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Patent-based strategies and R&D efficiency when innovations are cumulative and complementary

Yann Ménière

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Introduction

For the last two decades, a more systematic use of patents, along with a strengthening of patent law and the development of new technologies, has modified competition based on innovation, thereby challenging the traditional economic view of patents as a legal tool to promote innovation. In the agro-biotechnology sector, the semi-conductor and the software industry, firms tend to hedge their intellectual assets by accumulating large patent portfolios which they eventually license or cross-license to each other. Other firms specialize in R&D activities, and sell or license their patents to downstream operators. Some even specialize in filing patents which they use to sue other firms and reap part of their profits (Lemley & Shapiro, 2004). Patent grants in the United States and other industrialized countries such as France more than tripled between 1980 and 2001, whereas they had been stable over the previous 20 years (Jaffe, 2000; Gallini, 2002). It is difficult to say to what extent this "patent flood" is a cause or a consequence of the new strategies of the firms. Yet what is certain is that it has created a "patent thicket" which firms have now to navigate (Shapiro, 2001).

This thesis is made of three independent parts; each aims to shed light on how firms compete and innovate within the "patent thicket". More precisely, each part gives a different insight into the strategic uses of patents and their effects on R&D when the technology is such that firms build upon each other's innovations. Such cumulative innovations (Scotchmer, 1991) feature especially, although not exclusively, in high tech industries such as software, electronics, telecommunications and biotechnologies. In all of them, final products are likely to embody several patented elements, which results in increased strategic interaction between patent holders.

The strategic use of patents has arisen as a major concern during the last few years. In 2003, the National Science Agency in the US issued a report called *Patents in the Knowledge-Based Economy*, while the Federal Trade Commission organized hearings in 2002 that resulted in the publication, in 2003, of a Report entitled *To Promote Innovation: A Proper Balance of Competition and Patent Law and Policy*. Both initiatives were taken as a reaction to a perceived shift in the way firms innovate and compete in industries where patents have come to play a central role. Both conclude that patents may be harmful for competition and innovation, and identify a lack of enforcement of patent law by the US Patent Office as a major cause of the situation. In the European Union, the reflection on patent strategies is more prospective as high tech industries are in the main less developed than in the US and the opportunity of conferring patent protection to software and biotechnology inventions is still under debate. The European directive on software patent has not yet been adopted, while the European Directive 44/98 on biotechnology patents still has to be interpreted before being transposed into several national laws. It is all the more important if we are to understand how a shift in patent protection may influence the evolution of the industries mentioned above.

My thesis provides a theoretical approach to this question. It is thus a useful complement to surveys and empirical studies such as the NSA and FTC reports, and sets out to show what can be derived from the US experience and applied to the European one. In particular, an analytic approach helps to separate out which issues stem from a patent office enforcement failure on the one hand, and those that are the result of the mere application of patent law to some particular technologies on the other hand.

The theoretical approach which I adopt in each Part of the thesis can be summed up in three main points. Instead of carrying out the economic analysis of patents in a context of stand alone innovations, I focus on technologies that are fragmented into different patentable elements. Secondly, and as a consequence, I study the strategic interactions of firms in a context of fragmented patents. I therefore capture and propose a welfare analysis of strategic behaviours that have been observed empirically. Finally, I carry out this analysis by taking into account the effects of patent strategies on R&D investments and innovation. This adds on the one hand to papers that focus on how patents on stand alone innovations affect R&D investments and, on the other hand, to papers that study how fragmented patents affect pricing behaviours in a static framework. This analysis therefore contributes to the literature on cumulative innovation, which studies how patents may affect investments in subsequent innovations.

Focusing on cumulative and complementary innovations

Patents do not necessarily protect stand alone innovations. The intellectual property of one given technology may be fragmented into several patents that may belong to different owners. The classical way of analysing patents as temporary monopolies awarded on stand alone innovations is not sufficient to capture this fragmentation, nor its effects on the firms' behaviour. Therefore, throughout the thesis I thus use two theoretic concepts, namely cumulative and complementarity innovation. This allows me to capture how patented innovations can be aggregated to each other, as well as the specific issues that this may raise.

Patents on stand alone innovations

Economists generally justify patents as a means to foster innovation by granting innovators a temporary monopoly that allows them to recover their initial R&D investments. This argument can be outlined in a very simple setting derived from Scotchmer (2006). Consider an innovation of value v that can be developed by investing an amount c . Assume also that (v, c) is private information of one single agent until the innovation has been developed. Patent law creates an incentive to transform ideas into innovations only when their value exceeds their cost. As the innovator has been granted the exclusivity on the innovation, she can set a monopoly price and make a monopoly profit π . Yet the monopoly price dissuades some consumers from purchasing the innovation. This deadweight loss implies that the profit π is lower than the social value v of the innovation had it been distributed as a public good. In this context the innovator will invest only if $\pi > c$, so that innovations verifying $\pi < c < v$ will not be developed. As social efficiency requires that all ideas that verify $v > c$ are developed, this is only a second best.

As in this simple setting, the economic analysis of patents generally deals with a fundamental trade-off between innovation as a factor of dynamic efficiency, and the patentee's monopoly power as a factor of static inefficiency (Lévêque & Ménière, 2004). That said the main thrust of this thesis is to study specific questions raised by the cumulative and complementary nature of innovation and not the trade-off between static and dynamic efficiency.

Cumulative innovations and the hold up issue

The concept of cumulative innovation captures the fact that innovators build upon each other's works (Scotchmer, 1991). Two innovations are cumulative if the achievement of the first one is necessary to enable the achievement of the second one. The sequential link between cumulative innovations can take different forms. Innovations that improve the quality of an existing product, or that reduce the cost of a production process are cumulative. The discovery of a new application of an invention is also a form of cumulative innovation. Finally, cumulativeness is characteristic of research tools, which are innovations that are used to produce other innovations.

Cumulativeness raises the difficult problem of sharing the property of innovation between different subsequent innovators (Scotchmer, 1991). If an upstream innovation is not profitable per se, it may be necessary to grant its inventor a patent that confers him a right on the subsequent, downstream innovation. This can however jeopardize the development of the downstream innovation. Indeed the upstream patentee may be tempted to hold up the downstream innovator once it has been developed. If she expects this, the downstream innovator will thus be dissuaded from investing in R&D.

Complementary innovations and the multiple marginalization issue

The concept of complementarity captures the fact that a complete technology may embody several patented elements which, unlike cumulative innovations, do not result from each other (Shapiro, 2001). By the end of 2002, the MPEG standard for digital video compression contained for example 525 patents, belonging to 22 companies. In agro-

biotechnology, Golden Rice - a genetically engineered rice variety bred to help combat vitamin A deficiency - encompasses more than 70 patents from 5 different technological fields (Joly & Hervieu, 2003). Generally, most products in electronics, telecommunications and biotechnology encompass several patents.

Patented innovations can be analysed as perfect complements if each of them is necessary to work out a given technology. In this case each patent confers a monopoly on one input of the technology and behaves unilaterally as a monopolist. According to the Cournot theorem (1938), this triggers an underuse of each innovation. Indeed each patentee fixes a price mark up that reduces the overall demand for the technology and, thereby, the demand for each other complementary patent. This multiple marginalization is detrimental for both social welfare and the patent holders' profits.

Patent strategies when innovations are cumulative and complementary

Having defined cumulative and complementary innovations as a structural element of my analysis, one of the objectives of this thesis is to identify which patent strategies may take place within this framework. In particular, this work aims to understand the motives and effects of strategic behaviors that have been underscored by empirical references.

The tragedy of anticommons

Heller and Eisenberg (1998) summarize the conditions of innovation and competition within the "patent thicket" (Shapiro, 2001) as a "tragedy of anticommons". By contrast with the "tragedy of commons" which qualifies the overuse and depletion of scarce resources when they are in free access, the "tragedy of anticommons" describes a situation

in which several individuals own rights of exclusion on a non-rival resource such as a technology, which in turn leads to underuse of this resource. Although their paper focuses on biotechnologies, it can be applied to all industries where cumulative and complementary innovations are protected by patents.

The underlying idea is that the multiplication of patent owners results in higher transaction costs. This increases the cost of innovation and has thus a detrimental effect on the firms' incentives to innovate. The hold up of subsequent innovations and the multiple marginalization issue form part of these transaction costs, although they are not quoted by Eisenberg and Heller (1998). Other costs of transaction include costs related to identifying the patent owners, the cost of bargaining, designing and enforcing licensing contracts. In agricultural biotechnology, these costs have for example left unexplored several fields in which research would necessitate access to numerous patents (Graff & alii, 2003). Transaction costs also increase with legal uncertainty on the actual scope of the patent, and economic uncertainty on value of future products. This explains why, for instance, new U.S. biotechnology firms with high costs of litigation generally shy away from investing in technological fields where other firms already secured patents (Lerner, 1995).

The "tragedy of anticommons" gives an initial, pessimistic insight into how firms innovate within a "patent thicket". The more fragmented the patents, the less the innovation. This analysis is however limited in several respects. Indeed Heller and Eisenberg consider patents only as an external threat for innovators. They do not envisage that firms can rely on their own patents to elaborate new specific strategies that are adapted to their environment. Moreover they consider patents as a given. They do not explain the patenting

behaviour of firms, nor their subsequent patent trading strategies.

Patent strategies in practice

According to empirical studies, patents play their incentive role fully only in a small number of industries, such as the pharmaceutical industry (Arora et alii., 2001). A survey of R&D laboratories in the U.S. manufacturing sector (Cohen, Nelson & Walsh, 2000) highlights their managers' lack of faith in patents as an effective way of protecting their innovations. Firms cite trade secrecy and the first mover advantage as the most effective forms of protection, ahead of patents. Other studies, conducted in Europe, (Lanjouw, 1998; Schankerman, 1998) estimate the value of patent protection at 15% to 25% of R&D expenditure. In other words, patents seem to be generally inefficient at guaranteeing innovators return on their investment.

The apparent paradox between high patent figures and weak patent protection can be explained by an increase in the firms' propensity to patent for a given amount of R&D spending, especially in sectors with cumulative and complementary innovations. Hall and Ziedonis (2001) show that the number of patents per million of R&D dollars has doubled in the U.S. semi-conductor industry between 1982 and 1992. Graham and Mowery find similar results in the U.S. software industry. They show that the aggregate patent propensity of the top 15 U.S. packaged software firms has increased between 1987 and 1997, from less than 2 to more than 5 patents per \$100 millions of R&D spending¹. A monography by Bekkers and alii (2002) highlights a similar evolution in telecommunications equipment.

The increase in the patenting propensity has taken place against a background

¹The increase is limited from less than 2 to more than 3 patents per \$100 millions of R&D spending if Microsoft is dropped out of the panel

of lenient patent offices that allow firms to obtain additional low value patents for a given R&D effort (Hall, 2004; Lemley & Shapiro, 2004;). In this context there are various motives for inventors to file additional patents. Patents are used as a signal towards share holders, creditors or consumers (Lemley, 2000; Long, 2002) or to reduce strategic uncertainty by hedging their innovations (Lerner, 2002). Patents have also been increasingly used as strategic weapons in competition.

Table 0.1 reports other results from the survey of U.S. R&D laboratories (Cohen, Nelson & Walsh, 2000). It shows the four main motives for R&D managers to patent. Unsurprisingly their main reason for patenting an innovation is to protect it from imitation by rivals. Yet the other reasons correspond to a more strategic use of patents as a way of interacting with other firms. Patents are filed to prevent a competitor from patenting its own innovation (the "block" motive) or, conversely, to prevent being sued for infringement by a competitor. In this context of mutual threat of infringement, patents confer bargaining power to negotiate licenses.

A large study of the determining factors of patent suits and settlements in the US between 1978 and 1999 confirms the importance of filing patents for strategic purposes (Lanjouw and Shankerman, 2004). It shows that having a large patent portfolio reduces the probability of litigation. This applies more to large firms than to their smaller counterparts. Indeed large companies are more likely to have repeated interactions, both in intellectual property and product markets. According to game theory predictions, such repeated interactions are factors that facilitate cooperation.

Reasons to patent	Product innovations	Process innovations
Prevent copying	95.8%	77.6%
Blocking	81.8%	63.3%
Prevent law suits	58.8%	46.5%
Use in negotiations	47.4%	37.0%

Table 0.1: The motives for patenting innovations

Cohen, Nelson and Walsh (2000) find that the ranking of motives for patenting innovations vary from sector to sector. They distinguish between "discrete" and "complex" technologies. When a technology is "discrete", as in the pharmaceutical or the chemical industry, a marketable product or process comprizes relatively few patentable elements. In this instance the main motive for patenting is to prevent copying. The "complex" technologies correspond to sectors where innovations are in the main cumulative and complementary, such as telecommunications equipment, semiconductors, software or biotechnology. Here firms often need to secure an access to other firms' patents. Thus they accumulate large patent portfolios principally to block other firms, prevent law suits, and negotiate licences (Cohen, Nelson & Walsh, 2000; Hall & Ziedonis, 2001).

