\delta_0^\infty - \frac{1}{\alpha_S}\pi^d(\pi^m - \frac{1}{2}\pi^d)(\delta_{T_S}^\infty)^2]$.

The licensing thresholds defined by Equations 3.8 and 3.15 continue to hold because they are independent of β. The equilibrium actions maximise the joint profits of the firms, while the parameter β only determines the distribution of these profits. By solving for the equilibrium outcomes of the game, when $\{\alpha_P \leq \hat{\alpha}_P$ and $\alpha_S \leq \hat{\alpha}_S\}$ or $\{\alpha_P \leq \hat{\alpha}_P$

and $\alpha_S > \hat{\alpha}_S\}$, the study gives the following patenting threshold:

$$M^{NB} \equiv \frac{\pi^d\left[\pi^m - \pi^d - \beta(\pi^m - \frac{3}{2}\pi^d)\right]\left[\frac{1}{\alpha_S}(\delta^{\infty}_{T_S})^2 - \frac{1}{\alpha_P}(\delta^{T}_{T_P})^2\right]}{\left[\pi^m - \beta(\pi^m - 2\pi^d)\right](\delta^{\infty}_0 - \delta^{T}_0)} \geq 1. \tag{5.5}$$

When the parameter β is equal to one, it is immediate that the patenting threshold M^{NB} is equal to M, whereas when β is equal to zero, M^{NB} clearly is equal to N.[20] The properties of the patenting threshold M given by Corollary 5 continue to hold for M^{NB}, and the sign of $\partial M^{NB}/\partial\beta$ is ambiguous.

Ottoz and Cugno (2004) considered a similar Cournot duopoly with Nash bargaining composed by a patent owner and a single potential rival that can enter the market through licensing or imitation. The authors consider certain legal restrictions on licensing contracts and independent invention defence to infringement. They show that the independent invention defence encourages licensing because it typically reduces the equilibrium price of the product and does not affect the incentives to innovate.[21]

5.2 Leakage of the Secret

The basic model assumes that the holder of a trade secret has taken protection measures and contractual restrictions such that significant spillovers of proprietary information are prevented. Suppose that there is a positive probability of the public disclosure of the secret and its loss of legal status and economic value. The accidental leakage of concealed proprietary information to the public allows anyone to have access to the secret and use it at will. To begin with, we incorporate a random probability of leakage that is independent of whether only Firm 1 or both firms practice the technology protected through secrecy. Subsequently, we extend the analysis to consider a probability of the accidental leakage that depends on whether or not Firm 2 has also, through licensing or imitation, obtained the secret.

5.2.1 A Constant Probability of Leakage

Let unintentional or accidental leakage occur according to a Poisson distribution with a parameter λ, where $\lambda > 0$. Most of the analysis conducted until now is not affected

[20] It must be noted that the patenting threshold N corresponds to the case when $\{\alpha_P > \hat{\alpha}_P$ and $\alpha_S > \hat{\alpha}_S\}$ or $\{\alpha_P > \hat{\alpha}_P$ and $\alpha_S \leq \hat{\alpha}_S\}$.

[21] Maurer and Scotchmer (2002) considered the same problem assuming, however, an unlimited number of potential entrants.

as we proceed with the extension. For instance, introducing λ does not have an impact on the payoff outcomes of the case when Firm 1 relies on patent protection in the first stage of the game. Therefore, the equilibrium outcomes that correspond to a patented technology continue to hold. However, if Firm 1 keeps the invention secret, then the discounted-adjusted protection length of the trade secret, which was defined by Equation 3.1 in the existing analysis, would become

$$\tilde{\delta}_{t_1}^{t_2} \equiv \int_{t_1}^{t_2} e^{-rt} e^{-\lambda t} dt = \frac{e^{-(r+\lambda)t_1} - e^{-(r+\lambda)t_2}}{r+\lambda}, \tag{5.6}$$

because now we are considering the risk of leakage associated with secrecy. Acknowledging that only the discounted-adjusted duration of the trade secret is now different from the existing equilibrium analysis that corresponds to the case of an invention protected through secrecy, we can determine the equilibrium outcomes of this case as follows.

Let $\tilde{y}^*$ and $\tilde{F}_S^*$ be the optimal imitation effort and the equilibrium licensing fee, respectively, when the trade secret is prone to accidental leakage. It is immediate that $\tilde{y}^*$ is equal to $\frac{1}{\alpha_S}\pi^d\tilde{\delta}_{T_S}^{\infty}$ and the equilibrium licensing fee is:

$$\tilde{F}_S^* = (\pi^m - \pi^d)\tilde{\delta}_0^{\infty} - \frac{1}{\alpha_S}\pi^d(\pi^m - \pi^d)(\tilde{\delta}_{T_S}^{\infty})^2. \tag{5.7}$$

The probability of leakage λ does not affect the properties of the optimal licensing fee, and thus the properties of F_S^* given by Corollary 3 also continue to hold for $\tilde{F}_S^*$. Furthermore, the effect of a change in λ on $\tilde{F}_S^*$ cannot be determined.

