Licensing Games

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To my parents, Kosta and Fygalia,
and my grandmother, Anastasia

Abstract

Patents are legal instruments that protect ideas, and the rise of a knowledge-based society was inevitably accompanied with their increased economic importance. As a result of this growth, patented technology became an indispensable element of firms, governments, and modern economies. Nevertheless, patents preserve their economic value only if they can be enforced in court, which is, in fact, a trait common to various instruments designed to protect intellectual property. However, contract enforcement is often imperfect. Therefore, the protection offered by patents is not absolute, raising a number of implications for their use.

This thesis studies the use of intellectual property rights, with a focus on technology transfer through licensing. In particular, it examines the choice of a licensing mode by a patent owner when the protected technology can be transferred and imitated. Additional emphasis is put on the impact of patenting and secrecy on the strategic behaviour of innovating firms, specifically on the incentives to license and imitate. It also analyses the litigation of patented technology that is prone to imitation when the legal protection is imperfect. The main results derived from the analysis can be summarised as follows.

First, the analysis shows that the licensing mode of intellectual property is a strategic choice primarily driven by the relative magnitudes of the per-unit production costs, the magnitude of innovation—the reduction in the per-unit cost because of the new technology—and the imitation cost. Particularly, licensing by way of a per-unit royalty might be preferable to licensing by way of a fixed fee from the viewpoint of a patent owner, while fixed-fee licensing might be at least as good as royalty licensing for consumers. Additionally, licensing might be used to prevent imitation, but might not be used to strategically select competition before patent expiry.

Second, the analysis finds that the availability of a choice of protection affects the strategic behaviour of innovating firms and the type of inventions licensed in the industry. Patenting might be more or less preferable than secrecy from the viewpoint of a technology owner, depending on the efficiency of the imitation technology and the strength of intellectual property protection. Furthermore, highly inefficient imitation technologies might render licensing preferable to imitation, while highly efficient imitation technologies might lead to more imitation than licensing. Acknowledging that a trade secret might leak to the public and also considering that the probability of leakage might increase with the number of firms practising the secret, the analysis suggests an increase in the attractiveness of patent protection.

Third, the analysis also finds that licensing, imitating, and litigating over a patented technology is dependent on the magnitude of innovation, the efficacy of imitation, and the strength of the judicial system: the degree to which increased litigation spending can influence the outcome of the court. When litigants expect to settle the dispute out of court, a sufficiently small magnitude of innovation might lead to licensing before imitation (an ex-ante licence), while a sufficiently large magnitude of innovation might lead to licensing after imitation (an ex-post licence). In addition, a patent owner benefits by taking no action against a highly imperfect imitation.

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In loving memory of my grandmother, Anastasia.

Aineas Mallios
December 14, 2018
Gothenburg, Sweden

Contents

1 Introduction

The purpose of this doctoral thesis is to study the strategic use of intellectual property rights (IPRs) by focusing on technology transfer through licensing. We develop a theoretical framework to analyse the strategic interaction of innovating firms in an oligopolistic industry, when intellectual property can be transferred and imitated. Acknowledging that intellectual property is prone to imitation and considering that legal protection is not perfect, we aim to predict the licensing behaviour of firms endowed with intellectual property. Moreover, looking at the choice between patents and secrecy, we examine the licensing of proprietary technology in the context of imitation. We also take a comprehensive look on how licensing can be used to prevent or settle patent litigation.

The overarching contribution of this thesis is to provide an integrated framework that can be used to study the licensing of protected technology by an incumbent firm to other firms that compete in an oligopolistic industry. The competing firms might obtain the protected technology through a non-cooperative technology transfer or costly imitation. The analysis acknowledges that patents only grant a temporary and contestable monopoly power, instead of an exclusive and absolute one. Additionally, it considers that legal protection is not perfect and that the efficiency of the imitation technology might vary (imperfect imitation). Overall, the thesis covers the following issues.

First, the theoretical framework is used to predict the licensing behaviour of a patent owner and its impacts on the distribution of profits in the industry, the incentives to imitate, competition, and consumer surplus. Second, we explore the interplay between the choice of protecting a technological invention through a patent (requiring disclosure of valuable information) or through a trade secret (requiring concealment of valuable information) and the licensing and strategic interaction of innovating firms. Third, we analyse the litigation and settlement of patent infringement disputes through a licensing lens. Overall, the analysis can be used to partially explain the appropriability problem that arises when firms that invest in research and development (R&D) and innovation have difficulty securing returns on their investments.

This doctoral thesis consists of two parts. The remaining structure of the first part, which is an introduction to the research field and topic of the thesis, is as follows. Section 2 provides the context and motivation for the three appended papers that comprise the thesis. Section 3 reviews related theoretical and empirical literature on the economics of innovation. Section 4 poses the general and specific research questions and describes the methodology of the research, while Section 5 concludes with a discussion of the main findings, potential contributions, and propositions for future research. The second part

consists of three appended papers that collectively focus on the strategic licensing of technology.

2 Patents and Secrecy

The main economic purpose underlying the patent system is to promote research and development. This might, in turn, lead to innovation and technological advancement. The key channels to achieve this goal are the protection of the commercial exploitation of technological inventions and the encouragement of the disclosure of new valuable information. The increased interest in knowledge creation over the last few years has led to an expansion of patents in chemicals, computer electronics, communications, pharmaceuticals, biomedicine, biotechnology, and nanotechnology (Granstrand and Holgersson, 2012; Bourelos, 2013; Lerner and Seru, 2017). The objective of the patent system and the availability of reasonably reliable and good data on patents have resulted in patents often being used as proxies for innovation. However, the effectiveness of patents in achieving an accurate and reliable estimation of investment in innovation is dependent on a number of factors. Specifically, it depends on the ability of rival firms to imitate, the availability of alternative protection choices, and the efficacy of the legal system in protecting IPRs (Gallini, 1992; Crampes and Langinier, 2002). The imitation of protected inventions is, in turn, related to the size of innovation, the efficiency of the imitation technology, as well as the characteristics of the industry and the institutional setting. The use of an alternative protection choice might also depend on several factors such as the type of invention, the failure to protect essential technological information, or the availability of licensing. Intellectual property protection therefore involves economic uncertainty. Furthermore, the choice of protection poses a trade-off to innovating firms. For example, consider patents versus secrecy: on one hand, patents grant an option to litigate against potential infringement in exchange for a fixed protection term and information disclosure; on the other hand, secrecy might last indefinitely, but can be lost through independent rediscovery or accidental leakage to the public (Waldman and Jensen, 2013, Chapter 15). We examine these issues and develop a theoretical framework that can also be used to analyse the strategic interactions of innovating firms in other situations.