A theoretical approach of patent strategies when innovations are cumulative and complementary

The aim of this thesis is to use the tools of economic theory to capture and explain patent strategies that may take place in a framework of complementary and cumulative innovations. The three Parts of the thesis do not constitute a general theory. Rather, they shed light on different issues in a context either of cumulative or of complementary innovation. In each of them I go beyond the framework of the "tragedy of anticommons"

by asking why firms seek to acquire patents and how they use them. My goal is therefore to shed the light of economic theory on some of the patent strategies that have been revealed by empirical studies.

A welfare analysis focused on R&D investments

The theoretic approach of patent strategies allows the evaluation of their welfare effects. These effects include static elements such as market power and the resulting deadweigh loss, and dynamic elements such as R&D costs and the frequency and size of innovations. As I study patent strategies in the context of cumulative and complementary innovations, I focus on the interactions between patents holders rather than on how patents affect the welfare of consumers. I depart therefore from the usual trade-off between static and dynamic efficiency and concentrate on the dynamic effects of patent strategies on R&D investments.

R&D investments and social efficiency

The general problem of R&D efficiency is one of information aggregation (Scotchmer, 2005). Consider for instance n ideas $(v_i, c_i)_{i=1,n}$ featuring innovations of value v_i that can be developed at cost c_i , and assume that these innovations are substitutable. Social efficiency then requires that only the idea that maximizes $v_i - c_i$ is carried out. This optimum may however be difficult to achieve if the ideas (v_i, c_i) , or even the costs c_i and values v_i taken separately, are private information of different agents. There is therefore a need for a specific mechanism capable of gathering and aggregating these information so as to make the best investment decision. Patents, grants and prizes are such mechanisms. Yet

none of them can always ensure a first best optimum. The efficiency of R&D investments in the case of patents shall therefore be considered in a second best world.

The merit of patents is that only those agents whose ideas verify $v_i - c_i > 0$ have an incentive to invest c_i . Yet patents raise an important coordination issue when two or more firms have ideas (v_i, c_i) of substitutable innovations. Indeed several firms may then have an incentive to innovate in order to benefit from the exclusivity conferred by the patent. In this framework, the patent may not be awarded to the firm with the best idea. Moreover, a large body of literature (for a complete survey, see Reinganum, 1989) shows that such "patent races" trigger either excessive or insufficient R&D investments. Both the number of firms that invest in R&D and their individual level of investments may be inefficient. Whether they are excessive or insufficient principally depends on which "production function for knowledge" is considered (Scotchmer, 2005). More precisely, the efficiency of R&D duplications depends on how the aggregation of R&D costs affects the overall probability that the innovation will finally be developed. On the one hand, firms invest in R&D until the individual expected profit from an additional investment is zero. Thereby they dissipate the whole expected social value of the innovation. On the other hand, costs duplication may for instance compensate individual under-incentives to innovate when a patent owner cannot appropriate the whole social value of its innovation.

Patent races when innovations are cumulative and complementary

The three models that I develop in the thesis transpose different patterns of patent race between two firms in a framework of cumulative and complementary innovations. I thereby add to several papers on cumulative innovation (Green & Scotchmer, 1990; Scotch-

mer, 1996, Denicolò, 2000). These papers aim to fine tune patent policy. They evaluate the efficiency of R&D in patent races for that purpose. The first Part of this thesis extends these patent policy models to a framework of complementary innovations. By contrast the models that I develop in Parts 2 and 3 do not directly focus on policy levers. They nevertheless allow you to evaluate the welfare impact of patent strategies on the efficiency of R&D investments. In this way they shed light on the welfare properties of the patent regime in the context of cumulative and complementary innovation.

Outline of the thesis

The thesis consists of three Parts and five chapters. Chapters 1 and 3 contain surveys of the economic literature. In the remaining chapters I develop original theoretical models that study how firms compete and innovate in the context of cumulative and complementary innovations.

The economics of patent law

The first Part of the thesis focuses on the set of legal rules that constitute the patent system. The first chapter is a general survey of these rules and their economic functions. The second chapter develops a theoretical model that focuses more precisely on how one specific rule, namely the non-obviousness patentability requirement, can influence the degree of fragmentation of patents on complementary innovations, and thereby the efficiency of R&D investments.

The first chapter has a wider focus than the rest of the thesis, as it reviews the whole literature on patent law. It also adopts a different approach as its focus is patent as

a legal means to protect innovations, not patent strategies. I discuss to what extent the legal rules that make up the patent system allow me to adapt the protection conferred by patents to various patterns of innovation. To the end, I draw the distinction between stand alone and cumulative innovations, and consider as a third step the problem of enforcement of patent protection in the courts. In all instances, I argue that the patent system does not directly define protection in terms of the market, which gives the patent system more flexibility to adapt different patterns of innovation.

The second chapter focuses on one specific rule of the patent system, namely the non-obviousness patentability test. I develop a theoretical model showing that a strict non-obviousness requirement can prevent the negative effects of an excessive fragmentation of industrial property. I consider a marketable product or process that embodies two complementary innovations. In this setting I can define a strong non-obviousness test as the case in which only the marketable product or process is patentable, while each complementary innovation can be patented under a weak non-obviousness requirement. My argument for a strict test relies on a trade-off between the costs of patent fragmentation, namely transaction costs, hold-up and multiple marginalization, and the benefit of patent disclosure, which is to avoid the duplication of R&D costs. The model shows that although a severe non-obviousness requirement may result in R&D cost duplications because small innovations are neither patented nor disclosed, setting a minimum threshold of non-obviousness is an efficient way to limit the cost incurred if complementary patents are scattered between different owners.

Patents and the persistence of incumbent firms

In the second Part of the thesis, I analyse how patents and patent strategies affect the persistence of dominant firms. As in the previous Part, the first chapter is a general survey of the economic literature which is not limited to a cumulative and complementary innovations. The following chapter develops a theoretical model of cumulative innovation showing how an incumbent monopoly can persist by preempting an upstream patent on a drastic innovation.

The third chapter is a survey of the literature. I start from the framework initially developed by Arrow (1962) to study how innovation affects the market structure. I then introduce patents and patent strategies into this framework so as to review how they influence the persistence, or replacement, of dominant firms. The survey shows that introducing patents and licensing strategies into the traditional theory of innovation tends to reverse the general result that innovation favours the entry of new competitors rather than the persistence of incumbent firms. Admittedly, focusing on the exclusivity conferred by patents on a product market leads to the general conclusion that an entrant has more incentives to innovate than an incumbent monopoly, because of a business stealing effect. However, an effective way for the dominant firm to persist is to use patents as tools for trading technology. Indeed patent transactions between an entrant and an incumbent can often increase the industry surplus, by preventing price competition or costly R&D races. Finally, cumulative innovations create another set of effective persistence strategies for the incumbent.

The model that I develop in the fourth chapter upholds the conclusion of the

third one. The model shows that when innovation is cumulative, an incumbent will be able to pre-empt an upstream patent that enables the development of a sweeping, drastic innovation. I assume that this innovation is developed using an upstream patent, and that it is patentable too. In this case the value that the incumbent or an entrant can offer for the upstream patent depends on their respective bargaining power in case the upstream patent belongs to one firm, and the downstream patent to another firm. As the incumbent makes a profit even if the innovation is not marketed, it has a higher bargaining power than the entrant, and can thus systematically pre-empt basic patents that could later result in subsequent drastic innovations.

Blocking patents and R&D investments

The third Part is made of one chapter, derived from a joint paper with Sarah Parlane (Ménière & Parlane, 2004). It develops a theoretical model to study the incentives of symmetric competitors to use their patent to block each other, and to sign cross-licensing agreements.

I consider two symmetric firms that invest in R&D to develop new products. The firms operate independently from each other, so that their products, although perfect substitutes, are different and protected by different patents. However, I assume that the patents can be broader than the underlying innovations. As a result, patents may be used opportunistically by the firms as offensive tools to hold-up the product developed by their competitor.

This model sheds light on the free riding behavior of patent holders who tend to reduce their R&D investments if they expect to hold their competitor's product. As

a result investments decrease with the blocking power of patents, so that licensing agreements signed before developing new products are pro-competitive when patents are likely to be blocking. When patents have a weak blocking power, such licensing agreements are however anticompetitive because they give the firms an opportunity to tame investments in development and, thereby, to reduce the probability of having to compete neck and neck on the product market. The model also shows that it may not be welfare improving that the courts erode the market power conferred by patents. Indeed this raises the incentives for the firms to settle ex ante agreements, be they pro- or anti-competitive.

The model also allows us to capture the firms' incentives for increasing their blocking power by adding new patents to their portfolio. It predicts especially that firms will use this strategy in sectors where the development of new products is relative easy, in order to reduce the intensity of R&D competition. In that case the equilibrium patenting strategies are detrimental to welfare and they may even be detrimental to profit if the cost of filing new patents is low. By contrast the firms have no incentives to undertake such strategies if R&D is already expensive and uncertain, which explains for example why firms are less keen to accumulate large patent portfolios in industries such as pharmaceuticals or chemicals.

Part I

The Economics of Patent Law

This Part focuses on the legal rules that support the patent system. I review in Chapter 1 how patent protection adapts to different innovation patterns through a set of legal rules. I then then develop in Chapter 2 a model showing that the non-obviousness patentability requirement permits to prevent a socially inefficient fragmentation of patents on technologies made of complementary innovations.

Chapter 1

A legal system to allocate rights on innovations

1.1 Introduction

The question of patent design is at the crossroad of technology, law and economics. A patent delimits a correspondence between the realm of technology and the realm of law, while economic analysis is a way to evaluate and fine tune this correspondence. Economic analysis shall however be carried on, not only on a stand alone innovation basis, but also by taking into account the broad picture of a legal system that transforms non rival information into exclusive assets.

The purpose of this chapter is to review how patent protection can adapt to different innovations within such a general system. Recall that the economic function of patents is to create incentives to innovate by enabling the innovators to appropriate the reward of

their inventions. Consider for instance an innovation that is featured by its cost c and value v . Granting the inventor the exclusivity on her invention allows her to make a profit $\pi < v$. As a result she will develop the innovation if and only if $\pi > c$. Besides the problem of deadweight loss, this simple way of presenting the function of patents highlights other shortcomings. First, several innovations with different costs and values may perform the same function. Therefore patent protection may result in cost duplications (if several innovators invest in different ideas at the same time) and in patenting the wrong innovation (if the first developed innovation is not the most valuable one). However I rule out the problems of selection and cost duplications in this part, to consider only cases in which any innovation verifying $v > c$ is worth developing for the society. As stated by Maurer and Scotchmer (2004), this corresponds to the case of isolated idea where patent is supposed to work best. I can thereby focus on another issue raised by the patent rationale, namely the fact that one single form of intellectual property right, featured by general rules, is supposed to fit all innovations.

While the economic rationale of patents - to concede market power to innovators as a reward and an incentive for innovation - is relatively simple, the underlying legal construction is indeed far more complex. From a legal viewpoint, a patent is a temporary property right that can last up to twenty years. It consists of two parts: a description of the innovation and a list of claims delimiting the exclusive rights conferred by the patent. For an innovation to be patentable, its description has to meet three criteria. The precise definition of these criteria varies from country to country, but is substantially the same. For example, the European Patent Office's patentability criteria for an innovation are novelty, inventive

step, and industrial applicability, while they become respectively novelty, non-obviousness, and utility in US law. The scope of the claims delimits the market power granted to the patentee. To ensure that the claims are not excessive, they must be consistent with the description of the innovation. The extent of the protection conferred on an innovation is initially determined by a patent office examiner, who applies the three criteria and evaluates the consistency between the claims and the description of the innovation. A firm armed with a patent can then impose its legal monopoly by suing a competitor for infringement on the basis of the claims.

To what extent can this legal system fit heterogeneous innovations? I survey the literature to tackle this question, and argue that the patent system has enough flexibility to adapt different patterns of innovation, under some conditions however. I review as a first step what mechanisms allow to tailor patent protection to innovations differing in costs and values. I identify and discuss three different elements of patent law, namely the self selection of patent duration by the patentee, the requirement that the patentee discloses some knowledge if she patents her innovation, and the restriction of protection to technology rather than market. Then, as a second step, I turn as a second step to the particular case of cumulative innovation. By contrast with the stand alone innovations studied in the first part, cumulative innovations build upon each other. Hence the problem of allocating incentives has to be formulated for the whole sequence of innovation. I show that implementing patentability requirements and conferring a protection against future innovations are two different ways to distribute patent protection among successive innovators. I compare their respective efficiency, and discuss the conditions of this efficiency. I finally consider the

problem of enforcing patent protection once a patent has been granted. Such enforcement is indeed costly and distorts the effective patent protection conferred to some categories of innovations.

1.2 Stand alone innovations

I review as a first step how patent law can fit to stand alone innovations features by different costs and values. I discuss successively the role of patent duration, the formulation of patent claims in terms of technology, and the role of patent disclosure.

1.2.1 Patent duration is not sufficient to tailor patent protection to innovations

Patent duration is the most direct way of controlling the rights granted to innovators. The longer the patent duration, the higher the cumulated profit derived from this patent and thereby the R&D investment that can be financed¹. As the monopoly power awarded to patent holders also generates a deadweight loss for consumers, the duration of each patent should ideally be set so that the innovator's profit just compensates her R&D cost. This scenario would however require that the duration of each patent be set on a case by case basis by the patent office. This is actually not the case. The value and cost of innovations are private information of the innovators. In this context, the law sets ex ante general rules about duration, namely a system of renewal fees and a maximum duration. The innovators can then choose their patent's duration in conformity with the legal rules.