Define $\tilde{v}_i^L$ to be the profit of Firm i for $i = \{1, 2\}$, when Firm 1 keeps the invention secret, risking leakage, and a technology transfer occurs (*License*). Then, the equilibrium profits of Firms 1 and 2 in this case are:

$$\begin{aligned} \tilde{v}_1^L(\tilde{F}_S^*) &= \pi^m\tilde{\delta}_0^{\infty} - \frac{1}{\alpha_S}\pi^d(\pi^m - \pi^d)(\tilde{\delta}_{T_S}^{\infty})^2, \\ \tilde{v}_2^L(\tilde{F}_S^*) &= \frac{1}{\alpha_S}\pi^d(\pi^m - \pi^d)(\tilde{\delta}_{T_S}^{\infty})^2 - (\pi^m - 2\pi^d)\tilde{\delta}_0^{\infty}. \end{aligned} \tag{5.8}$$

Evidently, if a technology transfer does not occur in the second stage of the game, then Firm 2 will opt for imitation. Let $\tilde{v}_i^I$ be the profit of Firm i for $i = \{1, 2\}$, when Firm 1 keeps the invention secret, risking leakage, and Firm 2 imitates (*Imitate*). In this case, the expected profits of Firms 1 and 2 in equilibrium are:

$$\begin{aligned} \tilde{v}_1^I(\tilde{y}^*) &= \pi^m \tilde{\delta}_0^\infty - \frac{1}{\alpha_S}\pi^d(\pi^m - \pi^d)(\tilde{\delta}_{T_S}^\infty)^2, \\ \tilde{v}_2^I(\tilde{y}^*) &= \frac{1}{2\alpha_S}(\pi^d \tilde{\delta}_{T_S}^\infty)^2. \end{aligned} \tag{5.9}$$

As usual, a transfer of the secret occurs if $\alpha_S \leq \tilde{\alpha}_S$, where the threshold $\tilde{\alpha}_S$ is defined to be:

$$\tilde{\alpha}_S \equiv \left[\frac{(\pi^m - \frac{3}{2}\pi^d)\tilde{\delta}_{T_S}^\infty}{(\pi^m - 2\pi^d)\tilde{\delta}_0^\infty} \right] \pi^d \tilde{\delta}_{T_S}^\infty. \tag{5.10}$$

This licensing threshold has the same properties as the threshold defined by Equation 3.15, in addition to an important property. Particularly, $\partial\tilde{\alpha}_S/\partial\lambda < 0$ implies that an increase in the probability of the accidental leakage, such as due to misappropriation or for a variety of other reasons, discourages transferring a trade secret. Additionally, $\tilde{\alpha}_S < \hat{\alpha}_S$ suggests that acknowledging the risk of leakage increases the incentives to imitate.

Finally, let us determine the equilibrium outcomes of the game by comparing the two protection choices. To begin with, suppose that $\alpha_P \leq \hat{\alpha}_P$ and $\alpha_S \leq \tilde{\alpha}_S$; in this case, a technology transfer always occurs. However, patenting occurs in equilibrium if the following condition holds:

$$\tilde{M} \equiv \frac{\frac{1}{\alpha_S}\pi^d(\pi^m - \pi^d)(\tilde{\delta}_{T_S}^\infty)^2 - \frac{1}{2\alpha_P}(\pi^d \delta_{T_P}^T)^2}{\pi^m \tilde{\delta}_0^\infty - 2\pi^d \delta_0^T} \geq 1. \tag{5.11}$$

This threshold also characterises the case when $\alpha_P \leq \hat{\alpha}_P$ and $\alpha_S > \tilde{\alpha}_S$. Moreover, if $\hat{\alpha}_S > \alpha_S > \tilde{\alpha}_S$, then it will only be the risk of leakage that would cause imitation. The properties of the patenting threshold M given by Corollary 5 continue to hold for $\tilde{M}$ if $\lambda < (\pi^m \delta_0^\infty - 2\pi^d \delta_0^T)/(2\pi^d \delta_0^\infty \delta_0^T)$; otherwise, the properties of $\tilde{M}$ are exact opposite of those given by Corollary 5. Additionally, the sign of $\partial\tilde{M}/\partial\lambda$ cannot be determined.

Next, suppose that $\alpha_P > \hat{\alpha}_P$ and $\alpha_S > \tilde{\alpha}_S$; in this case, a technology transfer is never optimal, regardless of the protection choice of Firm 1 in the first stage of the game. In this case, patenting is preferable in equilibrium if the following condition is satisfied:

$$\tilde{N} \equiv \frac{\pi^d(\pi^m - \pi^d)\left[\frac{1}{\alpha_S}(\tilde{\delta}_{T_S}^{\infty})^2 - \frac{1}{\alpha_P}(\delta_{T_P}^{T})^2\right]}{\pi^m(\tilde{\delta}_0^{\infty} - \delta_0^{T})} \geq 1. \tag{5.12}$$

This threshold characterises the final case that has to be considered, particularly when $\alpha_P > \hat{\alpha}_P$ and $\alpha_S \geq \tilde{\alpha}_S$. The properties of the patenting threshold N also continue to hold for $\tilde{N}$ if $\tilde{\delta}_0^{\infty} > \delta_0^{T}$; otherwise, they have the exact opposite signs. Finally, the sign of $\partial\tilde{N}/\partial\lambda$ is ambiguous. Leakage is a factor that determines the strength of secrecy; for example, the easier the secret leaks to the public, the weaker is the protection under secrecy, and in turn, the less preferable is secrecy over patenting. It is more interesting and closer to the real-world to analyse the trade-off between certain and finite patent protection and infinite, but uncertain, trade secret protection.