Early studies on patent races have suggested that patents might spur innovation (Barzel, 1968; Wright, 1983; Reinganum, 1983). Considering the cumulative nature of innovation, relatively later studies have challenged the effectiveness of the patent system in promoting innovation (Scotchmer, 1991, 1999). Hall (2007) analysed the patent system trade-offs using a cost-benefit framework based on two dimensions: innovation and

competition. His analysis showed that patents might encourage innovation and technology transfer; however, they might also increase transaction costs and monopoly power. More recent studies have shown that patents are not effective at preventing imitation, appropriating returns from investment in R&D, and generating licensing fees (Hall, 2007; Bessen and Meurer, 2008; Bessen and Maskin, 2009; Hall et al., 2014). A number of surveys related to the effectiveness and appropriability of patent protection have found that firms depend heavily on alternative means of protection, particularly lead time and secrecy (Mansfield, 1985, 1986; Levin et al., 1987; Cohen et al., 2000; Arundel, 2001; Gonzalez-Alvarez and Nieto-Antolin, 2007).[1] The findings of these surveys suggest that patents might be used for objectives other than appropriating the returns from investment in innovation. In particular, they are mostly used strategically to prevent entry, deter imitation, and negotiate and file suits.

Trade secret law is designed to protect inventions from misappropriation, most notably when the disclosure of new information is not desirable. The promotion of research and development falls within the scope of secrecy as much as it does under that of patents. Therefore, both protection choices might serve the same utilitarian purpose. Nonetheless, the differences in protection between patents and secrecy have important implications on the strategic behaviour of innovating firms and, in turn, on the diffusion of technology through licensing (Waldman and Jensen, 2013, Chapter 15). On one hand, there are empirical studies suggesting that licensing patented technology is easier, less costly, and more frequent than licensing a trade secret (Arora and Ceccagnoli, 2006). This might indicate that the patent system is more effective in appropriating returns and encouraging innovation than secrecy. Patents might, in fact, be preferable to secrets in cases where secrecy is too risky to rely upon. For example, consider industries where reverse engineering is easy—such as pharmaceuticals—or when exclusive rights for a relatively short period of time are preferable. On the other hand, secrecy might be considered a better alternative to patent protection when considering the effects of rejected patent applications on the appropriation of returns and incentives to innovate. The information associated with an unsuccessful patent application will in any case be disclosed, wiping out the value of a potential trade secret. This might also discourage subsequent innovation. Save for the fact that both instruments are used to protect intellectual property and, thus, have common characteristics, patents and secrecy are often mutually exclusive means of protection.

To illustrate some of these issues, consider the candy industry. Dreyfuss and Strand-

[1] For a thorough review of the empirical evidence on innovation and appropriability, refer to Lopez (2009) and the literature cited therein.

burg (2011) describe a number of cases showing candy-makers being secretive about candy inventions. For example, consider the chocolate protected by Spanish monks in the sixteenth century, Mars' secret production processes and operations, Hershey chocolate products, and the recipe for Toblerone bars. On one hand, the candy industry is characterised by industrial espionage—stealing from and inventing around the attempts of competitors—in order to take competitive advantage away from rivals. On the other hand, candy-makers report holdings of patented technology and charge royalties to transfer the rights of their inventions to their competitors. For instance, consider the patents that Mars owns on the technology of vending machines. It appears that a candy-maker keeps others from learning certain inventions through secrecy but licenses the rights of other inventions through patents. This raises questions regarding the incentives to develop patentable inventions that are not patented but instead secretly protected, on the basis that secrecy outweighs the term of imperfect patent protection.[2]

In conclusion, patents and secrecy can be complements or substitutes, or can even be used together. Changes in policy might have ambiguous effects on the attractiveness of one choice over the other. For example, a weak and costly patent system might encourage greater reliance on secrecy. There are instances, however, where both choices of protection might respond similarly to a policy change, and there are evidently other situations where policy interventions might favour patents more than secrecy. The policy of IPRs should thus reflect a balance of these considerations (Pepall et al., 2008). It is still vitally important to explore the constantly changing role of IPRs to get an understanding of how the licensing of technology works.

2.1 Licensing and Imitation

Law and economics have been studying the impact of intangibles on the incentives of firms to invest in innovation and on economic activity for many years (see for example, Kitch, 1977; Kamien and Schwartz, 1982; Granstrand, 2003; Scotchmer, 2005; Falvey et al., 2006; Lemley and Shapiro, 2007; Farrell and Shapiro, 2008). Furthermore, there has been a growing interest over the last few decades in the exploitation of IPRs. The value of intangibles has increased from seventeen percent of the entire market value of the S&P 500 in 1975 to approximately eighty-seven percent in 2015.[3] According to the European Patent Office, ten percent of small- and medium-sized enterprises (SMEs), which represent ninety-nine percent of businesses in the EU, used IPRs to protect their inven-

[2]For a number of case studies on valuable trade secrets, see the online archive of the World Intellectual Property Organization (WIPO), available at www.wipo.int.

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

tions in 2015 and 2016.[4] In addition, the licensing of intellectual property has become the primary source of revenue for leading owners of standard essential patents (SEP) in high-technology industries, most notably in computer electronics, semiconductors, and telecommunications.[5] For example, Qualcomm, a pioneer and market leader in wireless telecommunications products and services, derived over three-quarters of its operating profits in 2017 from patent licensing.[6] Therefore, it is important to analyse the factors underlying this unprecedented salience of intangibles and licensing activities.

In the context of this analysis, licensing is an exclusive or non-exclusive legal contract between two parties known as the licensor and the licensee. The licensee is permitted to use proprietary technology owned by the licensor in exchange for a fixed fee or a per-unit royalty payment.[7] The cost of licensing is often smaller than the cost of independently developing new technology. In addition, licensing has become a strategic tool for innovating firms, particularly in industries where technological standards are interrelated. For instance, patent licensing is one of the most commonly used methods of technology transfer in information-based industries (Anand and Khanna, 2000). Prior literature has explicitly analysed the licensing of patented cost-reducing technologies (Arrow, 1962), licensing under asymmetric cost structures (Marjit, 1990), and optimal licensing from a game-theoretic lens (Kamien and Tauman, 1984, 1986; Kamien et al., 1992). Other studies have analysed the impact of the magnitude of innovation on the licensing behaviour of firms (Wang, 1998; San Martin and Saracho, 2010), alternative modes of licensing cost-reducing inventions when the patent owner is an external inventor (a research lab) or an incumbent firm (Sen and Tauman, 2007), and two-part tariff licensing when the competing firm can self-develop the patented technology without risking infringement (Kitagawa et al., 2014). Overall, licensing plays a significant role in the transfer and development of new technology.