¹Of course the discount rate erodes the incentive power of the profit flows that are remote in time. But it does not reverse the positive relation between the patent value and its duration.

This system improves upon the application of a uniform duration to innovations which values and costs differ. Nordhaus (1969) shows that besides providing incentives to develop costly innovations, lengthening uniformly the patent life also results in overprotecting those innovations which R&D costs are low. He develops a model to trade-off these two effects, and concludes that a uniform, finite patent scope duration exists that balances them efficiently. Nevertheless, this uniform solution cannot match the scenario in which each patent's duration is adapted to the cost and value of the underlying innovation.

As a matter of fact, the actual duration of patents rarely reaches the 20 years maximum set in the U.S. and European systems. From a market standpoint, a patent becomes worthless once it is not profitable anymore. Therefore, the effective patent life ends up when the patented innovation is replaced on the market by a better one, which may happen before the legal term (O'Donoghue, Scotchmer & Thisse, 1998). This market term is reflected in patent law through the patent renewal system. Indeed the 20 years legal duration is a maximum. Patent holders have to pay fees regularly if they want to renew their patents until this duration cap. In both the European and American patent systems, the fees increase over time so that only the most profitable patents will last. In this context, empirical studies on the French and German cases (respectively: Schankerman, 1998; and Lanjouw 1998) conclude that the proportion of patents that are extended beyond ten years does not exceed 50%. In Germany, patents that reach the maximum legal term never represent more than 30% of any investigated patent class (Schankerman, 1998). More generally, Pakes (1986) reports that the proportion of full terms patents in France and Germany is below 7% and 11% respectively.

How does this form of variable duration affect the patent system? The patent renewal system works as a delegation mechanism to produce innovations which cost and value are private information of the innovator (Gallini and Scotchmer, 2002). Cornelli and Schankerman (1999) and Scotchmer (1999) show that it leads to over-rewarding the most valuable innovations, because the high profit flows they generate are even amplified by more renewals. Consider for instance two innovations that have been patented at the same time. Assume that the profit flow expected from innovation A is higher than the renewal fee, while the profit flow from B is below the fee. As a result only the patent A is renewed. And the initial asymmetry between the profits generated by A and B is accentuated by the additional profit flow due to the longer duration of patent A.

This over-reward is justified only if these innovations are also the most costly to develop. Cornelli and Schankerman (1999) argue in that way by considering that an innovation's value depends on the innovator's effort. However, Scotchmer (1999) concludes against the efficiency of the renewal system by considering a more general setting where the value and cost of innovations are unobservable and can be independently distributed. If the cost of the innovation is a function of its value, she confirms that an optimal patent renewal system can be designed, but warns that the first renewal fees may have to be negative (Scotchmer, 1999; Cornelli & Schankerman, 1999). It would be difficult to implement such a system, because opportunistic firms could harvest these subsidies without really innovating (Gallini and Scotchmer, 2002). If the values and costs of innovations are independently distributed, Scotchmer shows that a uniform patent life should be preferred to a patent renewal system. One can therefore conclude that patent duration cannot be used to tailor

the incentive power of patents to each innovation. The patent renewal system is a weak screening mechanism, so that uniformity prevails.

1.2.2 Knowledge disclosure and selective patenting

While patent duration cannot efficiently dissociate the innovator's reward and the innovation's value, the patent disclosure rule tends to do so by moving the innovator's rewards closer to each other. Patenting requires the disclosure of enough knowledge to enable, in principle, the reproduction of the innovation. When deciding whether to patent or not an invention, an innovator faces a trade-off between the legal protection conferred by the patent and the requirement to disclose information to potential imitators. As reported in industry surveys, many firms prefer to rely on secret rather than on patents to protect their innovations (Levin & al., 1987; Cohen & al., 2000). Anton and Yao (2004) develop a model that captures this trade-off. They show that effective patent protection will not be proportionate to the value of innovations. Rather, patenting and disclosure strategies tend to level the protection conferred to innovators.

Anton and Yao (2004) consider a Cournot duopoly in which the two firms initially have the same marginal cost \bar{c} . One of the firms develops a process innovation that reduces its marginal cost to $c < \bar{c}$. It can decide to patent this innovation or not. In either case, it can also disclose some enabling knowledge s about the innovation, which its competitor can appropriate to produce at cost $s \geq c$. However, if the innovation is patented, the imitator may be held infringing with some probability γ , and have to pay royalties τ , that are independent from the innovation's value.

Why would the innovator disclose some knowledge to its competitor? Anton and

Yao show that in some cases, it may be profitable to patent and partially disclose the innovation, so as to manipulate its competitor's beliefs about the actual value of the innovation. An innovator will patent its invention and fully disclose it if the innovation is relatively small (e.g. if c is above a certain threshold denoted c^*). Indeed a small cost decrease is not worth risking an infringement penalty, so that the other firm will not use the disclosed knowledge. In that case it is profitable for the inventor to disclose as much knowledge as possible. The other firm will believe it is facing a competitor with a low marginal cost and, as usual in Cournot competition, it will reduce its output accordingly.

Anton and Yao show that innovations of medium value will be patented but not fully disclosed. If the disclosed knowledge is such that $s < c^*$ (meaning that the disclosed knowledge enables a marginal cost below c^*), then the second firm will always choose to imitate the innovation. By disclosing only part of it, the patentee can therefore trigger imitation and expect a benefit from infringement which, as the probability of infringement and the infringement royalty are exogenous, exceeds the profit loss due to imitation.

However, the result may not hold with the most valuable innovations. Indeed the lower the marginal cost of the innovator, the higher its direct market profits compared to the exogenously fixed infringement payments. So that the loss from imitation may outweigh the infringement payment if patent protection is not strong enough. In this case, the innovator will choose not to patent its invention. This decision, along with a small knowledge disclosure, will be sufficient to signal the other firm that the innovation is important. In that way, uniform probabilities of infringement and infringement fines induce a disconnection between the innovation's intrinsic value and the reward ensured by patent

protection.

1.2.3 Patents protect technologies, not markets

Besides patent length, the scope of the exclusive rights conferred by the patent may also be used to fine tune patent protection on a case by case basis. As I will argue, patent claims are formulated in terms of technology, which allows to link the innovator's profit to the innovation's R&D cost rather than the innovation's market value.

Note first that the patent scope is set by the patent office, while it is the patentee who selects the patent duration in a menu set by the law. As a result the problem of information asymmetries is often neglected in the economic analysis of patent scope. Examiners are generally supposed to know the cost and value of innovation. So their main problem is to delimit the patent scope so as to maximize social welfare. Note also that a patent may give rights on imitations and substitute products, but also on subsequent innovations that may be patentable too. As I focus here on the tailoring of patent protection to stand alone innovations, I keep this latter case aside and will consider it separately in the second part of the chapter. My purpose in this subpart is to review how the patent scope affects social welfare. This requires taking into account not only the market power held by the patentee, but also the overall R&D costs of innovation and imitation, and the patentee's licensing strategy. Articulating altogether these elements finally leads to the conclusion that patent scope should not include substitute innovations that have been developed independently.

A first direct way to think about patent scope is to focus on the market power it confers. Gilbert and Shapiro (1990) measure it by the price a patentee is able to charge for the innovation. Klemperer (1990) defines it more precisely as the power to exclude

substitute products. In his view a narrow scope would include close substitutes only, while a larger scope would permit to exclude even very imperfect substitutes. For example, Howard Head, the inventor of the oversized tennis racket, holds a patent that gives him a monopoly on rackets with a strung surface of between 85 and 130 square inches. A broader scope would grant him rights on strung surfaces of between, say, 50 and 150 square inches. In a welfare perspective, these first approaches of patent scope emphasize a trade-off between the additional reward of the innovator on the one hand, and the induced deadweight loss for consumers on the other hand. However, they overlook the effects of patent scope on research investments by rivals and imitators, and the licensing strategies available for the patentee in this context.

Competitors can circumvent a patent and offer products that represent a substitute to the innovation. Therefore Gallini (1992) makes a step forward by measuring the scope of a patent by the R&D cost required to imitate the patented innovation without infringing the patent. Because the innovation can be freely accessed once the patent expires, it is possible for imitators to make a profit in the market only during the validity of the patent. Hence, a long patent attracts imitators by giving them the time to recover the cost of their imitation, whereas a broad patent scope dissuades imitators by increasing the cost of imitation. Gallini (1992)'s definition sheds light on another social effect of patent scope. Besides creating competition, which is beneficial to consumers, imitation has a cost for society. Indeed the R&D expenditure undertaken by the imitators is useless, because an equivalent technology - the patented technology - has already been developed.

1.2.4 Marketing the patented technology

Introducing imitators into the picture also reveals new strategic opportunities for the patentee. Maurer and Scotchmer (1998) develop a model showing that licensing a patent can deter imitation. In their model, the patentee competes à la Cournot with licensees and/or imitators. Licensing contracts include a fixed fee and a per unit royalty. Absent any imitator, the licensor can fix the market price by setting the royalty rate and the number of licensees. Furthermore, it can recover all the licensees' profits through the fixed fee. Lowering the market price by licensing is then profitable for the licensor if it can thereby (i) deter imitation and (ii) get a profit which is higher than without licensing but with imitation².

Maurer and Scotchmer show that all these conditions are satisfied if the cost of imitation is sufficiently higher than the cost of the patented innovation. If circumventing a patent is relatively costly, a small price decrease is sufficient for the patentee to deter imitation while keeping most of the monopoly profit. By contrast, if a patent can be circumvented at a low cost, the patentee cannot recover her R&D investment even if she licenses the patent. In the model, this implies that patents should protect innovators against simple imitations whose cost is below one half of the R&D cost incurred by the patentee. Otherwise the innovations would not be produced. However, patent scope should not include imitations whose cost is closer to the R&D cost of the patented invention. It is socially more efficient that the patentee grants licenses to deter imitators. This prevents cost duplications and erodes the patentee's market power without jeopardizing its incentives to innovate.

²Furthermore, this strategy is possible only if (iii) the profit from licensing is higher than the R&D cost of the patented innovation. Otherwise the innovation would not be achieved at all.

A strict interpretation of this would be that patent scope should be determined on a case by case basis, by taking into account the respective costs of innovation and imitation and the shape of the demand curve. Patent examiners do not use such economic information, all the more because it is too costly to obtain them. Nevertheless, these findings show that patent protection should not be defined according to market substitutability. One should rather consider the technology underlying the innovation. As Maurer and Scotchmer (1998) argue, a way to implement their result could be to transpose the principle of independent innovation defense, that already exists for trade secret and copyright, into patent law. It states that an innovation should not be held infringing an intellectual property right if it has been developed independently from the protected innovation. As similar innovations that have been developed independently are likely to have close R&D costs, this principle easily matches the conditions for non infringement formulated by Maurer and Scotchmer³. Their model may more generally justify patent law requiring that claims are consistent with the description of the technology. It is for instance consistent with the infringement doctrines. Indeed, even the US doctrine of "equivalents", which allows interpreting patent claims beyond their literal meaning, requires that the infringing product be an economic substitute but also that it be based on the same technology. A 1950 statement by the US Supreme Court summarizes the point:

³Interestingly, the idea of independent innovation defense furthermore permits to extend their result to the case where several firms are engaged in a patent race. Indeed most papers on patent scope focus only on the ex post relation between the patentee and her competitors, without taking into account the efficiency issue raised by an eventual patent race if several firms have the same idea of innovation. Applying the independent innovation defense would then result in an oligopoly rather than a monopoly, because each successful innovator would have the right to market her innovation. Using a deterministic R&D function, Maurer and Scotchmer (1998) show that this would at the same time erode the patentee's monopoly and limit the R&D cost duplication, while preserving the firms' incentives to innovate. Beyond the principle of independent innovation defense, this result reinforces the insight that patent protection should allow substitute innovations developed upon different technologies. This can indeed limit cost duplications and enhance lower prices, while preserving enough incentives for the innovation to be achieved.

If two devices do the same work in substantially the same way, and accomplish substantially the same result, they are the same, even though they differ in name, form, or shape.

Separating the function performed by the innovation from the underlying technology may however be difficult in some cases. Regarding software, this problem is especially acute. Indeed software patents, when they are awarded, protect algorithms performing a functionality. However, the algorithm may be described in the patent in such an abstract way that it simply reformulates the performed functionality. It is then impossible to create another program performing the same functionality without infringing the patent. By contrast, there are many different ways to program an algorithm in source code. Under copyright protection they are considered as independent creations, but under patent protection they all infringe the patent on the algorithm. In that way copyright corresponds to a very narrow scope of the program protection, but patent tend to provide a monopoly on the functionality rather than on an exclusive use of the underlying technology.

A survey of how the patent system awards protection on stand alone innovations reveals that its uniform rules allow some tailoring of the rights granted on different innovations, although it does so quite imperfectly. The self selection of patent duration by innovators does not allow to link the protection of innovations to their development cost. The possibility for innovators to choose between patent and trade secret protection introduces a leveling mechanism, by which small innovations are fully protected by patents, medium ones are partly protected, and the largest ones are protected by trade secret if infringement compensations are not proportionate to their value. Linking the innovator's reward to the innovation's cost is however more effectively ensured by the requirement that

patent protection be defined in terms of technologies rather than of market, because the market power granted to the inventor is then lower the easier its innovation is to develop.