5.2.2 A Varying Probability of Leakage

In this section, we relax the assumption of a leakage probability that is independent of the number of firms practising the invention and compare the equilibrium outcomes with the existing results derived until now. Particularly, we assume a larger average rate of accidental leakage when both firms have a trade secret as opposed to when only Firm 1 has the secret. Let λ denote the probability of accidental leakage when only Firm 1 practices the invention (that is, a low-risk of leakage possibility) and Λ, where $\Lambda > \lambda$, be the probability of leakage when Firm 2 has also obtained the trade secret through a technology transfer or imitation (that is, a high-risk of leakage possibility). Establishing the model with a constant probability of leakage makes it evident that only the analysis of secrecy protection runs into alternations. When only one firm holds the trade secret, the discounted-adjusted protection length of the trade secret is given by Equation 5.5. Conversely, when both firms rely on secrecy the discounted-adjusted protection length becomes:

$$\tilde{\tilde{\delta}}_{t_1}^{t_2} \equiv \int_{t_1}^{t_2} e^{-rt}e^{-\Lambda t}dt = \frac{e^{-(r+\Lambda)t_1} - e^{-(r+\Lambda)t_2}}{r+\Lambda}. \tag{5.13}$$

The only difference between this case and the case assuming a constant probability of leakage is that a duopoly profit in this is equivalent to both firms practicing the secret mechanism, and thus it corresponds to a high-risk leakage possibility (that is, $\tilde{\tilde{\delta}}_{t_1}^{t_2}$). This case is opposed to a monopoly profit that corresponds to a low-risk leakage possibility (that is, $\tilde{\delta}_{t_1}^{t_2}$). Let $\tilde{v}_i^L$ for $i = \{1, 2\}$ be the profit of Firm i when a transfer of a secret that is prone to leakage is subscribed ($License$), then the equilibrium profits are:

$$\begin{aligned} \tilde{v}_1^L(\tilde{\tilde{F}}_S^*) &= \pi^m \tilde{\delta}_0^\infty - \frac{1}{\alpha_S} \pi^d \tilde{\tilde{\delta}}_{T_S}^\infty (\pi^m \tilde{\delta}_{T_S}^\infty - \pi^d \tilde{\tilde{\delta}}_{T_S}^\infty), \\ \tilde{v}_2^L(\tilde{\tilde{F}}_S^*) &= \frac{1}{\alpha_S} \pi^d \tilde{\tilde{\delta}}_{T_S}^\infty (\pi^m \tilde{\delta}_{T_S}^\infty - \pi^d \tilde{\tilde{\delta}}_{T_S}^\infty) - (\pi^m \tilde{\delta}_0^\infty - 2\pi^d \tilde{\tilde{\delta}}_0^\infty). \end{aligned} \tag{5.14}$$

Following the same reasoning, let $\tilde{v}_i^I$ for $i = \{1, 2\}$, be the profit of Firm i when Firm 2 imitates a trade secret that is prone to accidental leakage ($Imitate$). Then, the profits that Firms 1 and 2 earn in equilibrium are:

$$\begin{aligned} \tilde{v}_1^I(\tilde{\tilde{y}}^*) &= \pi^m \tilde{\delta}_0^\infty - \frac{1}{\alpha_S} \pi^d \tilde{\tilde{\delta}}_{T_S}^\infty (\pi^m \tilde{\delta}_{T_S}^\infty - \pi^d \tilde{\tilde{\delta}}_{T_S}^\infty), \\ \tilde{v}_2^I(\tilde{\tilde{y}}^*) &= \frac{1}{2\alpha_S} (\pi^d \tilde{\tilde{\delta}}_{T_S}^\infty)^2. \end{aligned} \tag{5.15}$$

The optimal imitation effort $\tilde{\tilde{y}}^*$ is equal to $\frac{1}{\alpha_S} \pi^d \tilde{\tilde{\delta}}_{T_S}^\infty$, whereas the optimal licensing fee $\tilde{\tilde{F}}^*$ is given from the following equation:

$$\tilde{\tilde{F}}_S^* = \pi^m \tilde{\delta}_{T_S}^\infty - \pi^d \tilde{\tilde{\delta}}_0^\infty - \frac{1}{\alpha_S} \pi^d \tilde{\tilde{\delta}}_{T_S}^\infty (\pi^m \tilde{\delta}_{T_S}^\infty - \pi^d \tilde{\tilde{\delta}}_{T_S}^\infty). \tag{5.16}$$

Clearly, the properties given by Corollary 3 hold for $\tilde{\tilde{F}}_S^*$, while the effect of a change of any probability of accidental leakage on the optimal licensing fee cannot be determined. Similar to the existing analysis, licensing a trade secret is optimal if $\alpha_S \leq \tilde{\tilde{\alpha}}_S$, where $\tilde{\tilde{\alpha}}_S$ is defined as follows:

$$\tilde{\tilde{\alpha}}_S \equiv \left[\frac{\pi^m \tilde{\delta}_{T_S}^\infty - \frac{3}{2} \pi^d \tilde{\tilde{\delta}}_{T_S}^\infty}{\pi^m \tilde{\delta}_0^\infty - 2\pi^d \tilde{\tilde{\delta}}_0^\infty} \right] \pi^d \tilde{\tilde{\delta}}_{T_S}^\infty. \tag{5.17}$$