In many different jurisdictions, firms are increasingly investing in intangible assets (Haskel and Westlake, 2017), challenging the conventional sources of competitive advantage and ways of conducting business. This phenomenon and the rising complexity of IPRs are associated with amendments to IPRs rules and new developments in intellectual property law. The constantly increasing importance of patents, secrecy, and other legal instruments designed to protect ideas in the context of current economic and legislative

[4]For more information regarding the performance of IPRs in the EU, see www.euipo.europa.eu.

[5]For more information regarding the value of licensing activities, see www.wiseharbor.com and www.marketrealist.com.

[6]For more information regarding the licensing business of Qualcomm, see www.qualcomm.com and www.forbes.com.

[7]In a typical licensing agreement, the licensee also agrees to certain conditions regarding the acquired use of the technology.

developments is inducing a primarily strategic use of IPRs. This shift in focus from a conventional use of IPRs to a mostly strategic one might partially explain the extensive use of contractual licences of intellectual property among individuals, organizations, and governments. The growth of licensing activities might facilitate the diffusion of technology. This might, in turn, stimulate innovation and economic activity. However, licensing is often associated with potential distortions (Nordhaus, 1969; Kamien and Schwartz, 1982; Pepall et al., 2008). For instance, market power built on patents and licences over proprietary technologies tends to continue long after the expiry of the underlying contracts in some situations. Collectively, these issues redefine the licensing of intellectual property as an indisputable element of modern firms and economies.

The availability of licensing might, in turn, have different effects on innovation, depending on competition, information asymmetry, and the threat of imitation. For example, technological imitation might explain the constantly rising rate of inefficiency in the appropriability of returns on investments. This might be a main source of underinvestment in R&D (Arrow, 1962; Martin, 2001). Imitation might reduce the value of technological inventions, thus discouraging firms to invest in innovation. Imitation might also explain why firms patent only a fraction of their patentable technological holdings. Clearly, there are also positive externalities of imitation, thus a clear consensus on the matter has not yet been reached (Bessen and Maskin, 2009; Im and Shon, 2018). Nevertheless, it is beyond dispute that imitation influences the strategic behaviour of firms, in particular with respect to licensing. Furthermore, acknowledging the importance of IPRs, and considering their imperfections, render the imitation of intellectual property an important issue, if not a concern, for innovating firms. This thesis studies technology licensing, considering the availability of a choice of protection, imitation, and the imperfect legal protection of IPRs.

2.2 Litigation

Patents, in addition of being imperfect means of protection, are increasingly being used less for conventional reasons. Thus, studying the strategic behaviour of patent-holding firms is important. The imperfections of the protection and legal systems have also lead to phenomena such as patent hold-ups or hold-outs (Bessen, 2004).[8] These issues have long attracted the attention of scholars and policy-makers (Hall and Harhoff,

[8] A patent hold-up occurs when a patent owner waits for a company to implement a technology and then sues for infringement aiming to obtain more than the fair, reasonable, and non-discriminatory (FRAND) royalty rate. Patent hold-out, or reverse hold-up, occurs when users of patented technology deliberately defer or ignore the payment of fees to the patent owner (Chien, 2014; Heiden and Petit, 2017).

2012). Prior literature has suggested that different legal regimes might induce different strategic behaviour in firms. Consider an agreement to license a patented technology in settlement of a patent infringement dispute out of court (Lemley and Shapiro, 2005). Prior empirical literature shows that only a small fraction of all litigated patents go to trial (Lanjouw and Schankerman, 2001; Bessen and Meurer, 2005). Nonetheless, these litigated patents are considered to be among the most valuable. A common explanation for that is the large legal cost of litigation. The patent value should, thus, be considerably high in order for litigants to engage in a costly and uncertain legal procedure. In other words, the incentives of the litigants to avoid trial strengthen as legal costs increase. According to Henry and Turner (2006), litigation has been increasing with the constantly rising number of patent grants, adversely impacting the courts and innovation.

To illustrate the issues described above, consider the 2011 legal dispute where Apple Inc. began litigating patent infringement suits against Samsung Electronics regarding the design and technology of smartphones (Gil, 2017). In this case, imitation was clearly a strategic choice that induced a legal suit. Whether or not the potential imitator could benefit more by risking infringement than by paying the licensing fees was up to the court to determine. It so happened that both firms in this legal case were rich and could afford to spend considerable amounts in litigation. Clearly, in a litigation dispute between a small and a large firm, the expenditure assigned to litigation might vary widely. It is not surprising, therefore, to ask whether the amount spent in litigation might affect the outcome of trial. In fact, increased litigation spending has a partial impact on the outcomes of a trial and thus indisputably affects technology transfer. Nevertheless, the legal cost is but a single factor that might explain why firms often settle out of court. The expected size of the award of damages in the case of infringement might influence the course of events. The availability of technology transfer through licensing might also have an impact on litigation. In particular, licensing can be used to deter, prevent, or privately settle an infringement dispute.

By considering the efficiency of imitation technology, the availability of licensing, and the strength of the judicial system, we take a more comprehensive look at litigation. It is therefore a purpose of this thesis to improve our understanding about licensing practices and litigation to provide relevant insights regarding the strategic conduct of firms and public policy, as well as to generate subsequent questions related to the economics of innovation.

3 Literature Review

This section reviews the existing literature on the licensing of proprietary technology. First, we focus on the theoretical contributions of licensing. We then discuss selected empirical studies on the imitation and litigation of intellectual property.

3.1 Theoretical Literature

In the 21st century, the technological progress and growth of the economy rest heavily on innovation and the public policy associated with it. Patents and secrecy are legal pretensions designed to protect intellectual property from harm over a restricted geographical area and for a fixed or undefined period of time. In general, the underlying purpose of IPRs is to provide incentives to innovate by granting (contestable) exclusivity and protection to firms in order to facilitate the partial (or full) recuperation of their effort and investment in R&D. The constantly rising value of intellectual property for the economy and the recent ubiquity of the knowledge-based society emphasised the importance of studying the strategic use of IPRs (Contractor and Lorange, 2002; Gallini and Scotchmer, 2002; Farrell and Shapiro, 2008; May, 2013).

3.1.1 Patent Licensing

Arrow (1962) is a first attempt to study the relationship between the optimal number of licences and the industry structure. He focused on the profits that could be generated from licensing a cost-reducing technology to a perfectly competitive industry. McGee (1966), Scherer (1967), and (Barzel, 1968) extended the results of Arrow (1962) to oligopoly markets and examined the relationship between patent licensing and incentives to innovate. Kamien and Schwartz (1972) analysed the effects of rivalry on the choice of development period and introduction time of an invention.[9]

Extending this early work on patent licensing, Gilbert and Newbery (1982), Kamien and Schwartz (1982), and Gallini (1984) set the stage for a strategic analysis of licensing technological inventions. Their work suggests that licensing might be used to lessen the incentives of a potential entrant to develop its own technology. Moreover, Kamien and Tauman (1984, 1986) followed up on strategic licensing by incorporating a game-theoretic approach in the analysis. In particular, Kamien and Tauman (1986) focused on the licensing of proprietary technology in an oligopolistic industry. Their findings

[9] Kitch (1977) provides a review of the early theoretical work on patent licensing.

suggest that licensing by means of a fixed fee is preferable to licensing by means of a per-unit royalty for both the technology owner and consumers. They also suggest that the licensing mode and the innovation size—the cost reduction in the per-unit production cost because of the patented technology—might determine the private value of a patent.