1.3 Cumulative innovations

So far I have focused on the protection conferred by patents on stand alone innovations. A different problem arises when innovations are cumulative, e.g. when upstream inventions enable downstream inventions. Patent law has to allocate incentives to innovate along the whole chain of cumulative innovations (Scotchmer, 1991). Insufficient incentives at one stage may otherwise jeopardize the development of one innovation, and thereby of all the following ones. For instance, it may be necessary that the inventor of a basic innovation that is worthless for consumers, a research tool for instance, can benefit from the profits generated by inventions developed upon it.

As I show below, two elements in patent law may allow to allocate protection between cumulative innovations. Patent claims may first confer forward protection against subsequent innovations, thereby allowing upstream innovators to derive a profit from subsequent improvements. In turn, implementing patentability requirements allows to grant patent protection more selectively, thereby ensuring a better protection to the eligible innovations by excluding some improvements from patentability.

1.3.1 Why granting forward patent protection?

There are three main arguments for granting forward patent protection on innovations, that are related to the sharing of incentives between innovators and the organization

of subsequent research. First, forward protection can be justified in terms of R&D efficiency. Kitch (1977) argues that concentrating the rights on the whole innovation prospect in the hands of the first innovator is an efficient way to organize the subsequent research. When it is profitable, the patentee has an incentive to delegate the research efforts to other firms through licensing contracts. Thereby, it can ensure an efficient allocation of resources, by avoiding the cost duplications triggered by patent races, and by delegating investments to the most efficient firms. The solution advocated by Kitch is therefore equivalent to delegating all the rights on a innovation lead to a private planner.

A second argument for granting forward patent protection against subsequent innovations is that some basic, upstream innovations are not profitable per se, although they open a prospect of profitable innovations (Scotchmer, 1991). Their inventors should then be rewarded by getting a part of the profits realized on subsequent innovations. Consider for instance two successive innovations, defined by their respective values and costs (v_1, c_1) and (v_2, c_2) . Assuming that $v_1 + v_2 - c_1 - c_2 > 0$, it is socially desirable for both innovations to be produced. Assuming also that $v_1 - c_1 < 0$, innovation 1 is not profitable as a stand alone innovation. Therefore it will not be developed, nor the second innovation. Here the condition for innovation 1 to be profitable is that the first innovator can derive a profit from innovation 2. This is possible if innovation 1 is protected by a patent whose scope includes innovation 2. Then the first innovator will be able to claim a right on the second innovation even if it has been developed - and eventually patented - by somebody else.

Sharing the rewards of innovation between subsequent inventors is all the more important as the innovations may compete with each other. In this case, forward protection

can prevent such competition, thereby increasing the effective duration of patents and the innovators' profits. This analysis is carried out by O'Donoghue, Scotchmer and Thisse (hereafter OST, 1998), who generalize the two-innovations pattern and show that forward protection is necessary to distribute incentives along a chain of heterogeneous innovations.

The OST model captures the technology by considering an infinite sequence of patentable quality improvements $(\Delta_1, \Delta_2, \Delta_3 \dots)$, with quality $q_n = q_{n-1} + \Delta_n$. The idea of a new improvement always comes to a new firm, so that there is no patent race and that the upstream patent holders cannot go on innovating alone. Each idea is a pair (Δ, c) with Δ the value of the improvement, and c its development cost. The ideas come randomly following a Poisson process. All ideas have the same R&D cost c , but the improvement value Δ is random, so that Δ and c are independent from each other. Besides the infinity of the improvement sequence, the originality of the model is that the successive innovations are vertically differentiated substitutes. As a consequence, a patented product can be dropped out of the market by a better quality version before the legal term of the patent. Introducing this negative 'business stealing' externality between successive innovators allows OST to conclude that protecting innovations against imitation only - which would correspond here to banning lower quality products - yields sub-optimal incentives to innovate. Forward patent protection is thus required to internalize business stealing externalities and restore optimal incentives to innovate.

OST characterize forward protection as a parameter K such that an innovation with quality q_i infringes the patent on quality q if $q_i - q < K$. Under such protection new innovators have to buy licenses on the upstream patents they have infringed. As a result, the

profits from cumulative innovations are pooled and shared more evenly between successive subsequent patent holders, which compensates the heterogeneity of the innovations' values. This chain of licensing is broken once an innovation comes up that does not infringe the previous patents. A new chain of licensing can in turn start.

1.3.2 Forward protection requires ex ante licensing

Forward patent protection is therefore both necessary to provide and secure incentives to early innovators, and useful to organize R&D efficiently. However these arguments may fall short if the upstream patentees fail to co-ordinate with the downstream innovators. Indeed, granting forward protection to upstream innovators creates a risk that they hold-up the downstream innovations and deprive their inventors from their incentives to innovate (Scotchmer, 1991). Green and Scotchmer (1995) show that such a hold-up by the upstream patentee is possible even when the downstream innovation has been patented too. Consider indeed the two stage model described above, in which $v_1 + v_2 - c_1 - c_2 > 0$ and $v_1 - c_1 < 0$ so that innovation 1 is not profitable per se and forward protection is required. Now, if the two inventors bargain once the second innovation has been achieved and patented, the cost c_2 is already sunk and the bargaining surplus is only v_2 . Assuming an equal sharing of this surplus, the second innovators can expect a net profit of $\frac{v_2}{2} - c_2$, which may be negative. If it is negative, neither the second, nor the first inventor have the incentives to innovate and the innovation lead is not explored. Even if the second innovator's profit is positive, the unbalance in the incentives to innovate may in turn induce too much R&D investments in the first innovation and not enough in the second one (Denicolò, 2000), which contradicts Kitch (1977)'s argument about the R&D efficiency of forward protection. In any case, the

patent system fails to allocate effective incentives to innovate. Lerner (1995) finds for example that new U.S. biotechnology firms with high costs of litigation generally avoid investing in technological areas where other firms already have patents.

Given the risk of hold-up, the key condition for forward protection to be efficient is that licensing agreement can be signed before the downstream inventor invests in R&D. In the above case, such a deal would indeed allow to include c_2 in the bargaining surplus, therefore ensuring positive net profits of $v_1 - c_1 + \frac{v_2 - c_2}{2}$ and $\frac{v_2 - c_2}{2}$ for the first and second innovators respectively. If ex ante agreements are possible, Scotchmer (1996) even shows that it would be welfare improving not to patent subsequent innovations. In that case the upstream patentee would benefit from a better bargaining power, and end up with higher incentives to innovate.

Such contracting on future innovations may however be difficult to achieve because they generate high transaction costs. Identifying the subsequent innovators sufficiently early may prove difficult for the patentee. In turn, the subsequent innovators often have to incur sunk costs of R&D before really contracting with the patentee, which they may be reluctant to do (Barton, 1997). Furthermore, as the contract is on future improvements, the parties may have different expectations on their value, which complicates the negotiations. Finally, the transaction costs are particularly important when a subsequent innovator has to bargain separately with several different upstream patent owners (Merges & Nelson, 1991; Mazzoleni & Nelson, 1998). In the case of biotechnology, Heller and Eisenberg (1998) warn that the stacking of royalties on gene fragment patents may block the development of new diagnostic kits. As a matter of fact, Merges and Nelson (1991) report cases from the early aircraft,

radio and pharmaceutical industries where broad upstream patents have blocked or impeded further research improvements. For example, in the electric light bulb industry, technical progress was severely slowed by Edison's patent on the use of carbon filament as a light source. The same thing happened in aeronautics, after the Wright brothers' patented their system for stabilizing and controlling airplanes.

To sum up the discussion, forward protection appears to be a critical element of patent law. On the one hand forward protection is necessary for upstream innovators to have enough incentives to invest in R&D. But on the other hand, such protection may jeopardize downstream innovations unless licensing contracts can be stroke ex ante, which is difficult to achieve. A way to ensure the efficiency of the patent system is therefore to facilitate licensing. It is of prime importance that the patents related to a given research lead are recorded and can be identified easily. The fact that this condition is met, cumulated with the use of standard contracts for licensing research tools, explains for instance that the patent system permits a good pace of innovation in biotechnology (Arora & alii, 2003). By contrast, it is particularly difficult to build a database of software patents, because software was not patentable initially, and because the technology is now quickly evolving. Not surprisingly, software is thus an industry where the risk of hold-up is particularly high.

1.3.3 Patentability requirements

Forward protection is not the only way of controlling the distribution of rights between subsequent innovators. Implementing patentability requirements also allows to select the innovations that will receive patent protection. Recall that innovations can be patented only if they match the novelty, non-obviousness and utility (in the US) or technical

effect (in Europe) tests. From an economic viewpoint, it is difficult to sort out the respective effects of each criterion. Economists generally refer either to novelty, or to non-obviousness, to capture the economic effects that actually result from the combination of both.

As for forward protection, the patentability requirements affect the allocation of profits between subsequent innovators. O'Donoghue (1998) and Hunt (1999) justify respectively the enforcement of the novelty and non-obviousness requirements in this way. Measuring innovative improvements along a chain of cumulative innovations, they show two opposing effects of a stricter test. On the one hand, getting a patent is more difficult, which lowers the incentives to innovate. On the other hand, granted patents are more valuable for the innovator since the future improvements are more difficult to patent too. As a consequence the next innovation is delayed (O'Donoghue, 1998), and the owner of the initial patent can imitate the non-patented improvements in the meantime (Hunt, 1999). Both authors show that the second positive effect justifies a novelty requirement to foster R&D investments.

The patentability requirements thus play a similar role as forward protection in displaying incentives to each innovator along a chain of cumulative innovations. This conclusion in turn raises the issue of complementarity, or redundancy, of forward protection and patentability tests. This question is addressed by Denicolò and Zanchettin (2002), who develop a two stage innovation model to study the optimal combination of novelty and forward protection. They first emphasize that although both novelty and forward protection protect the early innovators, they do so in different ways. On the one hand non-obviousness blocks a range of subsequent innovations that cannot be patented. On the other hand for-

ward protection favours the development of such innovations, and merely imposes that the profits they generate are shared between their inventor and the upstream patentee. Absent *ex ante* contracting, forward protection may still let too small a share of profits to the subsequent inventor for small innovations to be developed. But this blocking effect is lesser than under the novelty requirement.

Denicolò and Zanchettin can show that forward protection is generally superior to novelty. Indeed the two rules are equivalent if the level of protection is low, because both would prevent the development of small subsequent innovations. As the level of protection increases, a greater forward protection allows the development and sharing of bigger innovations, while a more stringent novelty requirement would block them. Finally, Denicolò and Zanchettin conclude that novelty should be used only as a complement to forward protection when the level of protection is very high.

Taking into account the cumulative nature of innovation changes the way the patent system allocates incentives to innovate. When innovations follow each other, the way patents are granted and designed determine how subsequent innovators will coordinate and share the benefits of the whole innovation prospect. Economic analysis shows that two parameters ensure that the reward from each innovation is closer to its costs. Forward protection grants the patentee some rights over the next innovations. It creates the conditions of a coordination between subsequent innovators through licensing agreements. By contrast, the implementation of patentability requirements rather discriminates between innovators, rewarding only those whose inventions are sufficiently valuable and protecting them against minor improvements by competitors. Whether forward protection is better

than patentability requirements depends on which one is the more likely to block subsequent innovations. Forward protection seems superior as it allows the development of more innovations. However, this is true only if licensing agreements can be struck in good conditions, and especially before R&D costs are sunk. In industries where this is not the case, one can therefore expect strong patentability requirements to be more efficient.

1.4 Patent enforcement

In the first two parts of this chapter, I have discussed how patent law is designed to distribute incentives to develop a set of stand alone or cumulative innovations. However I have kept aside the problem of enforcement, assuming that patents effectively confer the intended protection at no cost. While this assumption is useful to study questions related to the design of patents, it also rules out important features of patents that deserve scrutiny. Once a patent has been granted by the office examiners, it is up to a court to decide ultimately whether this patent is infringed or not. In turn, any alleged infringer can contest the validity of the patent with regards to the patentability requirements. In this context, enforcing patent protection is both costly and uncertain, which changes the nature and repartition of the rights granted to innovators under patent law.

1.4.1 Patent protection is not perfect

Crampes and Langinier (2002) develop a model that captures the whole process of patent enforcement. They identify the different ways patents can be enforced by their holders, and the underlying costs and benefits that determine the strategies of patentees

and infringers. For the patent holder, enforcing her right is a two stages process. First, she has to detect infringements by other firms, which requires incurring monitoring costs. As stated by Crampes and Langinier (2002), some forms of patent infringement can indeed be detected and evidenced only by checking the production processes within the infringer's plants. This activity is costly, and may even necessitate the intervention of another firm specialized in economic intelligence. The patentee faces a trade-off between these monitoring costs and the benefits of detecting infringers.