The properties of Corollary 4 also continue to hold for $\tilde{\tilde{\alpha}}_S$; however, changing λ or Λ has an ambiguous effect on the licensing threshold. Finally, when $\{\alpha_P \leq \hat{\alpha}_P$ and $\alpha_S \leq \tilde{\tilde{\alpha}}_S\}$ or $\{\alpha_P \leq \hat{\alpha}_P$ and $\alpha_S > \tilde{\tilde{\alpha}}_S\}$, the invention is patented in equilibrium if the following condition holds:

$$\tilde{\tilde{M}} \equiv \frac{\frac{1}{\alpha_S}\pi^d \tilde{\tilde{\delta}}_{T_S}^{\infty}(\pi^m \tilde{\delta}_{T_S}^{\infty} - \pi^d \tilde{\tilde{\delta}}_{T_S}^{\infty}) - \frac{1}{2\alpha_P}(\pi^d \delta_{T_P}^{T})^2}{\pi^m \tilde{\delta}_0^{\infty} - 2\pi^d \delta_0^T} \geq 1, \tag{5.18}$$

whereas patenting is preferable if:

$$\tilde{\tilde{N}} \equiv \frac{\frac{1}{\alpha_S}\pi^d \tilde{\tilde{\delta}}_{T_S}^{\infty}(\pi^m \tilde{\delta}_{T_S}^{\infty} - \pi^d \tilde{\tilde{\delta}}_{T_S}^{\infty}) - \frac{1}{\alpha_P}\pi^d(\pi^m - \pi^d)(\delta_{T_P}^{T})^2}{\pi^m(\tilde{\delta}_0^{\infty} - \delta_0^T)} \geq 1. \tag{5.19}$$

The properties of $\tilde{M}$ and $\tilde{N}$ continue to hold, and the sign of $\partial\tilde{\tilde{M}}/\partial\Lambda$ is ambiguous. Additionally, both patenting thresholds are higher than the related thresholds that correspond to the case when the probability of the accidental leakage is constant, that is, $\tilde{\tilde{M}} > \tilde{M}$ and $\tilde{\tilde{N}} > \tilde{N}$. This result implies that patent attractiveness increases when the probability of leakage depends on the number of firms sharing the secret. Acknowledging that, the probability of accidental leakage might, in fact, increase with the number of firms practising a secret, which in turn would weaken the trade secret protection and encourage or discourage imitation; however, it strengthens the incentives to patent.

6 Conclusion

In this study, we examine the strategic behaviour of innovating firms by comparing the effects of patenting and secrecy on the incentives to license and imitate. We determine the equilibrium actions and outcomes of a two-stage game. In the first stage of the game, an inventor endowed with new technology, along with filing for a patent protection, also has the option of keeping the invention a secret. In the second stage, a single potential entrant can enter the market through technology transfer or imitation.

The analysis suggests that both patent protection and secrecy might prevail in equilibrium depending on the efficiency of the imitation technology and the strength of intellectual property protection. Particularly, the ease and time required to achieve imitation, and the type of intellectual property protection employed by the inventor are the main factors that determine the equilibrium outcomes of the game. We show that, if the technological efficiency to imitate a patented invention and to imitate a secret are sufficiently low, then, in equilibrium, a technology transfer would always be better than imitation, regardless of the protection type employed by the inventor. Conversely, highly efficient imitation technologies result in imitation. We also find that trade secret protection weakens in the presence of a positive probability of accidental leakage, thereby increasing the attractiveness of the patent protection. Although imitation might be more or less attractive than licensing under secrecy, often the risk of leakage tends to make it preferable.

It is evident that the results described above come from a simple model, which needs to be refined along several lines. For example, the model can be extended to analysing how the enforcement efficiency of intellectual property rights and the size of the firms affect the incentives to license, imitate, and litigate. Next, observing that licensing and imitation are more frequent in specific industries and geographical locations, it is essential to enrich the model to ensure that it can be used to analyse industry-specific effects of patenting and secrecy on technology diffusion and imitation. Finally, the analysis of the relevance of the propositions established in this study and their testable welfare considerations is left for future research.

Appendix

Proof of Corollary 1. It must be noted that $\frac{1}{\alpha_P}\pi^d\delta_{T_P}^T \leq 1$ to ensure that $x \leq 1$. Hence, the partial derivatives of Corollary 1 can be derived in a straightforward manner as follows:

$$\begin{aligned}
\frac{\partial F_P^*}{\partial \pi^d} &= \delta_0^T - \left(\frac{1}{\alpha_P}\pi^d\delta_{T_P}^T\right)\delta_{T_P}^T > 0,\\
\frac{\partial F_P^*}{\partial \alpha_P} &= \frac{1}{2(\alpha_P)^2}\left(\pi^d\delta_{T_P}^T\right)^2 > 0,\\
\frac{\partial F_P^*}{\partial T} &= \pi^d e^{-rT} - \left(\frac{1}{\alpha_P}\pi^d\delta_{T_P}^T\right)\pi^d e^{-rT} \geq 0,\\
\frac{\partial F_P^*}{\partial r} &= \frac{\pi^d e^{-rT}}{r} - \frac{\pi^d\delta_0^T}{r} + \left(\frac{1}{\alpha_P}\pi^d\delta_{T_P}^T\right)\frac{\pi^d\left(e^{-rT_P}T_P - e^{-rT}T\right)}{r} + \left(\frac{1}{\alpha_P}\pi^d\delta_{T_P}^T\right)\pi^d\delta_{T_P}^T \gtrless 0.
\end{aligned} \tag{A.1}$$