Similar to Kamien and Tauman (1984, 1986), a series of subsequent papers applied game theory to the analysis of optimal patent design and strategic licensing (Shapiro, 1985; Katz and Shapiro, 1985, 1986; Shepard, 1987; Kamien et al., 1988). For example, Katz and Shapiro (1986) studied the incentives of an independent research lab to develop an invention and license it to downstream firms in the industry. They also considered the licensing behaviour of a research joint venture (a research lab owned by one or more downstream firms). Marjit (1990) addressed the problem of technology transfer from a firm with advanced technology to a rival firm with less-efficient technology. She suggests that initial technologies between firms that are reasonably close might encourage the transfer of technology. In other words, the magnitude of innovation or innovation size might influence the licensing of technology. A comprehensive review of the early game-theoretic literature on patent licensing is given by Kamien (1992).[10]

Wang (1998) compared the most common licensing modes of a cost-reducing technology in a homogeneous-good Cournot duopoly. He finds that royalty licensing is at least as good as fixed-fee licensing from the perspective of a patent owner. An explanation for this might be the cost advantages of royalties enjoyed by the patent owner. In turn, Wang and Yang (1999) and Wang (2002) extended the basic model to compare the licensing modes in differentiated Bertrand and Cournot settings, respectively. Kamien and Tauman (2002) extended Wang (1998) to a general Cournot oligopoly market. They suggest that an internal patent owner competing in an industry with a sufficiently large number of firms might prefer a fixed fee to a per-unit royalty or an auction. The incentives to innovate might, however, be maximised in a perfectly competitive industry. If, however, the patent owner is an outsider, then auctioning is better than the other two choices; however, his incentives to innovate are stronger when the industry is an oligopoly or a monopoly.

Additional important studies in the field are as follows: Fauli-Oller and Sandonis (2002), who focused on the two-part tariff licensing of a cost-reducing invention to a single rival firm in a differentiated Bertrand or Cournot duopoly; Filippini (2002), who

[10]For additional references, refer to Gallini and Wright (1990), Beggs (1992), Choi (2001), and Poddar and Sinha (2004) for licensing under informational asymmetry; Muto (1987) for re-licensing issues; Muto (1993) for licensing and product differentiation; and Mukherjee (2001) and Kabiraj (2004) for technology licensing under pre-commitment strategies and a Stackelberg market structure, respectively.

studied optimal licensing strategies in a Stackelberg duopoly economy; Sen (2002), who analysed the licensing of a cost-reducing invention in a Cournot oligopolistic market with at least three firms; and Sen (2005a,b), who considered optimal licensing strategies in an oligopolistic Cournot setting with an outsider patent owner. Moreover, Maurer and Scotchmer (2002) suggest that licensing might be used as a managerial tool to prevent duplication even when independent invention is legal. They find that typically, the threat of independent invention might induce a more generous licensing policy. They also show that the incentives to innovate depend on the relative size of the cost of re-invention and the original cost of invention. Ottoz and Cugno (2004) examined technology transfers taking into consideration a number of licensing restrictions when rediscovery does not risk infringement. A comprehensive review of this relatively more recent literature is given by Sen and Tauman (2007). In this thesis, we first focus on technology licensing and assume the following: no uncertainty about innovation size, certain imitation, no infringement, and complete information, similar to the considerations of the literature described above. We determine the optimal licensing choice from the viewpoint of the patent owner and consumers, as well as the effects of licensing on the incentives to duplicate and competition.

Another strand of the theoretical literature explores the effects of technology licensing on litigation. For example, Meurer (1989) examined patent litigation using a bargaining model. He suggests that a common inventor might refuse to license a valid patent, while the holder of a potentially invalid patent might prefer to privately settle in some situations. Additionally, he argues that going to trial is not an intended choice, but rather a failure to settle in private. Hause (1989) emphasised the importance of litigants having different perceived probabilities of winning in court, as well as the impact of litigation spending on the outcome of court proceedings. Hay (1995) used a two-round litigation model to determine the factors that lead disputes to trial rather than to private settlement. He suggests that asymmetric information is only one of the many reasons that might lead infringement disputes to trial. The preparation of a legal dispute—for example the presence of a legal cell—might also affect litigation.

Aoki and Hu (1999a,b, 2003) developed a framework that can be used to study patent litigation in a different situation. In particular, Aoki and Hu (1999a) focused on the effects that different rules for allocating legal costs have on settlement behaviour. They suggest that the avoidance of legal costs remains the main factor in inducing settlements. In addition, Aoki and Hu (1999b) studied the impact of an imperfect legal system on the incentives of firms to innovate. They find that the threat of litigation might, in fact, deter imitation. Aoki and Hu (2003) focused on the impact of a time factor on licensing.

They show that licensing before patent expiry might be encouraged where litigation cost is sufficiently large and imitation takes a sufficiently long time.

Crampes and Langinier (2002) examined the optimal reaction of a patentee in the context of infringement. They incorporated in the analysis monitoring efforts by the patentee to detect infringement. They suggest that such monitoring efforts might serve as a tool to deter entry. Llobet (2003) suggested that weak patent enforcement might be optimal for valuable inventions; this will encourage licensing and preserve the incentives to innovate. Moreover, Farrell and Shapiro (2008) and Encaoua and Lefouili (2009) discussed technology licensing where patent validity is uncertain. In particular, Encaoua and Lefouili (2009) focused on the licensing of 'weak patents': patents that might be invalidated in court with relative ease. They suggest that optimal licensing is dependent on whether the per-unit royalty might deter litigation. Lemley and Shapiro (2013) discussed litigation in the context of the FRAND commitment, while Wyatt (2014) argued that Nash bargaining should be used to determine reasonable royalties in a patent infringement case. We also explore litigation using Nash bargaining and consider the joint impact of the size of innovation, the efficacy of imitation, and the strength of the judicial system. We find that licensing might occur before or after imitation, and litigation might be settled in or out of court, depending on specific conditions.