If she incurs the cost and detects an infringer, the patent holder has then to decide whether to sue him. Patent litigations are quite expensive, and their outcomes are uncertain. Therefore the patentee may choose to accept the infringer entry in order to save high litigation costs. Still there is a third alternative. The patent holder and the infringer can also settle an agreement. This solution, which often occurs during the litigation process, allows to save part of the litigation cost. It however implies that the patentee accepts to share her surplus with the infringer, most often through a licensing agreement. There are thus three degrees of enforcement of patent protection, from trial to settlement to mere acceptance of entry. The choice of the patent holder depends on the respective costs and benefits of the three strategies. This in turn determines the patentee's monitoring effort and the infringer's entry decision.

The cost of enforcement creates a gap between patent protection, as it is specified in patent claims, and an actual protection that is only probabilistic and conditional on the detection of infringement. Besides weakening patent protection, the enforcement gap also creates distortions in the way this protection is granted. Indeed, some factors may

push towards either form of enforcement, thereby favouring or penalizing some categories of innovators.

1.4.2 Patent protection through litigation

The model developed by Crampes and Langinier shows that the infringer entry may be deterred only if, conditional on infringement detection, she expects either a trial or a settlement. As settlement is always a win-win alternative to litigation, it follows that patent protection is effective only if the threat of successful litigation is credible. Hence the patent's value ultimately depends on different factors making that threat more or less credible.

Firstly, enforcing patents is easier the lower the cost of trial. In Crampes and Langinier (2002)'s theoretical model, the frequency of entry decreases when justice becomes more efficient. For the patent holder, the benefit of asserting a patent is less likely to be counterbalanced by the cost of litigation, so that litigation becomes a more credible strategy. This is confirmed empirically. In a survey on patent suits in the United States during the period 1975-1991, Lanjouw and Schankerman (2001) show that foreign and individual patentees are more likely to file patent suits than domestic and corporate patentees, the latter ones having generally lower legal costs than the former ones (Lanjouw and Lerner, 1996). For the same reason, one can expect full litigations to be more frequent in Europe than in the US, where the costs of a suit are between \$500,000 and \$3,000,000 (AIPLA, 2001), while they are limited to €50,000 to €500,000 in any national court of Europe (Hall & alii, 2003).

Besides the cost of trial, the size of the stakes is a factor of litigation (Cooter &

Rubinfeld, 1989). Crampes and Langinier (2002) demonstrate that the frequency of entry is usually decreasing with the amount of the infringement penalty, because the patentee's incentives to sue are higher. Also, the stake of a trial may include a signal about the patent's scope and strength, or the patentee's will to enforce his patents, that can be leveraged into other litigations. In their empirical work, Lanjouw and Schankerman (2001) find that patents are more likely to be litigated when they open a chain of cumulative innovations. Their owner can leverage an early litigation to appropriate the whole cumulative chain, by deterring potential infringers or by building a strong bargaining position vis-à-vis subsequent innovators. Another possibility is that the patentee leverages her reputation in trials involving other patents. Large firms with patent portfolios can thereby enforce their patents at lower costs and negotiate more advantageous licensing or cross-licensing agreements, while it is more costly for startup firms and individual owners to enforce their unique or few patents (Lanjouw & Schankerman, 2001, 2004). A survey conducted in the biotechnology sector reveals for example that 55% of small firms regard litigation as an impediment to innovation, compared with only 33% of large firms (Lerner, 1995). Reputation can even provide a credible threat to enforce an obviously weak patent and obtain a license that is below the litigation cost (FTC, 2003).

Finally litigation is of course all the more likely as there is a high probability that the patentee wins the trial. Note however that when this probability is unclear, a trial may also be a way to clarify it so as to facilitate an eventual settlement. Court decision is indeed the best way to dissipate the uncertainty on the scope of the patent, shifting from probabilistic to asserted protection. This is for example why Texas Instruments, after

successfully asserting its patents in court during 1985-1986, has been able to lean on this confirmation of the scope of its patents to charge higher royalties to the firms using its technology (Hall & Ziedonis, 2001). This is also why litigation is more likely when there is a divergence in the parties' expectations about the trial (Cooter & Rubinfeld, 1989). In those cases, litigation is a way to clarify the delineation of patent protection prior to an eventual settlement. This is especially true in emerging technologies and where patent protection is new, such as in the biotechnology and software industries during the 1990s (Lanjouw & Schankerman, 2001).

1.4.3 Do settlements relax patent protection?

As a matter of fact, only 1.5% of the approximately two millions patents in force in the U.S.A are litigated each year (Lemley, 2001). Focusing on the patent litigation cases that were terminated in 1998-2000, Allison and Tiller (2003) find a slightly higher litigation rate of approximately 3.2%⁴. However, these low figures are misleading about the actual role of litigation. On the one hand, they do not take into account many cases in which litigation matters. Besides the numerous worthless patents that are not worth infringing, there are indeed valuable patents that are not infringed precisely because the threat of litigation is credible. Following on, it is the very threat of litigation that enables any licensing contract. A strong, clearly delineated patent is a key factor in a patentee's decision to license her technology rather than using it exclusively (Merges, 1998; Arora & Merges, 2000). Therefore licensing is more frequent in sectors where innovations are

⁴These average figures may however hide important differences between industries. Lerner (1995) reports a litigation rate of 6% in the pharmaceutical and biotechnology industries.

protected by strong patents, such as chemicals (Arora & Fosturi, 2000) or biotechnology (Anand & Khanna, 2000). On the other hand, even the weak figures on the litigation rates are misleading about the actual role played by courts. Lemley (2001) estimates that a settlement is reached before the end of the trial in more than 90% of the litigated patents, which again sheds light on the function of litigation as a baseline for any licensing agreement. If the actual scope and validity of a patent are uncertain, starting a litigation process can indeed make them clearer and facilitate a settlement before the court's decision.

If the firms settle during a litigation, the expected outcome of the trial determines their respective bargaining threat points, e.g. the expected surplus level that each party should improve through the agreement. A first incentive to settle is to save litigation costs. It follows that litigation is less likely the lower the settlement cost relative to the litigation cost (Cooter & Rubinfeld, 1989). Other incentives may stem from additional profits created thanks to the agreement, such as a more efficient division of labor between the licensor and the licensee.

However they may also stem from an anticompetitive use of the patent. Shapiro (2004) shows that a patentee and an alleged infringer can benefit from asymmetries of information vis-à-vis the antitrust authorities. They can settle before the court makes a decision, and thereby consider systematically that the infringement claim is valid so as to share a monopoly profit instead of having to compete again. Even if they do not create a pure monopoly, they can design a licensing agreement that reduces competition beyond what would have been expected from ongoing litigation. Shapiro shows that it is possible and welfare improving that the antitrust authorities require that the patent settlement lets

the consumers as well off as they would have been from ongoing litigation. Whether the settlements of patent litigation are beneficial to the social welfare thus strongly depends on the stringency of the antitrust authorities.

If collusion is ruled out, then settlements with imitators erode the profits that can be derived from weak, probabilistic, patents. Taken *ex post*, patent settlement may be a profitable way for a patentee to cope with an entrant who infringes her patent. But it also results in giving away some profit to the imitator, thereby creating *ex ante* incentives to infringe the patent. This effect of settlement is reflected in the model of Crampes and Langinier (2002). They find for example that the frequency of entry is usually increasing when the settlement cost is decreasing, because litigation becomes less likely. They also find, counter-intuitively, that the frequency of entry may be increasing or decreasing with the bargaining power of the patentee. This bargaining power may for example consist of private information on the actual strength of the patent. It allows the patentee to obtain a higher share of the settlement surplus (Meurer, 1989). When the firms would have settled anyway, this power reduces the incentives to infringe for the imitator. However, this may also induce the patentee to shift from a litigation to a settlement strategy, as the latter becomes more profitable. In this case, the imitator can expect a positive payoff, which increases his incentive to infringe. Similarly, Crampes and Langinier (2002) find that the frequency of entry may sometimes be increasing with the amount of the infringement penalty. Indeed, this confers the patentee a stronger bargaining power in case of settlement. So that she is more likely to settle, which in turn increases the imitator's incentive to infringe.

Finally, how settlements affect patent protection depends on the antitrust policy.

Indeed, the protection conferred by patents permits sound contracting when it is clearly defined and easily enforceable. By contrast, technologic areas where patent protection is more probabilistic are likely to attract infringers who expect a settlement. This may be seen as an efficient feedback that erodes the market power of firms whose patent claims are likely to be rejected by a court. However this interpretation requires that collusive settlements are ruled out. Otherwise, the market power generated in the shadow of a weak patent will not be threatened by the entry of infringers.

1.4.4 Patent protection without litigation

The numerous cases of patents that are infringed and not litigated include very different situations that shall be sorted out. Of course the choice not to sue infringers may result from the comparison of the cost and benefit of litigation. Crampes and Langinier (2002) show for instance that entry is more frequent when the infringing product is strongly differentiated from the patented one. Indeed the competitive harm to the patentee is limited, so that she is more likely to accept the entry without reacting. More generally, low penalties and justice inefficiency deter the patentee from suing infringers, thereby increasing the frequency of entry. Or, quite simply, litigation is less likely, and entry more frequent, when the probability that the infringement is detected is low. As a result some patents on process innovations may for instance be infringed without their owner being aware of it. In these cases, the absence of litigation denotes a deficient enforcement of patent protection, which is not due basically to the patent itself.

By contrast, the absence of litigation may in some cases benefit to patent holders who would not be ensured to win a trial. Indeed, patent owners generally have better

information than the alleged infringer on the strength of their patents (Allison, Lemley, Moore & Trunkey, 2004). They can attempt to draw a benefit from these asymmetries of information. Choi (1998) develops a theoretical model in which a patentee is threatened by two imitators who may enter her market in a row. The probability α that an imitator is held infringing by a court is private information of the patentee⁵. By suing the first entrant, the patent holder can at the same time eliminate him and signal the strength of her patent to the other ones, thereby deterring them from entry. In this framework, Choi shows that the expected payoff to the patentee is discontinuous in α . For either high or low values of α , Choi's model predicts that the patentee will sue the first entrant. The second imitator will then stay out or enter depending on the decision of the court, so that the payoffs of the patentee is increasing and linear with α . However, for intermediate value of α , the patentee has a higher incentive to accept the first entrant without filing a suit. Preserving the uncertainty on her patent is indeed the better way for her to deter the entry of new imitators. By contrast, a trial would likely end up with a rejection of the infringement claim, signaling that the market is open to other imitators. In that case, a limited and uncertain patent protection is therefore reinforced by the absence of litigation.

Focusing on patent enforcement sheds lights on distortions in how patent protection is actually allocated. First, it is costly and risky to enforce patent protection, which creates asymmetries between patentees. Indeed only valuable patents whose imitation can be detected easily, can be effectively enforced. Moreover enforcement is easier for large firms that can build and leverage a reputation than for small firms. In a context where patent

⁵Choi does not consider the possibility of settlement.

protection ultimately depends on the likely outcome of a virtual litigation, the probabilistic nature of patents may also affect the protection they confer. The prospect of a settlement attracts imitators who infringe on patents which protection may be invalidated by a court. However the profit generated by such weak patents is eroded only if collusive settlements can be ruled out, which may be difficult to achieve. In other cases, the blurred protection conferred by patents may not always be clarified by imitation and litigation. An uncertain protection may be sufficient to deter infringers, to the greater benefit of the holders of weak patents. Given these distortions in patent enforcement, it is all the more important that such weak patents are not awarded at the level of the patent office.

1.5 Conclusion

Implementing patents as an incentive mechanism for innovation creates a tension between the uniform rules that are implemented and various types of innovations and innovation patterns. An economic analysis of the main rules underlying the patent system allows to highlight to what extent and under what conditions it can accommodate this tension.

A first tension opposes a uniform patent protection to the specific cost and value of each innovation. In this context, the variable duration of patents under the renewal system does not really allow to tailor the profits to the R&D cost. Indeed it overrewards the most valuable innovations, without any guarantee that they are also the most costly to develop. Knowledge disclosure through patents triggers signaling strategies that tend to make the innovator's rewards closer whatever their innovations' values. Only small innovations are fully protected by patent, while medium innovations are subject to imitation,

which erodes their inventor's profit. To prevent disclosure and imitation, inventors of the most valuable innovations are likely to renounce patent protection and rely on secret to protect their innovation, which reduces their profits. Finally, the most effective means to link the innovator's profit to the innovation's value is to ensure that substitute innovations requiring comparable R&D investments can be developed independently. This implies that patent protection be not defined in terms of market, but rather in terms of technology.

A second issue arises when innovation is cumulative, because patent protection has then to be allocated among two or more subsequent inventions. Forward protection against subsequent innovations and the implementation of patentability requirements are two different ways of allocating the incentives to innovate to subsequent innovators. Forward protection is a superior solution because it does not block the development of small improvements upon patented innovations. However this requires that licensing agreements between the patentee and his follower can be signed *ex ante* to prevent hold-up issues. The possibility of such transactions is a necessary condition for patents to be an efficient incentive mechanism when innovation is cumulative.

Patent protection must finally be enforceable by the patent holders. Given the costs of patent enforcement, economic analysis predicts that patent protection is not always effective and that it mostly concerns the most valuable innovations. The effectiveness of patent protection also depends on the probability that an imitator be held infringing by a court. A weak probability attracts imitators who can expect a settlement with the patentee. It may conduct to an erosion of the protection conferred by undeserved and ambiguous patents. It however requires that the patentee and the alleged infringer do not use the

settlement to collude. In some cases, weak patents may moreover suffice to deter competitors entry without being litigated, which reinforces the need to prevent the granting of such patents.