Proof of Corollary 2. The partial derivatives of Corollary 2 are derived as follows:

$$\begin{aligned}
\frac{\partial \hat{\alpha}_P}{\partial \pi^m} &= -\frac{\frac{1}{2}\left(\pi^d\delta_{T_P}^T\right)^2}{(\pi^m - 2\pi^d)^2\delta_0^T} < 0,\\
\frac{\partial \hat{\alpha}_P}{\partial \pi^d} &= \frac{\left[3(\pi^d)^2 - 3\pi^d\pi^m + (\pi^m)^2\right](\delta_{T_P}^T)^2}{(\pi^m - 2\pi^d)^2\delta_0^T} > 0,\\
\frac{\partial \hat{\alpha}_P}{\partial T} &= \frac{2\left(\pi^m - \frac{3}{2}\pi^d\right)\delta_{T_P}^T\pi^d e^{-rT}}{(\pi^m - 2\pi^d)\delta_0^T} - \frac{\left(\pi^m - \frac{3}{2}\pi^d\right)(\delta_{T_P}^T)^2\pi^d e^{-rT}}{(\pi^m - 2\pi^d)(\delta_0^T)^2} > 0,\\
\frac{\partial \hat{\alpha}_P}{\partial T_P} &= -\frac{2(\pi^m - \frac{3}{2}\pi^d)\delta_{T_P}^T\pi^d e^{-rT_P}}{(\pi^m - 2\pi^d)\delta_0^T} < 0,\\
\frac{\partial \hat{\alpha}_P}{\partial r} &= \frac{(\pi^m - \frac{3}{2}\pi^d)\delta_{T_P}^T\pi^d\left[2(e^{-rT_P}T_P - e^{-rT}T) - \delta_{T_P}^T\right]}{(\pi^m - 2\pi^d)\delta_0^T r} - \frac{(\pi^m - \frac{3}{2}\pi^d)(\delta_{T_P}^T)^2\pi^d T e^{-rT}}{(\pi^m - 2\pi^d)(\delta_0^T)^2 r} \gtrless 0.
\end{aligned} \tag{A.2}$$

Proof of Corollary 3. Similar to the proof of Corollary 1, $\frac{1}{\alpha_S}\pi^d\delta_{T_S}^{\infty} \leq 1$ so that $y \leq 1$, and thus the proof of Corollary 3 is straightforward:

$$\begin{aligned}
\frac{\partial F_S^*}{\partial \pi^m} &= \delta_0^{\infty} - \left(\frac{1}{\alpha_S}\pi^d\delta_{T_S}^{\infty}\right)\delta_{T_S}^{\infty} > 0, \\
\frac{\partial F_S^*}{\partial \pi^d} &= -\delta_0^{\infty} - \tfrac{1}{\alpha_S}(\pi^m - 2\pi^d)\delta_{T_S}^{\infty} < 0, \\
\frac{\partial F_S^*}{\partial \alpha_S} &= \frac{\pi^d(\pi^m - \pi^d)(\delta_{T_S}^{\infty})^2}{(\alpha_S)^2} > 0, \\
\frac{\partial F_S^*}{\partial T_S} &= \frac{2\pi^d(\pi^m - \pi^d)\delta_{T_S}^{\infty}e^{-rT_S}}{\alpha_S} > 0, \\
\frac{\partial F_S^*}{\partial r} &= -(\pi^m - \pi^d)\delta_0^{\infty} + \frac{1}{\alpha_S}2\pi^d(\pi^m - \pi^d)(\delta_{T_S}^{\infty})^2\left(T_S + \frac{1}{r}\right) \gtreqless 0.
\end{aligned} \tag{A.3}$$

Proof of Corollary 4. Similar to Corollary 2, the partial derivatives of $\hat{\alpha}_S$ are:

$$\begin{aligned}
\frac{\partial \hat{\alpha}_S}{\partial \pi^m} &= -\frac{\frac{1}{2}\left(\pi^d\delta_{T_S}^{\infty}\right)^2}{\left(\pi^m - 2\pi^d\right)^2\delta_0^{\infty}} < 0, \\
\frac{\partial \hat{\alpha}_S}{\partial \pi^d} &= \frac{\left[3\left(\pi^d\right)^2 - 3\pi^d\pi^m + \left(\pi^m\right)^2\right](\delta_{T_S}^{\infty})^2}{\left(\pi^m - 2\pi^d\right)^2\delta_0^{\infty}} > 0, \\
\frac{\partial \hat{\alpha}_S}{\partial T_S} &= -\frac{2\left(\pi^m - \frac{3}{2}\pi^d\right)\delta_{T_S}^{\infty}\pi^d e^{-rT_S}}{\left(\pi^m - 2\pi^d\right)\delta_0^{\infty}} < 0, \\
\frac{\partial \hat{\alpha}_S}{\partial r} &= -\frac{1}{2}\frac{(2\pi^m - 3\pi^d)(\delta_{T_S}^{\infty})^2\pi^d(2T_S r + 1)}{\left(\pi^m - 2\pi^d\right)} < 0.
\end{aligned} \tag{A.4}$$