3.1.2 Trade Secret Licensing

Friedman et al. (1991) addressed the lack of trade secret law in protecting intellectual property against reverse engineering and accidental leakage. They suggest that secrecy is an attractive protection choice because, in contrast to patents, it is not technology-specific. Gallini (1992) explicitly modelled the decision of an inventor on whether to patent or keep an invention secret, where sequential innovation is prone to costly imitation. Her analysis suggests that the incentives to imitate increase throughout the life term of the patent. Specifically, if the patent length is the only policy instrument, sufficiently short-lived patents might be optimal to discourage imitation. If, however, patent policy also includes patent breadth, broad patents and an adjusted patent length might lead to a larger social surplus. These results might, in turn, have implications regarding the rate of technology transfer and patent litigation. Takalo (1998) built on Gallini (1992) and developed a setting where the inventor can determine the spillover level of R&D. His findings suggest that increasing patent breadth might encourage the incentives to patent and discourage reliance on secrecy.

Denicolo and Franzoni (2003) conducted an economic analysis of the contract theory

of patents with an emphasis on the role of imitation and the market size of innovation. Their findings suggest that, overall, patenting might be socially preferable to secrecy. Kultti et al. (2006) revisited the choice between patenting and secrecy, assuming simultaneous innovation. They suggest that patenting is superior to secrecy because it prevents competitors from patenting similar inventions. In a companion paper, Kultti et al. (2007) studied the effects of patents and secrecy on the incentives of firms to innovate and social welfare. They suggest that the patent system might encourage innovation and information disclosure. However, patents might provide less protection than secrecy.[11]

Moreover, Ottoz and Cugno (2011) analysed licensing by focusing on the relationship of duplication and social welfare, where the protection of intellectual property is composed of a mixture of patents and trade secrets. Hall et al. (2014) provide an excellent review of the theoretical and empirical literature related to the trade-off between patents and secrecy, while Yeh (2016) overviews the features of trade secret law. In our analysis, we consider patenting and secrecy to be mutually exclusive protection choices. Moreover, we acknowledge that imitation is costly, uncertain, and takes time to materialise. The findings suggest that both patenting and secrecy might be adopted depending on specific conditions. We extend the analysis to also consider the accidental leakage of a trade secret to the public.

3.2 Empirical Literature

Investment in R&D is essential for economic growth and progress (Metrick and Yasuda, 2011). The gross expenditure in R&D as a percentage of GDP in 2015 was about three percent of the US economy and in the range of two to three percent of the major EU economies (OECD, 2017). Although R&D is not categorised as an intangible asset in the balance sheet, it is closely related to investment in innovation. R&D might, in fact, be one of the main sources of intellectual property. However, in order to preserve their incentives to invest in R&D, firms should be able to recover (at least in part) their innovative efforts or appropriate returns on investments. Patents and secrecy—at least theoretically, if not practically—serve such an underlying protective and stimulating purpose. Nevertheless, they are imperfect means of protection. Patents might provide weak protection or be invalid or invented around, while trade secrets might be obtained improperly, re-invented, or accidentally leaked out (Dreyfuss, 1998; Hall, 2007). Decker (2003) discussed a famous US legal dispute regarding the improper use of secrecy, namely

[11]For more information regarding the dilemma on how much new and valuable information an innovating firm should disclose and how much it should conceal, refer to Anton and Yao (2004): they consider incomplete information, imitation, and limited legal protection.

the Procter & Gamble lawsuit against Potlatch Corporation regarding the theft of secret methods used in manufacturing paper. These imperfections of patents and secrecy might have an adverse impact on investment and technological progress.

In addition, consider imitation, which might also lead to the imperfect appropriability of returns from industrial R&D (Dasgupta and Stiglitz, 1980; Gilbert and Newbery, 1982). For example, Mansfield et al. (1981) show that over half of the patents in their surveyed sample are imitated within four years after their initial introduction. This finding might explain why innovating firms have difficulty in appropriating returns from investment in R&D. Mansfield (1985) examined the speed that technological information leaks to the public. He suggests that the high speed and large scale of leakage of industrial technology might explain the difficulties of US public policy in preventing the export of US inventions overseas. In a follow-up paper, Mansfield (1986) studied the importance of the patent system in the development and commercialisation of inventions across industries and over time. He argues that only in very few industries, namely pharmaceuticals and chemicals, does the patent system play a substantial role in the introduction of new inventions. He then finds that firms tend to patent patentable inventions, regardless of the availability of other protection choices. Furthermore, there is no evidence of a reduction in patent use due to a shift to other means of protection.

Levin et al. (1987) conducted a survey among US firms in the manufacturing sector to empirically examine the effectiveness of patents and other means of appropriation in preventing imitation. They suggest that patenting technological inventions is not an effective means of appropriation. The amount of information disclosure under the patent system lessens the effectiveness of patents because it facilitates inventing around them. Specifically, only three out of the 25 industries into which the manufacturing sector is divided consider patents to be a partially effective means of appropriation. On one hand, the ineffectiveness of patents might challenge their widespread use in the industry. On the other hand, other strategic purposes of patents might appear, thus justifying their extended use. Park and Ginarte (1997) constructed an index that measures the strength of patent protection and used it to explore economic growth. They suggest that increasing the strength of IPRs might foster economic growth by stimulating investment in R&D. In a companion paper, Ginarte and Park (1997) examined the factors that determine the strength of patent protection. They argue that more-developed economies respect IPRs more than less-developed ones. Specifically, it is the level of R&D activity, market structure (freedom), and international integration (openness) that might determine the level of protection afforded by a nation to patents. Cohen et al. (2000) conducted another survey among firms in the manufacturing sector to identify the most important reasons

that lead US firms to decide whether to patent, similar to Levin et al. (1987). The authors report an increasing tendency of firms to use secrets as a protection mechanism, as well as a growing concern from the firms regarding the reliance on patents.

Arundel (2001), considering patents as a mutually exclusive alternative to secrecy, suggests that secrecy can be at least as effective as patents. Furthermore, he argues that patents are often used by small firms as a protection tool against infringement disputes initiated by large firms. This might, in turn, explain why small firms rely mostly on secrecy, while large firms prefer patents. In addition, Yang and Maskus (2001) suggest that licensing by US multinational corporations increase in frequency as the strength of IPRs increase. Arora and Ceccagnoli (2006) focused on the relationship between the strength of patent protection and the licensing of proprietary technology. Their study shows that the propensity to patent might increase with patent strength if the firm lacks the knowledge to commercialise new technological inventions. On the contrary, patent strength might increase the propensity to patent, but might reduce the propensity to license, if the firm has the know-how to sell new inventions. Arora et al. (2008) examined the impact of patenting on industrial R&D. Their analysis shows that although most inventions should not be patented, patents in fact provide incentives for R&D. In addition, the patent system stimulates incumbent firms to undertake research.[12]

Another strand of the empirical literature focused on patent litigation. For example, Lerner (1994) developed a proxy to measure the scope of patents. He suggests that the value of patents has been increasing with the breadth of patent protection. Additionally, his findings are in accordance with the propositions that valuable patents tend to be litigated more than less-valuable ones. In addition, Lerner (1995) focused on the litigation of patents and secrets using a large sample of US manufacturing firms. He shows that trade secret disputes account for 43 percent of the total litigated cases in the sample. His findings are also consistent with the argument that small firms rely more on secrecy because the patenting process is considerably expensive. Lanjouw and Lerner (1998) surveyed the empirical literature on patent litigation with an emphasis on the benefits of litigation, the enforcement process, and the expected litigation costs. They suggest that litigation costs might be used as a strategic means by large firms to win legal disputes against small ones (see also Lanjouw and Lerner, 1996).