Chapter 2

Non-obviousness and complementary innovations

The literature on the definition and distribution of patent protection has so far neglected the case of complementary innovations, although specific issues arise in sectors where innovations are strongly complementary. In biotechnology, scattered complementary patents on research tools or gene fragments may lead to royalty stacking and coordination failures (Arora & alii, 2003; Heller & Eisenberg, 1998; Graff & alii, 2003). Empirical inquiries and surveys highlight similar issues in the computer hardware and software industry (Bessen & Hunt, 2003; Graham & Mowery, 2003; FTC, 2003). In this chapter, I develop a normative model that aims to build a bridge between the literature on patent law and the fragmentation of protection into complementary patents. I describe how a too weak interpretation of the non-obviousness requirement by the patent offices can result in the excessive scattering of complementary patents. I identify the social costs and benefits of this regime, and conclude

that the non-obviousness requirement should be sufficiently stringent for the social benefits to exceed the social costs.

Of the three patentability criteria, non-obviousness is probably the most difficult to analyze, because it is closely linked to technology. It requires that the innovation should not be obvious for a person having ordinary skill in the state of the art. In other words, small improvements upon the state of the art should not be patentable. A straightforward way to capture this requirement is to measure it along a chain of cumulative innovations (Scotchmer & Green, 1990; Hunt, 1999; O'Donoghue, 1998; Denicolò and Zanchettin, 2002). Non-obviousness may however also affect the fragmentation of protection into innovations which are all necessary to work out a technology but, contrary to cumulative ones, do not result from each other. Such innovations are mere complements aggregated in a broader technology (Merges and Nelson, 1990).

For instance, isolating a gene fragment is an innovation. But commercial products such as therapeutic proteins or genetic diagnostic tests typically require the use of multiple fragments. Eisenberg and Heller (1998) have therefore expressed some concern about the patentability of gene fragments without any specified application. One can recast this problem in terms of non-obviousness by considering that under a weak non-obviousness requirement any isolated gene fragment is patentable, while under a strong requirement only the commercial product combining several innovations is. The strictness of the non-obviousness requirement then determines how many patents are included in the aggregate technology.

Software is probably the best example of this (Lemley, 1995; Cohen & Lemley,

2001). When he states that "Good programmers know what to write" while "great ones know what to rewrite (and reuse)", Raymond (2004) means that software programs usually combine different pieces of source code. In this context, whether one can patent "either the idea of a program or [each] of its subroutines" (Lemley, 1995) may have a dramatic impact on the economics of software. As a matter of fact, this question is at the heart of the current European debate about software patentability. Indeed the divergence between the European Commission and Council on the one hand, and the European Parliament on the other hand, regards principally the opportunity of enforcing a stringent requirement of "technical contribution" (Buck, 2004; Buck & Minder, 2005).

Besides high tech industries, complementarity more generally features most technologies. Barton (2002) shows for instance that a weak application of the non-obviousness standards has led to the grant of numerous patents on coffee cup holders in the US. Many of these patents are substitutes, yet some of them protect complementary elements of coffee cup holders, such as the design of cup sleeves and the material they are made of. In Barton's view, this fragmentation of patents is excessive and could have been avoided by implementing a more stringent non-obviousness requirement.

I develop a model that establishes that under weak conditions the smallest pieces of technology should not be patentable. At the basis of the argument is the cost of scattered patents. When there are several patent monopolies on different complementary innovations, the setting of a monopoly fee for each license yields the classic complement issue (Cournot, 1838). Multiple margins by the monopolists lower the profits of all patent holders compared to an integrated case where one single license is granted for all innovations. To overcome

this problem, patent holders can cooperate to lower their royalties by cross licensing or the creation of a patent pool (Shapiro, 2001). But the creation and monitoring of patent pools and cross licenses yields transaction costs. To sum up, there is no way of aggregating complementary patents ex post for free. This is why aggregating complementary innovations ex ante into one single patent through a strong non-obviousness requirement can provide a better solution.

This ex ante solution however raises dynamic concerns. One should take into account the effects of patent design on the innovation process, namely the role of patent disclosure and the excessive investments due to patent races (Scotchmer and Green, 1990; O'Donoghue, Scotchmer and Thisse, 1998; Denicolò, 2000). In the case of complementary innovations, the role of disclosure is more limited than with cumulative innovations. Indeed the achievement of one innovation is not necessary to enable the research on the complementary one. But disclosure still informs other patent owners that the complementary innovation does exist. Without a patent, the inventor of a small innovation cannot disclose it without exposing herself to free riding by other inventors. As a result, non patented innovations are not disclosed, and each innovator has to achieve all the required complementary innovations in order to get a broad patent. In that sense a strong non-obviousness requirement leads to duplicate R&D investments and slows down the pace of innovation.

The model analyses the trade-off between these two opposing effects of a strong non-obviousness requirement on complementary innovations. It identifies the conditions of efficiency of a strong requirement, defined as the need to aggregate several innovations into one single patent, compared to a weak requirement, under which each innovation would be

patentable. The model establishes that one single innovation should be patented as such either if the outcome of R&D is very uncertain, or if the innovation's value is very low. This result thus provides an economic rationale for the legal definition of the non-obviousness requirement, but it also reveals its drawback: the deterrence of the least value innovations.

Besides interpreting non-obviousness in terms of complementarity rather than cumulativity, this analysis has a different approach than the papers of Hunt (1999) and O'Donoghue (1998). Indeed it focuses on the optimal R&D investment rather than on the optimal incentive to innovate. In that way it is closer to the model of Scotchmer and Green (1990), from which it derives .

The general framework of the model is presented in section 2. Two firms are involved in a race for two elementary and complementary innovations. Section 3 deals with the case of a weak requirement, that is when each elementary innovation is patentable. I establish that a firm may drop out of the race once the other firm has achieved the first elementary innovation, so that even the weak requirement provides a de facto monopoly on the whole aggregate technology. Section 4 focuses on the strong non-obviousness requirement. Section 5 compares the social outcomes, defined as the total expected payoff of achieving the aggregate technology, under the weak and strong requirements. The efficiency of a strong requirement appears to depend on the technical hardship of R&D. Research costs savings due to the disclosure have indeed to be high enough to outweigh either the expected cost of patent scattering, or the further delay when one firm would drop out. Section 6 concludes.

2.1 The model

The role of patent disclosure on the market for R&D is taken in account in a framework derived from the model of Scotchmer and Green (1990). An aggregate innovation includes two elementary innovations, say 1 and 2. The timing of each elementary innovation follows the same Poisson discovery process with a hit rate λ , for a constant R&D cost c per unit of time and per innovation. Note here that λ characterizes the specific hardship of the R&D process leading to a given innovation, while c rather captures a general market price of R&D. By contrast with Scotchmer and Green's model, the elementary innovations are not cumulative, but complementary. This means that both 1 and 2 are necessary to produce an marketable technology and that there is no time order between them, so that their processes are independent. Two identical firms compete in R&D for patenting the technology. The private and social discount rate is r . I analyze two patent law regimes. Under a weak requirement, each elementary innovation is patentable as such. Thus the patentee can disclose and license any elementary innovation, and the race for this innovation ends. Under a strong requirement, only the aggregate innovation is patentable. So the race goes on until one firm has achieved both elementary innovations. In particular a firm goes on investing in R&D for one elementary innovation when the other firm has already been achieved it.

For simplicity I assume that the private value of the aggregate technology equals its social value. I normalize this value to 1. I model the cost of patent scattering as follows. Under a strong requirement, the winner of the race benefits from the whole value. Under a weak requirement, the firm benefits from the whole value only if it has patented both

elementary innovations. If each firm patents one elementary innovation, they equally share the benefit of the aggregate innovation. In addition, each of them also incurs a scattering cost S . This cost captures either the lost profit due to multiple marginalization, or the transaction cost associated with patent pooling or cross licensing.

2.2 Weak non-obviousness requirement

Consider first the patent race under the weak non-obviousness requirement. The corresponding dynamic game is represented in Figure 1. The firms are symmetrical and thus they decide simultaneously whether to enter the race or not (Node 1). Note that, as both elementary innovations are also symmetrical, with identical, constant and independent Poisson hit rates λ , a firm will either invest in R&D for both innovations, or not invest at all. In the case the firms enter the race, the Nature decides which firm achieves and patents one elementary innovation first. It also determines which elementary innovation is achieved, and when it happens. Then (Node 2 and Node 3), the firm that has not patented any innovation yet may decide either to stay in the race for the second elementary innovation, or to drop out.

I now proceed backwards to identify the equilibria in pure strategies. Consider first Node 2, where firm A has just patented one elementary innovation, so that firm B has to decide whether to stay in the race or not. Table 1 shows the continuation payoffs to A and B at this node. If B decides to stay in the race, each firm incurs an R&D cost c at each time period dt until the second innovation has been achieved. There is a probability λ that A achieves the second innovation in time period dt . If this occurs, the payoff to A is 1 since

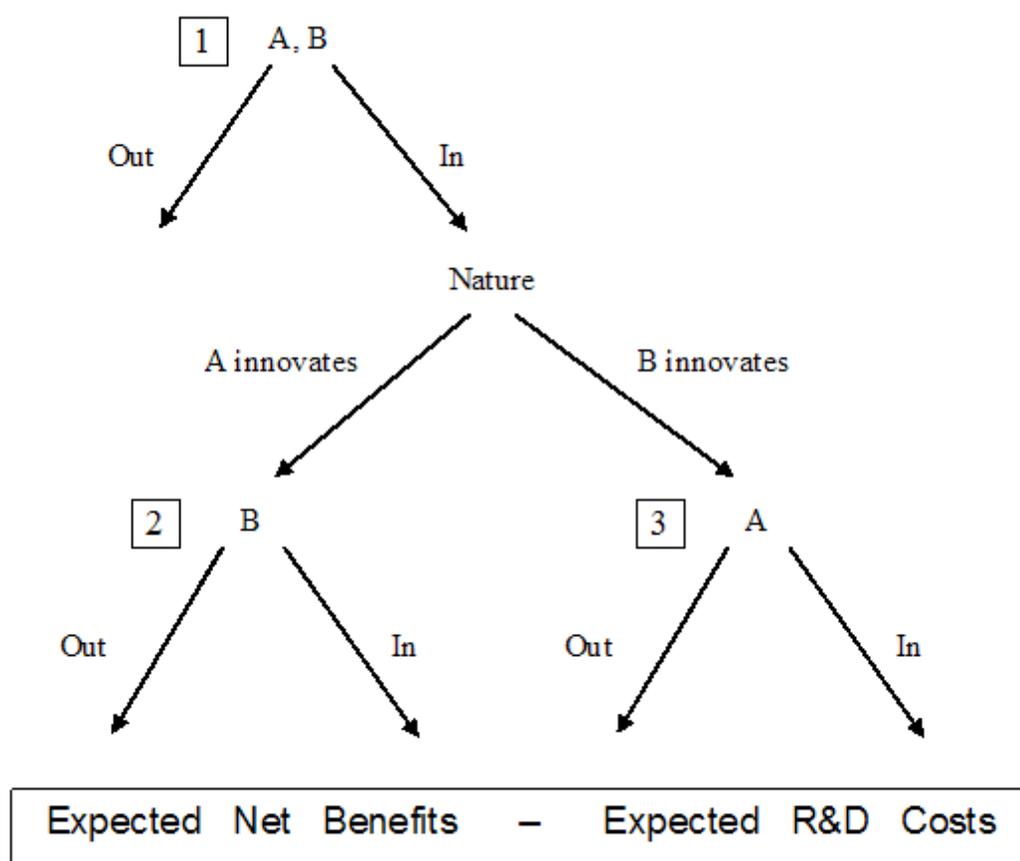


Figure 2.1: The patent race under the weak requirement

	B stays in	B drops out
A stays in	$\frac{\lambda(\frac{3}{2}-S)-c}{r+2\lambda}$	$\frac{\lambda-c}{r+\lambda}$
A drops out	$\frac{\lambda(\frac{1}{2}-S)-c}{r+2\lambda}$	0

Table 2.1: Continuation payoffs if A has patented the first innovation (Node 2)

A has already patented the first elementary innovation, and the payoff to B is 0. But there is also a probability λ that B achieves the innovation. In this case, A and B have to share the profit and incur the patent scattering cost S , leading to individual payoffs of $(\frac{1}{2} - S)$. So the expected payoffs to A and B in time period dt are $\lambda(\frac{3}{2} - S) - c$ and $\lambda(\frac{1}{2} - S) - c$ respectively. As the date of achieving the second innovation has exponential distribution with parameter 2λ , the present expected payoffs to A and B are respectively $\frac{\lambda(\frac{3}{2}-S)-c}{r+2\lambda}$ and $\frac{\lambda(\frac{1}{2}-S)-c}{r+2\lambda}$.

If B drops out, its continuation payoff is 0. Firm A still incurs an R&D cost c at each time period dt . It achieves the second innovation with a probability λ and has a payoff 1. As A remains alone in the race, the date of achievement of the second innovation has now an exponential distribution with parameter λ , leading to a continuation payoff of $\frac{\lambda-c}{r+2\lambda}$.