Proof of Corollary 5. As usual, the derivation of the partial derivatives is straightforward:

$$
\begin{aligned}
\frac{\partial M}{\partial \alpha_P} &= \frac{1}{2(\alpha_P)^2}\left[\frac{(\pi^d)^2(\delta_{T_P}^T)^2}{\pi^m\delta_0^\infty - 2\pi^d\delta_0^T}\right] > 0,\\
\frac{\partial M}{\partial \alpha_S} &= -\frac{\pi^d(\pi^m-\pi^d)(\delta_{T_S}^\infty)^2}{(\alpha_S)^2(\pi^m\delta_0^\infty - 2\pi^d\delta_0^T)} < 0,\\
\frac{\partial M}{\partial T_P} &= \frac{(\pi^d)^2\delta_{T_P}^T e^{-rT}}{\alpha_P(\pi^m\delta_0^\infty - 2\pi^d\delta_0^T)} > 0,\\
\frac{\partial M}{\partial T_S} &= -\frac{2\pi^d(\pi^m-\pi^d)\delta_{T_S}^\infty e^{-rT_S}}{\alpha_S(\pi^m\delta_0^\infty - 2\pi^d\delta_0^T)} < 0,\\
\frac{\partial M}{\partial T} &= -\frac{(\pi^d)^2\delta_{T_P}^T e^{-rT}}{\alpha_P(\pi^m\delta_0^\infty - 2\pi^d\delta_0^T)} + \frac{2\left[\frac{1}{\alpha_S}\pi^d(\pi^m-\pi^d)(\delta_{T_S}^\infty)^2 - \frac{1}{2\alpha_P}\left(\pi^d\delta_{T_P}^T\right)^2\right]\pi^d e^{-rT}}{\left(\pi^m\delta_0^\infty - 2\pi^d\delta_0^T\right)^2} \gtrless 0,\\
\frac{\partial M}{\partial r} &= -\frac{\frac{1}{\alpha_S}2\pi^d(\pi^m-\pi^d)(\delta_{T_S}^\infty)^2 T_S + 2\pi^d(\pi^m-\pi^d)(\delta_{T_S}^\infty)^2\delta_0^\infty}{\pi^m\delta_0^\infty - 2\pi^d\delta_0^T} + \\
&\quad \frac{\frac{1}{\alpha_P}(\pi^d)^2\delta_{T_P}^T(e^{-rT_P}T_P - e^{-rT}T)\delta_0^\infty + (\pi^d\delta_{T_P}^T)^2\delta_0^\infty}{\pi^m\delta_0^\infty - 2\pi^d\delta_0^T} + \\
&\quad \frac{\left[\frac{1}{\alpha_S}\pi^d(\pi^m-\pi^d)(\delta_{T_S}^T)^2 - \frac{1}{2\alpha_P}(\pi^d\delta_{T_P}^T)^2\right]\left[\pi^m(\delta_0^\infty)^2 + 2\pi^d\delta_0^\infty e^{-rT}T - 2\pi^d\delta_0^T\delta_0^\infty\right]}{\left(\pi^m\delta_0^\infty - 2\pi^d\delta_0^T\right)^2} \gtrless 0,\\
\frac{\partial M}{\partial \pi^d} &= \frac{\frac{1}{\alpha_S}(\pi^m-2\pi^d)(\delta_{T_S}^\infty)^2 - \frac{1}{\alpha_P}\pi^d(\delta_{T_P}^T)^2}{\pi^m\delta_0^\infty - 2\pi^d\delta_0^T} + \frac{\left[\frac{2}{\alpha_S}\pi^d(\pi^m-\pi^d)(\delta_{T_S}^\infty)^2 - \frac{1}{\alpha_P}(\pi^d\delta_{T_P}^T)^2\right]\delta_0^T}{\left(\pi^m\delta_0^\infty - 2\pi^d\delta_0^T\right)^2} \gtrless 0,\\
\frac{\partial M}{\partial \pi^m} &= \frac{\frac{1}{\alpha_S}\pi^d(\delta_{T_S}^\infty)^2}{\pi^m\delta_0^\infty - 2\pi^d\delta_0^T} - \frac{\left[\frac{1}{\alpha_S}\pi^d(\pi^m-\pi^d)(\delta_{T_S}^\infty)^2 - \frac{1}{2\alpha_P}(\pi^d\delta_{T_P}^T)^2\right]\delta_0^T}{\left(\pi^m\delta_0^\infty - 2\pi^d\delta_0^T\right)^2} \gtrless 0.
\end{aligned}
\tag{A.5}
$$

Proof of Corollary 6. Similar to the proof of Corollary 3 above, the proof of Corollary 6 is straightforward:

$$
\begin{aligned}
\frac{\partial F_P^{NB}}{\partial \pi^m} &= (1-\beta)\delta_0^T - (1-\beta)\left(\frac{1}{\alpha_P}\pi^d \delta_{T_P}^T\right)\delta_{T_P}^T \geq 0,\\
\frac{\partial F_P^{NB}}{\partial \alpha_P} &= \frac{\pi^d\big[\pi^m - \pi^d - \beta(\pi^m - \frac{3}{2}\pi^d)\big](\delta_{T_P}^T)^2}{(\alpha_P)^2} > 0,\\
\frac{\partial F_P^{NB}}{\partial T_P} &= \frac{2\pi^d\big[\pi^m - \pi^d - \beta(\pi^m - \frac{3}{2}D)\big]\delta_{T_P}^T e^{-rT_P}}{\alpha_P} > 0,\\
\frac{\partial F_P^{NB}}{\partial \pi^d} &= (2\beta-1)\delta_0^T - \frac{\big[\pi^m - \pi^d - \beta(\pi^m - \frac{3}{2}\pi^d)\big](\delta_{T_P}^T)^2}{(\alpha_P)^2} - \frac{\pi^d(\frac{3}{2}\beta - 1)(\delta_{T_P}^T)^2}{\alpha_P} \gtrless 0,\\
\frac{\partial F_P^{NB}}{\partial \beta} &= \left(\frac{1}{\alpha_P}\pi^d \delta_{T_P}^T\right)(\pi^m - \tfrac{3}{2}\pi^d)\delta_{T_P}^T - (\pi^m - 2\pi^d)\delta_0^T \gtrless 0,\\
\frac{\partial F_P^{NB}}{\partial r} &= \frac{1}{r}\big[\pi^m - \pi^d - \beta(\pi^m - 2\pi^d)\big](e^{-rT}T - \delta_0^T) +\\
&\quad \frac{2}{r}\left(\frac{1}{\alpha_P}\pi^d \delta_{T_P}^T\right)\big[\pi^m - \pi^d - \beta(\pi^m - \tfrac{3}{2}\pi^d)\big](e^{-rT_P}T_P - e^{-rT}T) \gtrless 0.
\end{aligned}
\tag{A.6}
$$

References

Almeling, D. (2012). Seven reasons why trade secrets are increasingly important. *Berkeley Technology Law Journal 27*(2), 1091–1117.

Anton, J. and D. Yao (2004). Little patents and big secrets: Managing intellectual property. *The RAND Journal of Economics 35*(1), 1–22.

Aoki, R. and J. L. Hu (2003). Time factors of patent litigation and licensing. *Journal of Institutional and Theoretical Economics 159*(2), 280–301.

Arora, A. and M. Ceccagnoli (2006). Patent protection, complementary assets, and firms' incentives for technology licensing. *Management Science 52*(2), 293–308.

Arora, A., M. Ceccagnoli, and W. Cohen (2008). R&D and the patent premium. *International Journal of Industrial Organization 26*(5), 1153–1179.

Arundel, A. (2001). The relative effectiveness of patents and secrecy for appropriation. *Research Policy 30*(4), 611–624.

Baldi, F. and L. Trigeorgis (2014). IP licensing: how to structure a good deal. *Sinergie, Rivista di Studi e Ricerche* (93), 55–78.

Bessen, J. and E. Maskin (2009). Sequential innovation, patents, and imitation. *The RAND Journal of Economics 40*(4), 611–635.

Bogers, M., R. Bekkers, and O. Granstrand (2012). Intellectual property and licensing strategies in open collaborative innovation. In C. de Pablos Heredero and D. L. Berzosa (Eds.), *Open innovation in firms and public administrations: Technologies for value creation*, Chapter 3, pp. 37–58. IGI Global, Hershey, PA.

Bulut, H. and G. Moschini (2006). Patents, trade secrets and the correlation among R&D projects. *Economics Letters 91*(1), 131–137.

Cohen, W., R. Nelson, and J. Walsh (2000). Protecting their intellectual assets: Appropriability conditions and why U.S. manufacturing firms patent (or not). *NBER Working Paper* (7552).

Cournot, A. and I. Fisher (1929). *Researches into the mathematical principles of the theory of wealth by Augustine Cournot, 1838; English translation by Nathaniel T. Bacon; With an essay on Cournot and mathematical economics and a bibliography of mathematical economics by Irving Fisher*. The Macmillan Co.

Denicolo, V. (2007). Do patents over-compensate innovators? *Economic Policy 22*(52), 679–729.

Denicolo, V. and L. Franzoni (2003). The contract theory of patents. *International Review of Law and Economics 23*(4), 365–380.

Denicolo, V. and L. Franzoni (2004). Patents, secrets, and the first-inventor defense. *Journal of Economics and Management Strategy 13*(3), 517–538.

Denicolo, V. and L. Franzoni (2008). Innovation, duplication, and the contract theory of patents. In R. Cellini and L. Lambertini (Eds.), *The economics of innovation*, Volume 286 of *Contribution to economic analysis*, Chapter 2, pp. 15–32. Emerald Group Publishing Limited.

Denicolo, V. and P. Zanchettin (2002). How should forward patent protection be provided? *International Journal of Industrial Organization 20*(6), 801–827.

Dreyfuss, R. and K. Strandburg (Eds.) (2011). *The law and theory of trade secrecy: A handbook of contemporary research.* Edward Elgar.

Epstein, R. (2003). Trade secrets as private property: Their constitutional protection. *University of Chicago Law and Economics, Olin working paper* (190).

Friedman, D., W. Landes, and R. Posner (1991). Some economics of trade secret law. *The Journal of Economic Perspectives 5*(1), 61–72.

Gallini, N. (1984). Deterrence by market sharing: A strategic incentive for licensing. *The American Economic Review 74*(5), 931–941.

Gallini, N. (1992). Patent policy and costly imitation. *The RAND Journal of Economics 23*(1), 52–63.

Gallini, N. and S. Scotchmer (2002). Intellectual property: When is it the best incentive system? In *Innovation policy and the economy*, Volume 2, pp. 51–78. MIT Press.

Garvey, J. and A. Baluch (2007). Intellectual property: Patent or padlock: Patents and trade secrets form the heart of an effective IP strategy. *BioPharm International 20*(2), 1–5.