Lanjouw and Schankerman (2004) suggest that litigation risk might be higher for small firms because they do not have a patent portfolio to be used for protection against

[12]For other studies that focus on the relationship between patenting and innovation, refer to Pepall and Richards (1994), Lanjouw et al. (1998), Hall and Ziedonis (2001), Lerner (2002), and Bessen and Hunt (2007).

a lawsuit with respect to any single patent (see also Lanjouw and Schankerman, 2001). In other words, small firms might avoid investing in innovation that requires patents owned by large firms; this might not constitute a problem for large firms. Maskus (2006) analysed the impact of stronger IPRs on the diffusion of technology, infringement costs, and the inventiveness of emerging economies. Galasso and Schankerman (2010) focused on the settlement of patent infringement disputes using a time factor and an ownership fragmentation lens. Allison et al. (2011) tested whether a serial patent plaintiff is more likely to settle before trial and whether the most-litigated patents are more likely to succeed in court (see also Allison et al., 2009). These studies might serve as useful guides for empirically testing the theoretical propositions derived from our analysis.

4 Research Design

This section presents an overview of the broad research question that drives this thesis, with a focus on explaining the intersections and complementarities among the three appended papers. In addition, we discuss the assumptions and theoretical arguments that are common throughout the analysis, and those that are specific to each paper. Emphasis is also placed on describing the methods applied and in discussing the overall importance and relevance of the analysis.

4.1 Purpose and Research Question

The broad research question, that we try to answer here, is how technology licensing can be strategically used to maximise the profit of innovating firms (i.e. firms endowed with intellectual property). Our purpose is to understand the impact of imitation on firms' licensing behaviour, considering that IPRs are imperfect means of protecting proprietary technology; and how technology licensing can be used to prevent or settle litigation, considering that the outcome of court proceedings depends on firms' litigation costs. In order to address the broad research question, we consider a particular licensing game in each paper. Specifically, in the first paper, we focus on the optimal mode of patent licensing (a fixed fee or a per-unit royalty); in the second paper, we look at the optimal choice of protection for proprietary technology (patents or secrecy); and in the third paper, we study the strategic use of technology licensing in a patent infringement dispute (to settle or to litigate).

These games aim to uncover the factors that determine the strategic use of tech-

nology licensing by innovating firms. This is important for innovators, scholars, and policy-makers. For instance, the optimal licensing of a proprietary technology that is prone to imitation might help firms effectively appropriate returns from investment in innovation. The importance of augmenting firms' return appropriation increases in the case of information-based industries or knowledge-based economies, since innovation is essential for these markets. This is better understood when considering the implications of effective return appropriability on the growth of leading knowledge-based economies such as Sweden, Switzerland, or the Netherlands. Ensuring that IPRs were optimally employed and respected, encouraged innovation and put these economies on a path towards sustainable development.

Our analysis might also be useful in partially explaining the difference between the rates of economic growth of developed and less-developed or emerging economies. Intellectual property licensing policies influence the diffusion of technology, which in turn might affect the evolution of innovation. While presenting at the Global Innovation Index (GII) 2017 in Geneva, the Director General of the World Intellectual Property Organization (WIPO), Francis Gurry, said: '*Innovation is the engine of economic growth in an increasingly knowledge-based global economy, but more investment is needed to help boost human creativity and economic output. Innovation can help transform the current economic up-swing into longer-term growth.*'[13] Emerging economies, in particular India and China, have also shown a distinct interest in and immense progress on the process of respecting IPRs. This shift in focus towards the stronger protection and enforcement of IPRs might explain the presence of an emerging economy like China in the world's top 25 most-innovative countries, according to GII in 2017.

China has traditionally misused IPRs owned by foreign organisations, mainly because its local organisations did not possess their own intellectual property in high-tech industries. However, Chinese organisations have been developing their own intellectual property over the last few decades. Weak protection for and enforcement of IPRs could not prevent the Chinese IPRs from being copied and used illegally in other emerging economies such as India. Thus, the up-and-coming Chinese organisations might have constrained their government to better protect their own IPRs, which in turn might have raised the overall respect for IPRs (Fishman, 2005). The strengthened legislation, the amendments to the patent act, the entry into the WIPO, the intensification of R&D by enterprises, and the greater development of the country, led to an explosion in patent applications and licensing activities in China (Hu and Jefferson, 2009).

Moreover, exploring the role of imitation and the imperfect protection of IPRs is useful

[13]For more information regarding the presentation of the GII 2017 in Geneva, see www.wipo.int.

in understanding the effectiveness of alternative means of protecting intellectual property, the impact of technology transfer on the incentives of firms to innovate, and the rate of technological diffusion. Understanding the latter relationships might, in turn, help firms get closer to achieving their economic objectives and policy-makers in proposing effective changes to public policy related to IPRs. The theoretical framework developed here can be extended in a number of ways to be applied towards the study of other situations and economic phenomena. We will now describe the main assumptions, theoretical arguments, and research questions that correspond to each paper, as well as bridge the gap between each paper and the general question posed in the beginning of this section.

Paper I: The first paper aims to determine the optimal licensing choice from the perspectives of a patent owner and consumers. It also questions the effect of technology licensing on duplication and competition. Firms often license to pre-empt competing firms developing alternative technologies or imitations. Hence, the game analysed in this paper is essentially a trade-off between licensing (sharing technological information) and choosing not to license (risking rediscovery). Another purpose of licensing might be to increase the appropriation of returns from investment. However, the effectiveness of appropriability depends on the ease of imitation, which in turn depends on competition, the industry, and the strength of the protecting instrument (Schilling, 2013). Specifically, we extend the analysis of Wang (1998), who studied patent licensing in a Cournot duopoly, by considering duplication and an industry composed of three firms with asymmetric per-unit costs. This paper, in fact, introduces the basic assumptions and industrial organisation principles to be used in the papers to follow. We compare fixed-fee licensing and royalty licensing of a cost-reducing technology under Cournot competition, where one of the firms develops and patents a cost-reducing technology and at least one of the other competing firms might obtain the patented invention through technology transfer or imitation. Thus, the game is static and acknowledges that patent protection is not absolute: it only grants temporary contestable exclusivity over the use of an invention. Moreover, we assume that imitation is perfect, instantaneous, certain, and does not aim to risk infringement. The game is one of complete information.