It can easily be checked from Table 1 that firm B will stay in the race only if $S \leq \frac{1-c}{2}$. Symmetrically, this condition is also necessary for firm A to stay in the race at Node 3.

Consider now Node 1, where A and B have to decide whether to enter the race for the elementary innovations or not. At this node, the expected payoffs to both firms are the same, so that both make the same decision. These payoffs depend on the subgame

	If both firms stay in $(S \leq \frac{1}{2} - \frac{c}{\lambda})$	If one firm drops out $(S > \frac{1}{2} - \frac{c}{\lambda})$
Payoffs	$\frac{\lambda(\frac{1}{2}-S)-c}{r+2\lambda}$	$\frac{2\lambda^2-(r+2\lambda)2c}{(r+\lambda)(r+4\lambda)}$

Table 2.2: Entry payoffs (Node 1)

equilibria, that is on whether a firm will drop out once one first elementary innovation has been achieved by the other. They are represented in Table 2. Until the first innovation, each firm incurs an R&D cost $2c$ at each time period dt because they invest for both innovations 1 and 2. The expected payoff to a firm, say A, then depends on which firm will patent the first elementary innovation.

Let us compute the payoff to A if both firms stay in the race until both innovations have been achieved. At each time period dt , there is a probability 2λ that A achieves either innovation 1 or innovation 2. Then its expected payoff is $\frac{\lambda(\frac{3}{2}-S)-c}{r+2\lambda}$, as given in table 1, when B stays in. There is also a probability 2λ that B achieves either innovation 1 or innovation 2. In this case, the payoff to A corresponds to that of B in Table 1 when B stays in, that is $\frac{\lambda(\frac{1}{2}-S)-c}{r+2\lambda}$. As the date of achieving the first elementary innovation has an exponential distribution with parameter 4λ , the present expected payoff to A if she enters is, after some simple calculation, $\frac{4\lambda^2(1-S)-(r+4\lambda)2c}{(r+2\lambda)(r+4\lambda)}$. Likewise for B. For notational simplicity, let \underline{E}_1 denote this present expected payoff.

Let us now compute the payoffs to A if one firm drops out of the race once the first elementary innovation has been achieved. At each time period dt , there is still a probability 2λ that A achieves either innovation 1 or innovation 2. However her expected payoff is then that of Table 1 when B drops out, that is $\frac{\lambda-c}{r+\lambda}$. The probability that B achieves either

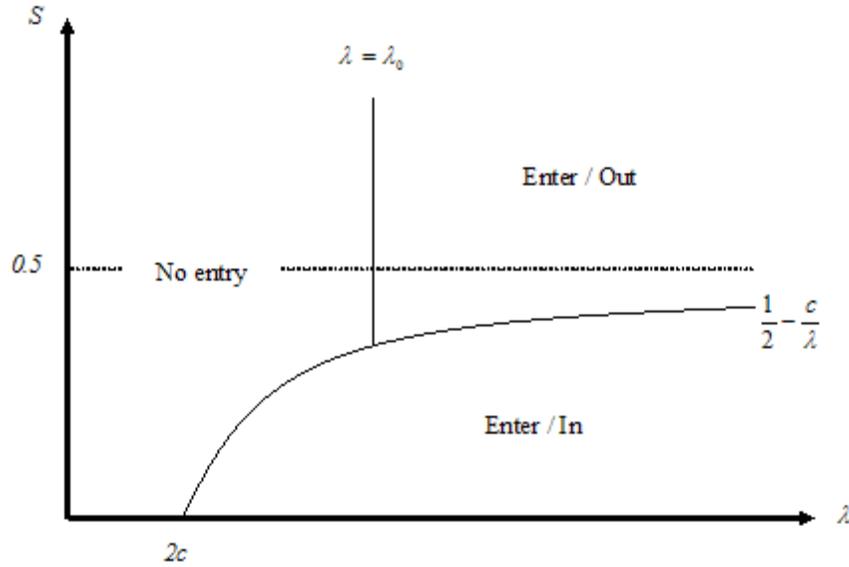


Figure 2.2: Outcomes under the weak requirement

innovation 1 or innovation 2 is 2λ as well. In this case the payoff to A corresponds to that to B in Table 1 when she drops out, that is 0. The date of achievement of the first elementary innovation has exponential distribution with parameter 4λ . Thus the expected payoff to A (or B) if it enters is $\frac{2\lambda^2 - (r+2\lambda)2c}{(r+\lambda)(r+4\lambda)}$. Let denote \underline{E}_2 denote this expected payoff.

Figure 2 is a representation of the equilibria of the game depending on the scattering cost, S , and on the Poisson hit rate, λ , that measures the technical hardship of innovating. Once one elementary innovation has been achieved by one firm, the other firm only stays in the race if $S \leq \frac{1}{2} - \frac{c}{\lambda}$. Entry in the race depends on the signs of the expected payoffs in Table 2. It is easy to show that if both firms stay in the race once the first innovation has been achieved, the expected payoff \underline{E}_1 is always positive for $S \leq \frac{1}{2} - \frac{c}{\lambda}$, so

that the firms always enter the race. If one firm drops out, the expected payoff of entry E_2 is not necessarily positive. However there is a unique threshold, λ_0 , for which it is positive for all $\lambda > \lambda_0$ ¹. Note that this threshold does not depend on the scattering cost S , because this cost is never incurred when one firm drops out.

In the end, three equilibria are possible. In a North West area, the firms do not enter because the technical hardship of innovating or the scattering cost are too high. In a South East area, both firms enter the race and stay in until both innovations have been patented. This equilibrium no longer holds if the scattering cost is high. In this case, a firm drops out once the first innovation has been achieved, so that one single firm finishes the race and patents both elementary innovations. This equilibrium corresponds to the North East area. Paradoxically, high scattering costs are a way to avoid the occurrence of scattered patents. They indeed lead a firm to drop out, which creates a de facto first mover monopoly on the aggregate technology. Note also that in this case, the achievement of the second innovation is delayed since the patentee is the only one investing in R&D for this second innovation.

2.3 Strong non-obviousness requirement

Consider now the patent race under a strong non-obviousness requirement. In this case both elementary innovations are required in order to get a patent on the aggregate technology. Furthermore a firm that has achieved one elementary innovation does not disclose it because it is not protected against imitation. As a result, a firm has to be the

¹ λ_0 is the single positive root of $\lambda^2 - c\lambda - rc$. Note also that λ_0 always satisfies $\lambda_0 > 2c$.

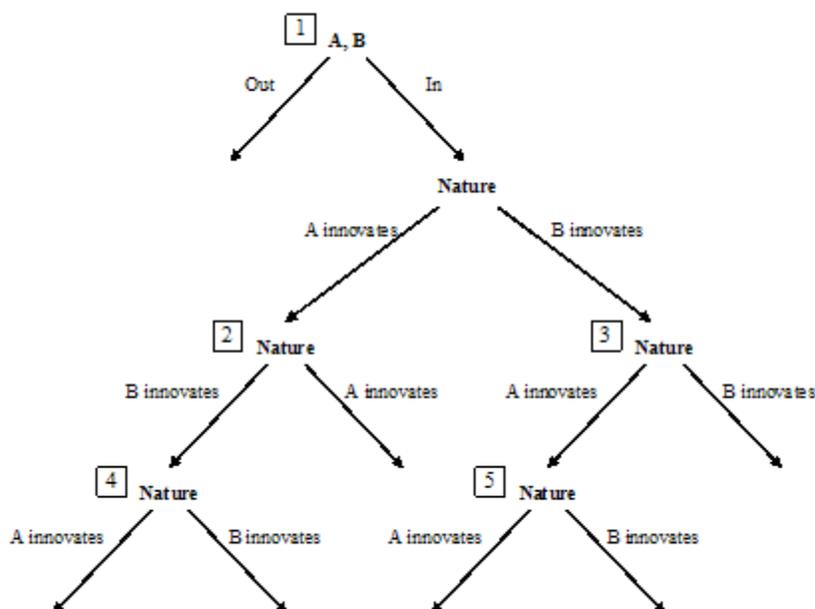


Figure 2.3: The patent race under the strong requirement

first one to achieve both innovations 1 and 2 in order to get a patent. Put differently, the patent race is a ‘two hits’ one. Figure 3 represents this race. The firms enter for each elementary innovation simultaneously (Node 1). Thus a firm bears the R&D cost of two research lines until it has achieved the first innovation (Nodes 2 and 5 for A, and nodes 3 and 4 for B), or alternatively until the other firm has patented the aggregate technology. Then the firm incurs the R&D cost of one research line until it or the other firm has patented the aggregate technology. The strong requirement implies zero scattering costs, and the payoff to the patentee is always 1.

Let us now calculate the payoffs. Consider first Nodes 4 and 5. At these Nodes, both firms have already achieved one elementary innovation. Thus the first firm to achieve

	Node 2	Node 3
Payoffs to A	$\frac{(r+4\lambda)(\lambda-c)}{(r+2\lambda)(r+3\lambda)}$	$\frac{2\lambda^2-(r+3\lambda)2c}{(r+2\lambda)(r+3\lambda)}$
Payoffs to B	$\frac{2\lambda^2-(r+3\lambda)2c}{(r+2\lambda)(r+3\lambda)}$	$\frac{(r+4\lambda)(\lambda-c)}{(r+2\lambda)(r+3\lambda)}$

Table 2.3: Continuation payoffs of A and B at Nodes 2 and 3

the second elementary innovation wins the race. Each firm incurs an R&D cost c at each time period dt until the aggregate innovation has been achieved. There is a probability λ that A achieves a second innovation in time period dt . In this case A's payoff is 1 and B's payoff is 0. There is also a probability λ that B achieves the innovation. Then its payoff is 1 and that of A is 0. As the date of achievement of the latest innovation has exponential distribution with parameter 2λ , the present continuation payoff to each firm is $\frac{\lambda-c}{r+2\lambda}$.

Table 3 shows the continuation payoffs to A and B at Nodes 2 and 3. At Node 2, only firm A has already achieved one elementary innovation. So A incurs an R&D cost c at each time period dt in order to achieve the second innovation, while B incurs $2c$. The probability that A achieves its second innovation in time period dt is λ . If it succeeds the race end, implying its payoff to be 1 and B's payoff to be 0. The probability that B achieves one innovation in time period dt is 2λ . Then the payoffs to the firms will be those of Node 5. There is a probability 3λ that either A or B achieves an elementary innovation in time period dt . So after simplification, the present continuation payoff to A is $\frac{(r+4\lambda)(\lambda-c)}{(r+2\lambda)(r+3\lambda)}$, and that of B is $\frac{2\lambda^2-(r+3\lambda)2c}{(r+2\lambda)(r+3\lambda)}$.

Furthermore the payoffs to A and B at Node 3 are merely inverted at Node 2.

The last step consists in calculating the payoffs to the firms at Node 1, if they

enter the race. At this stage no elementary innovation has been achieved, so both firms invest in both research lines. Therefore each firm incurs a cost $2c$ in time period dt . One firm, say A, may achieve one elementary innovation with a probability 2λ at each time period dt . In this case its payoff is that of A at Node 2. There is also a probability 2λ that the B achieves an elementary innovation in time period dt . Then the payoff to firm A is that of Node 3. As there is a probability 4λ that either A or B achieves an elementary innovation in time period dt , the expected entry payoff to each firm can be shown to be $\frac{12\lambda^3+2\lambda^2r-(16\lambda^2+8\lambda r+r^2)2c}{(r+2\lambda)(r+3\lambda)(r+4\lambda)} \equiv \bar{E}$. In the end, the firms enter the patent race under a strong non-obviousness requirement only if $\bar{E} \geq 0$.

2.4 Optimal non-obviousness requirement

The last step of the analysis consists in comparing the expected social outcomes under the weak and strong non-obviousness requirements. As I have assumed that the social value of the aggregate innovation is equal to its private value, the comparison only needs to take into account the expected total costs of the R&D, the delay of achievement of the aggregate technology, and the eventual scattering cost. Therefore the expected social welfare associated with a non-obviousness requirement equals the sum of expected payoffs to the firms.

I can therefore consider as socially optimal the non-obviousness requirement that yields the greater expected payoffs to the firms, for given parameters of discount rate r , scattering cost S , R&D cost c , and R&D Poisson hit rate λ . This approach especially enables us to focus on how the optimality of either patentability requirement depends on

the underlying R&D trial and its particular hardship λ . My result then stems from the proposition below.

Proposition 2.1 *If either $S < \frac{1}{2}$ or $c < \frac{r}{2}$, then there exists a particular threshold for λ denoted $T(S, c, r)$ such that for any $\lambda > T(S, c, r)$, the strong non-obviousness requirement is optimal. If $S \geq \frac{1}{2}$ and $c \geq \frac{r}{2}$, the weak non-obviousness requirement is optimal for any $\lambda > 0$.*

Proof. *Recall first that under the weak requirement, both firms stay in the race until the whole aggregate innovation is achieved if $S \leq \frac{1}{2} - \frac{c}{\lambda}$. One can reformulate this condition as follows: $\lambda(1 - 2S) \geq 2c$. As c and λ are strictly positive, the condition $\lambda \geq \frac{2c}{1-2S}$ is satisfied only if $S < \frac{1}{2}$. If $S \geq \frac{1}{2}$, the condition does not hold. Thus there exists a threshold value for λ equal to $\frac{2c}{1-2S}$ such that both firms stay in the race under the weak requirement, if and only if $S < \frac{1}{2}$.*

Consider the case where $S < \frac{1}{2}$. If $\lambda \geq \frac{2c}{1-2S}$, both firms stay in the race under the weak requirement. Then the strong non-obviousness requirement is optimal if $\bar{E} > \underline{E}_1$.