Gilbert, R. and D. Newbery (1982). Preemptive patenting and the persistence of monopoly. *The American Economic Review 72*(3), 514–526.

Hall, B. (2007). Patents and patent policy. *Oxford Review of Economic Policy 23*(4), 568–587.

Hall, B., C. Helmers, M. Rogers, and V. Sena (2014). The choice between formal and informal intellectual property: A review. *Journal of Economic Literature 52*(2), 375–423.

Horstmann, I., G. MacDonald, and A. Slivinski (1985). Patents as information transfer mechanisms: To patent or (maybe) not to patent. *Journal of Political Economy 93*(5), 837–858.

Hussinger, K. (2006). Is silence golden? Patents versus secrecy at the firm level. *Economics of Innovation and New Technology 15*(8), 735–752.

Kamien, M. (1992). Patent licensing. In R. Aumann and S. Hart (Eds.), *Handbook of Game Theory*, Volume 1, pp. 331–354. Elsevier.

Kamien, M., S. Oren, and Y. Tauman (1992). Optimal licensing of cost-reducing innovation. *Journal of Mathematical Economics 21*(5), 483–508.

Kamien, M. and Y. Tauman (1984). The private value of a patent: A game theoretic analysis. *Journal of Economics 4*, 93–118.

Kamien, M. and Y. Tauman (1986). Fees versus royalties and the private value of a patent. *The Quarterly Journal of Economics 101*(3), 471–491.

Kamien, M., Y. Tauman, and I. Zang (1988). Optimal license fees for a new product. *Mathematical Social Sciences 16*(1), 77–106.

Katz, M. and C. Shapiro (1985). On the licensing of innovations. *The RAND Journal of Economics 16*(4), 504–520.

Katz, M. and C. Shapiro (1986). How to license intangible property. *The Quarterly Journal of Economics 101*(3), 567–589.

Katz, M. and C. Shapiro (1987). R and D rivalry with licensing or imitation. *The American Economic Review 77*(3), 402–420.

Kultti, K., T. Takalo, and J. Toikka (2006). Simultaneous model of innovation, secrecy, and patent policy. *The American Economic Review 96*(2), 82–86.

Kultti, K., T. Takalo, and J. Toikka (2007). Secrecy versus patenting. *The RAND Journal of Economics 38*(1), 22–42.

Layne-Farrar, A. (2014). Moving past the SEP FRAND obsession: Some thoughts on the economic implications of unilateral commitments and the complexities of patent licensing. *George Mason Law Review 21*(4), 1093–1110.

Layne-Farrar, A. (2016). *Antitrust intellectual property and high tech handbook*, Chapter The Economics of FRAND. University of Cambridge Press.

Lemley, M. and C. Shapiro (2005). Probabilistic patents. *The Journal of Economic Perspectives 19*(2), 75–98.

Lemley, M. and C. Shapiro (2007). Patent holdup and royalty stacking. *Texas Law Review 85*(7), 1991–2049.

Lemley, M. and C. Shapiro (2013). A simple approach to setting reasonable royalties for standard-essential patents. *Berkeley Technology Law Journal 28*(2), 1135–1166.

Levin, R., A. Klevorick, R. Nelson, S. Winter, R. Gilbert, and Z. Griliches (1987). Appropriating the returns from industrial research and development. *Brookings Papers on Economic Activity 1987*(3), 783–831.

Mansfield, E., M. Schwartz, and S. Wagner (1981). Imitation costs and patents: An empirical study. *The Economic Journal 91*(364), 907–918.

Maurer, S. and S. Scotchmer (2002). The independent invention defence in intellectual property. *Economica 69*(276), 535–547.

Ottoz, E. and F. Cugno (2004). The independent invention defence in a Cournot duopoly model. *Economics Bulletin 12*(5), 1–7.

Ottoz, E. and F. Cugno (2011). Choosing the scope of trade secret law when secrets complement patents. *International Review of Law and Economics 31*(4), 219–227.

Pakes, A. (1985). On patents, R&D, and the stock market rate of return. *Journal of Political Economy 93*(2), 390–409.

Pakes, A. (1986). Patents as options: Some estimates of the value of holding European patent stocks. *Econometrica 54*(4), 755–784.

Reinganum, J. (1983). Uncertain innovation and the persistence of monopoly. *The American Economic Review 73*(4), 741–748.

Rostoker, M. (1983). PTC research report: A survey of corporate licensing. *Idea 24*(2), 59–92.

Scherer, F. (1967). Research and development resource allocation under rivalry. *The Quarterly Journal of Economics 81*(3), 359–394.

Scherer, F. (1983). The propensity to patent. *International Journal of Industrial Organization 1*(1), 107–128.

Schwartz, E. (2004). Patents and R&D as real options. *Economic Notes 33*(1), 23–54.

Scotchmer, S. (1991). Standing on the shoulders of giants: Cumulative research and the patent law. *The Journal of Economic Perspectives 5*(1), 29–41.

Shapiro, C. (2006). Prior user rights. *The American Economic Review 96*(2), 92–96.

Takalo, T. (1998). Innovation and imitation under imperfect patent protection. *Journal of Economics 67*(3), 229–241.

Yeh, B. (2016). Protection of trade secrets: Overview of current law and legislation. *Congressional Research Service Report* (7-5700).