The analysis suggests that royalty licensing is at least as attractive as fixed-fee licensing for a patent owner, but might be the least-preferable licensing mode for consumers. The analysis also suggests that a patent owner might use licensing to prevent duplication. However, licensing might not be strategically used to select competition during the life term of the patent. Understanding technology licensing might enable policy-makers to increase the overall efficiency of the patent system and IPRs at large.

Paper II: This paper uses the basic framework developed in the first paper to explore

technology licensing when an innovating firm has a choice between patents and secrecy for protection of its IPRs. Specifically, it questions the effects of patenting and secrecy on the incentives to license and imitate when the two choices of protection are mutually exclusive alternatives. This is achieved by comparing the profits of a firm that has a patented new technology with those of a firm where the same technology is protected by secrecy. The duration of patents is finite, while that of secrecy is indefinite unless the secret accidentally leaks to the public. We again assume that the enforcement of IPRs is imperfect and imitation does not lead to infringement. The game is one of complete information and static.

We extend the analysis conducted in the first paper in a number of ways. First, imitation does not happen with certainty. Second, the imitation cost is a function of the ease and probability of success of imitation. Third, we discount all payoffs with a positive rate. Last, imitation takes time to materialise. Relaxing the assumptions presented in the first paper allows a non-trivial analysis of firms' strategic interactions and technology licensing. We find that patent protection might be more or less preferable to secrecy depending on specific conditions. We also show that technology transfer will always occur if the efficiency of imitating a patented technology and of imitating a secret are both sufficiently low. The analysis also suggests that the risk of accidental leakage lessens the attractiveness of trade secret protection and might encourage imitation.

Paper III: The third paper considers a litigation game between an innovating firm holding a patented cost-reducing technology and a competing firm producing with less-efficient technology. In particular, we ask what are the factors that drive legal disputes to private settlement or litigation. The model is an extension of the models developed in the first two papers. Specifically, we examine how imitation and the strength of the judicial system affect technology licensing and litigation. A distinctive feature of this static model is that it considers imitation to be imperfect. In addition, we assume that the probability of imitation depends on firms' litigation costs and, therefore, is endogenously determined. The cost of imitation is also assumed to be endogenous, thus bringing the analysis closer to approximating real-world legal disputes. The game is again one of complete information.

We find that if litigants expect to settle the dispute privately and the magnitude of innovation is sufficiently small, technology transfer will occur before imitation (an ex-ante licence). If firms expect a private settlement but the innovation size is sufficiently large, the outcome of the game depends on the efficiency of imitation. Specifically, if imitation is highly efficient, technology transfer will occur after imitation (an ex-post licence); if the efficiency of imitation is sufficiently low, litigation will not occur. The analysis also suggests that changes in policy instruments, such as the award of damages, might have

an effect on technology licensing and firms' profit distributions.

The three appended papers address the broad research question posed in the beginning of the section. First, we develop an integrated framework that can be used to examine technology licensing and patent litigation, acknowledging the imperfect legal protection of IPRs, perfect and imperfect imitation, and the strength of the judicial system. Most notably, the framework is parsimonious and suitable for studying the strategic licensing of proprietary technology that is prone to imitation. It can also be used to address other broad questions posed by studies on the economics of innovation.

4.2 Methods

In principle, this thesis examines the strategic licensing of intellectual property under the threat of imitation. However, licensing depends on a number of factors and policy changes which might affect the incentives of firms to engage in R&D (Bessen, 2003; Hunt, 2006). The analysis of these relationships is mainly conducted using industrial organisation, which is an area of economics that studies strategic behaviour among firms and market structure, as well as game theory, which is the mathematical modelling of strategic interactions among agents. Additional perspectives from economics, law, management, and strategy have also been used across the papers. The main methods employed to address the questions posed are further explained below.

Industrial organisation is a typical method used to study the strategic behaviour and interaction of firms in imperfect markets. However, according to Martin (2001), industrial organisation covers more than just the study of imperfectly competitive markets; it extends to almost all branches of economics and economic modelling that deal with market organisation, negotiation, collusion, and intellectual property, to name a few. Einav and Levin (2010) explored the use of theoretical industrial organisation to examine the behaviour of firms with the goal of understanding and explaining the causes and consequences of deviations from perfect competition. Transaction costs, economies of scale, and firms' strategic behaviour are some of the factors that determine the structure of industries in the economy. Market structures characterised by firms that undertake anticompetitive actions or industries that are highly concentrated indicate imperfectly competitive markets. This, in turn, warrants further research and potential governmental intervention. In this doctoral thesis, we study the interesting topics of market organisation such as technology licensing games characterised by conflicts of interest and entry deterrence.

Game theory enables industrial organisation to address problems such as product dif-

ferentiation, barriers to entry, collusion, and asymmetric information (moral hazard and adverse selection) (Tirole, 1988). Most notably, game theory is a branch of the social sciences that studies strategic decision-making (Dixit and Nalebuff, 2008). Therefore, game theory is essential to determine the outcome of an economic situation characterised by firms whose actions depend on the actions of other competing firms in the industry. The unit of analysis throughout this thesis is a profit-maximising innovating firm. The concept of equilibrium is a refinement of the Nash equilibrium, namely subgame perfection. We consider the Nash subgame perfect equilibrium to be appropriate for the analysis because it determines the equilibrium outcome in each subgame of the complete game. In particular, two oligopolistic settings are used, namely a duopoly and a three-firm oligopoly. Moreover, we assume that firms with symmetric or asymmetric per-unit costs compete simultaneously in quantities of a homogeneous good. The hypothetical market that characterises the licensing games is then an imperfectly competitive industry. The most common model of imperfect market competition is the Cournot model of an oligopoly; we therefore employ a standard Cournot-Nash model throughout our analysis (Cournot and Fisher, 1929; Martin, 2001).

There are numerous existing studies that focus on the impact of imitation on economic activity. Nevertheless, the imitation of intellectual property is a phenomenon that calls for both further analysis and effective public policies. The theoretical and empirical literature reviewed before gives support to the research design of this thesis. On one hand, the use of economic theory, industrial organisation practices, and game-theoretic principles make up an integrated theoretical approach that aims to understand the mechanics of technology licensing in imperfectly competitive markets. On the other hand, there are some limitations regarding the choice of methods. Extending the analysis to include an arbitrary number of firms and information asymmetry might contribute to the underlying purpose of this thesis and its applied impact. Further theoretical and empirical work is needed to assert the applied validity of this thesis' propositions.

5 Conclusions

This section contains the main findings and contributions of the thesis, relative to the existing literature. It also includes potential extensions to the appended papers and directions for future research.

5.1 Findings and Contributions

Intellectual property consists of patents, trade secrets, copyrights, and many other instruments. Patents—temporary property rights on technological inventions—might be the most important form of IPRs related to technology transfer, especially in relation to chemical products and mechanical inventions. However, patenting is a choice and might not be suitable to protect all kinds of inventions. Some technologies might be better protected via secrecy, depending on the nature of the technological information and knowledge: consider the technologies related to national security, military, and aerospace. Nevertheless, the relative importance of patents and secrecy depends on the firm's size, the complex nature of the legal framework that supports them, the country's legal environment, the level of effective enforcement of those mechanisms, and firms' strategic motivations (Hall and Ziedonis, 2001). Another important factor that affects this trade-off is imitation, an intellectual property phenomenon that needs to be addressed by academics, practitioners, courts, and policy-makers in their decision-making processes. We focus on the adverse impact of imitation on the incentives to innovate.[14] We develop an integrated theoretical framework, comprising the imperfect protection of IPRs, imitation, and bargaining, with the aim of understanding the strategic use of technology licensing.

We study these issues in a hypothetical oligopolistic setting, where firms compete simultaneously in quantities and imitation might occur. The broad question is how strategic licensing can be used optimally so as to maximise the profit of an innovating firm that has a protected cost-reducing technology. Within this broad area, there are several specific questions that we address using different licensing games. The first set of questions relate to the optimal mode of patent licensing; the second to the optimal choice of protection for intellectual property; and the third to the relationship between technology licensing and patent infringement. We conclude with the following propositions.

We show that the mode of licensing intellectual property is a strategic choice that depends on the relative magnitudes of the per-unit production costs, innovation, and imitation cost. Typically, royalty licensing might be preferable to fixed-fee licensing for a patent owner, while the converse is generally true for consumers. A per-unit royalty might be superior for a patent owner because it raises the per-unit costs of licensees. Royalty rates are more adjustable than fixed fees, and might in turn be chosen optimally so as to yield monopoly rent. Next, the analysis suggests that licensing might be strategically used to prevent imitation. However, there is no indication that licensing might be used selectively to affect competition during the life term of the patent. A patent owner might

[14]Note, however, that imitation might also encourage investment in innovation (Hurmelinna-Laukkanen and Puumalainen, 2007).

also benefit by licensing either to a weak or a strong competitor, depending on specific conditions.

In addition, we find that the choice of protection affects technology licensing. Patents might be more or less preferable than secrecy for a technology owner, depending on imitation and the strength of protection. When imitation is not sufficiently efficient, licensing might prevail; however, if imitation is efficient, then imitation might be optimal. Furthermore, the risk of leakage and its increasing relationship with the number of firms practising the protected technology might increase the attractiveness of, and consequently reliance on, patent protection.

Moreover, the analysis suggests that the type of invention and imitation, and the legal system have an impact on technology licensing. Specifically, when settlement in private is expected to occur, small inventions might be licensed before imitation (an ex-ante licence), while large ones might have the opposite effect (an ex-post licence). Also, a patent owner benefits by taking no action against a highly imperfect imitation.

We contribute to the existing literature by providing an integrated framework that examines strategic licensing and technology transfer. We revisit existing studies within this field of research, but from an imitation lens. Finally, this thesis adds to the discourse and emphasises the need to further examine the use of IPRs to appropriate returns from innovation and their use for objectives other than appropriation, mainly as strategic tools in business.

5.2 Future Research

The analysis used throughout this thesis can be used to further research a number of other interesting themes. The findings revealed the relations among technology licensing, innovation, imitation, and litigation. However, we could also focus on other interesting avenues of research.

A straightforward avenue for future research is to extend our analysis to compare and contrast licensing when a technology owner is an outsider and the competition setting is dynamic (Stackelberg). Extending the analysis from a static to a dynamic game allows the consideration of the dimension of time and, thus, the analysis of the effect of lengthy legal procedures on the decision-making processes of innovating firms. Moreover, it will allow a focus on alternative strategic reasons of firms to deter settlement, such as litigating now in order to gain better licensing terms in the future, or other similar behaviour (consider, for example, patent hold-up and hold-out, which have only been partially modelled in

the existing literature).

Another direction for future research is to examine the patent licensing of proprietary technology when the validity of the patent is uncertain. This is a standard issue that existing studies have addressed. However, further research is needed to analyse the strategic use of weak patents with an aim towards enhancing the bargaining position of a patent owner with competing firms that might also imitate the protected technology. In this case, preliminary injunctive relief awarded by the court can also be incorporated into the analysis. The economic modelling of optimal technology licensing and litigation of IPRs is extensive, but still does not explicitly examine the impact of preliminary injunctive relief on firms' strategic behaviour to delay or avoid licensing payments.

It is also interesting to study licensing games in the context of collaboration or collusion (cooperative games). Coordinated behaviour often increases firms' profits and, thus, it has been practised by firms for a long time. Additionally, coordinated or collusive behaviour might be used to prevent entry, achieve different strategic objectives, or enhance firms' positions within an industry. In particular, collusive behaviour is anti-competitive, inheriting specific risks. In an attempt to study collusion in a Cournot-Nash setting—similar as to the games discussed in this thesis—a number of factors should be taken into consideration such as: the number of firms in the industry, the ease of negotiating and enforcing an agreement, and the expected gain relative to punishment if collusion is detected. Analysing cooperative licensing games when IPRs are imperfect and imitation is probable, might aid regulators in examining anti-competitive practices.

In addition, firms might rely on different protection and licensing mechanisms at different stages of their R&D. For instance, they can rely on secrecy before launching a technological invention and apply patent protection immediately after its launch. Furthermore, other instruments that we did not consider in our analysis might also be employed (e.g. relying on lead time with the aim of gaining a competitive advantage early in the process, and subsequently deterring imitation by competing firms). Hence, innovating firms differ in the extent and use of protection instruments. This heterogeneity in behaviours might be related to idiosyncratic firm factors (firm size and strategic goals), to technology-specific factors (innovation size and ease of imitation), industry-specific factors (market structure and the appropriation of returns from investment), and institutional factors (legal protection and the enforcement of IPRs). The importance of the aforementioned factors is of immense interest and could be assessed in future research.

Finally, technology licensing and firms' incentives to innovate is also of intense interest to regulatory institutions and policy-makers. The existing literature has generated a

tremendous amount of policy suggestions and implications. However, new theoretical and further empirical work can be conducted to analyse the impact of policy interventions on social welfare. Intellectual property is an important driver of progress, and firms often do not have clear protection, usage, and appropriation strategies with respect to it. Moreover, these strategies vary over time and across industries and legal systems. The continuously rising value of intellectual property is increasing the awareness of the strategic use of IPRs, consequently increasing the relative importance of further research on the economics of innovation.

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