After some calculations, I obtain that this condition is equivalent to $S > f(\lambda)$, where $f(\lambda) = \frac{r}{2r+6\lambda} + c\frac{r+4\lambda}{2r\lambda+6\lambda^2}$ is a continuous and decreasing function of λ from $]0; \infty)$ to $]0; \infty)$. Hence for $\lambda > f^{-1}(S)$, a strong non-obviousness requirement is optimal.

If $\frac{2c}{(1-2S)} \leq f^{-1}(S)$, then $T(S, c, r) = f^{-1}(S)$ can be defined such that for $\lambda > T(S, c, r)$, granting a patent only for the aggregate innovation is optimal.

If $\frac{2c}{(1-2S)} > f^{-1}(S)$, then $T(S, c, r) = \frac{2c}{(1-2S)}$ can be defined such that for $\lambda > T(S, c, r)$, granting a patent only for the aggregate innovation is optimal.

Consider now the case where $S \geq \frac{1}{2}$. Under the weak requirement, one firm would

give up once the first innovation has been achieved whatever the value of λ . Here the condition for the strong requirement to be optimal is $\bar{E} > \underline{E}_2$.

After some calculations, this condition is equivalent to $c < g(\lambda)$, where $g(\lambda) = \frac{r\lambda^2}{r^2+4r\lambda+2\lambda^2}$ is a continuous and increasing function from $[0; \infty)$ to $[0; \frac{r}{2}[$.

Finally, when $c < \frac{r}{2}$ the condition for the strong requirement to be optimal can be reformulated as $\lambda > T(S, c, r)$, with $T(S, c, r) = g^{-1}(\lambda)$.

Consider still the case where $S \geq \frac{1}{2}$. If $c < g(\lambda)$, where $g(\lambda)$ is a continuous and increasing function from $[0; \infty)$ to $[0; \frac{r}{2}[$, granting a patent only for the aggregate innovation is optimal. Thus, for $c \geq g(\lambda)$, the weak non-obviousness requirement is optimal for any $\lambda > 0$. ■

The first part of proposition 2.1 establishes the existence of a threshold value of the R&D Poisson hit rate above which the aggregate technology should be patentable, while the elementary complementary innovations should not. As λ captures the uncertainty of the R&D outcome independently of the R&D market cost c , it provides an interesting proxy for the degree of obviousness of an innovation. In this way, the proposition establishes a relation between this proxy for *non-obviousness* and our definition of a strict non-obviousness requirement as the need to achieve the whole aggregate technology prior to patenting. Only the innovations that are sufficiently difficult to achieve, that is those which $\lambda \leq T(S, c, r)$, should be patentable as such. Obvious innovations, which $\lambda > T(S, c, r)$, should be combined with other innovations prior to patenting. This result is due to the additional costs incurred when patents on complementary innovations are scattered. These costs may consist either in the cost S directly incurred when the patents are effectively scattered or,

indirectly, in a delayed innovation when one firm drops out. The other side of the coin is the social benefit of patenting the most obvious ideas, that is saved R&D thanks to disclosure. Setting a minimum threshold on λ is a way to ensure that the benefit of disclosure will outweigh either the expected scattering cost induced by the creation of a new patent, or the further delay of achievement of the aggregate technology if one firm drops out. The first proposition therefore provides an economic rationale for the non-obviousness requirement.

This result is however conditional on conditions that are emphasized in the second part of the proposition. If $S \geq \frac{1}{2}$ and $c \geq \frac{r}{2}$, this does not hold anymore and the weak requirement always dominates the strong one. Recall that the value of the aggregate innovation is normalized to 1. So one can interpret S and c as the respective scattering and R&D costs relative to this value. In this way, the condition $S \geq \frac{1}{2}$ and $c \geq \frac{r}{2}$ characterizes a low value aggregate technology. Note that in this case, a firm would drop out once the first elementary innovation has been achieved. Then it is too costly to maintain three research lines – one for the achieved innovation, two for the remaining one – though it may reduce the delay of achievement of the aggregate technology. In other terms, a strong non-obviousness requirement stifles low value innovations.

2.5 Conclusion

The analysis of the consequence of non-obviousness on complementary innovations sheds light on an economic rationale for this patentability requirement. If the requirement is weakly enforced, each innovation is patentable as such. This may induce either static costs due to scattered patents or delayed innovations when patenting a piece provides a de facto

monopoly on the whole aggregate technology. Aggregating the simplest innovations into one patent thanks to a strong non-obviousness requirement is a way to limit the scattering costs in the first case, or to accelerate innovation in the second case. However, this efficiency argument for non-obviousness does not always hold. A strong non-obviousness requirement has indeed a drawback: some innovations are not disclosed, leading to duplicate R&D costs. I show that the positive effects of non-obviousness generally outweigh these duplication costs, except when the innovation value is very low (less than one half of the scattering cost). So that non-obviousness turns out to be inefficient in this specific case. In all other cases, a non-obviousness threshold for patentability does exist and depends on specific parameters of the sector, namely the cost of R&D, the discount rate, the expected scattering cost and the innovation values.

Interestingly, my interpretation of non-obviousness as reflecting the uncertainty of the R&D process upholds the "technical contribution" requirement which is put forward in the European debate on software patentability. As developing new software is relative easy by comparison with innovation in other field, my result indeed suggests that a stringent application of the "technical contribution" requirement could improve the efficiency of software patents by preventing an excessive scattering of complementary patents.

Part II

Patents and the Persistence of the Incumbent

This part focuses on how patents and patent strategies affect the persistence of a dominant firm. I tackle this issue in two ways. I first survey the economic literature in Chapter 3 and show that it indeed confirms that patents facilitate the persistence of dominant firms. I then develop a specific model in Chapter 4. It shows that an incumbent monopoly may be able to prevent upstream patents that enable the development of a cumulative and drastic innovation.

Chapter 3

Patent strategies and the persistence of dominant firms

In first analysis, patents imply monopoly and market power. This correspondence is however very imperfect. A patented innovation may have to compete with substitutes, so that the legal monopoly conferred by the patent does not necessarily imply market power. Furthermore, patents foster dynamic competition because any patentee enjoying a monopoly can be replaced by a new patentee who has developed a better innovation. This mechanism partly matches the Schumpeterian view of competition (Schumpeter, 1934). His key concept, "creative destruction", indeed expresses the idea that firms mainly compete by developing sweeping innovations. Such innovations destroy the incumbent's market position and provide the new entrant with a monopoly position. For Schumpeter (1942), innovation also requires large firms with market power, for they have a better ability to innovate. Such firms can indeed make enough profits to recover their fixed cost of R&D before the

next innovator pushes them out of the market. They can also benefit from economies of scale for R&D. They can at last manage the hazard of R&D by pooling different research projects and by finding internal applications of unexpected research results. In a nutshell, large firms with market power can innovate thanks to their size and organization. And the monopoly in turn results from the innovation itself, not from the patent. Patents exist at best implicitly, as by-products of innovation.

Our problem here is to revisit this Schumpeterian view - namely that innovation favours the replacement of dominant firms - through the prism of patents and patent strategies. For this purpose, I will move away from Schumpeter's language and transpose his main ideas into other works. As a first step, I will define dominant firms as (i) incumbent monopolies and (ii) firms enjoying a technological lead upon a competitive fringe. I shall then determine whether the use of patents favours the persistence of such firms or, to the contrary, their replacement by challengers. The survey that answers this question is interesting in several respects. It puts together papers that are generally taken separately, and sheds light on the consistence of the economics literature on an issue that, as far as I know, has not been addressed in this way yet. It thereby helps linking the theory and practice of patents, by shifting from a stand alone innovation approach to an industry wide approach. As I will show, it finally seriously challenges the Schumpeterian view of creative destruction in a context of patent protection.

To carry on this survey, I will follow the research lead initiated by Arrow (1962), the second father of the economics of innovation. This approach focuses on the firms' incentives to innovate rather than on their capacity to innovate. Although it does not initially focus on

patents, it is an appropriate approach to capture their specific effect on the firms' incentives to innovate. It also offers a useful pattern to study the strategic use of patents by dominant firms and entrants. It allows one's to recast the Schumpeterian "creative destruction" in terms of "drastic innovations". Finally, it can be extended to R&D investments and social efficiency issues.

I will thus adopt the perspective opened by Arrow (1962), and follow it with other theoretical, legal and empirical elements. In the first part of the chapter, I investigate whether the incentive power conferred by patent exclusivity is higher for an incumbent monopoly or for a new entrant. I present the successive stages of a scholar debate that leads us to the conclusion that patent exclusivity rather favours the entry of new competitors. This notion of exclusivity is however restrictive in that it assumes a perfect adequation between patent and product market. By contrast, the two following parts introduce a distinction between a final product market where competitors operate, and a market for R&D where patents can be traded. I show that adopting this perspective may reverse the conclusions of the first part, namely that patents generally favour the persistence of dominant firms. I review in part two how a dominant firm can use patent as a trading tool to stay in place. When innovations are non drastic, it can indeed persist by granting licenses on its own technology to its followers, or by buying the new entrant's patent ex post. The third part explores how the literature on cumulative patents can contribute to our issue. I show how patents provide a very effective means for dominant firms to persist in sectors with cumulative technologies.

3.1 Patent and exclusivity

How does patent protection affect the incentives to innovate of a dominant firm on the one hand and its challenger on the other hand? A first characteristic of patents, which is also what they are meant for, is indeed to transform non rival information into exclusive assets. Of course this feature is not neutral with respect to competition. It creates a "winner takes all" pattern, where the first innovator can patent its invention so as to exclude its competitors. Note that this pattern may include cases where the innovation is protected by a bundle of patents as well as by one single patent. It may also only create partial exclusivity if, for instance, inferior technologies do not infringe the patent. Innovation thus affects the market structure by creating either a monopoly or, at least, a technological leader. In either case, patent exclusivity confers a market power that grants the innovator a positive profit.

Although it does not explicitly focus on patent exclusivity, the literature initiated by Arrow (1962) explores how the "winner takes all" pattern affects the incentives to innovate of a dominant and a challenger. I review it below in order to show that the contributions of Arrow (1962), Gilbert and Newberry (1982) and Reinganum (1983), although their conclusions are diverging, can be viewed as a progressive enrichment of Arrow (1962)'s model resulting in Reinganum (1983)'s synthesis. I conclude with Reinganum that patent exclusivity rather favours new entrants, and uphold this result by relaxing some assumptions and referring to empirical evidence.

3.1.1 The incentives to innovate

This debate has been framed by the early work of Arrow (1962). He proposes a simple framework where an innovation allows to produce a good at a constant unit cost \underline{x} , instead of an initial constant unit cost $\bar{x} > \underline{x}$. Starting from the case where the market is initially competitive with an equilibrium price equal to the unit cost \bar{x} , Arrow establishes a seminal distinction between drastic and non drastic innovations. An innovation is drastic if it is important enough to grant its inventor a monopoly on its market. Conversely, the inventor of a non drastic innovation has to compete and share the market with other firms using the second best technology. These definitions can be captured analytically. Consider $p^m(\underline{x})$ as the price that would be fixed by a monopolist with unit cost \underline{x} . If $p^m(\underline{x}) < \bar{x}$, then the innovation is drastic and the patentee can behave like a monopolist. If $p^m(\underline{x}) > \bar{x}$, then the innovation is non drastic and the patentee has to compete with the firms that produce the good at cost \bar{x} . Because of this competitive fringe, the patentee must indeed price the good at $\bar{x} - \varepsilon < p^m(\underline{x})$.

These definitions make it straightforward that drastic innovations are more profitable than non drastic ones, so that firms have more incentives to develop the former than the latter. However, in either case these incentives remain below the total surplus created by the innovation, because they include neither the consumer's deadweight loss, nor the eventual knowledge spillovers.

As a second step, Arrow establishes that a firm with cost \bar{x} has less incentives to develop an innovation - be it a drastic or a non drastic one - if it initially enjoys a monopoly than if it is competing with other similar firms. I can use this pattern here to compare

the incentives to innovate of an incumbent monopoly with initial cost \bar{x} and a new entrant. Let $\pi^m(p)$ denote a monopolist's profit at a price p . Let also V^m denote an incumbent monopoly's incentive to develop an innovation. We have:

$$V^m = \pi^m(p^m(\underline{x})) - \pi^m(p^m(\bar{x})),$$

As regards the new entrant, it does not make any profit before innovating. And its profit in case it innovates depends on whether its innovation is important enough to sweep the incumbent away from the industry. Let also V^e denote an outsider's incentive to develop an innovation. We have:

$$V^e = \begin{cases} \pi^m(p^m(\underline{x})) & \text{for a drastic innovation} \\ \pi^m(\bar{x}) & \text{for a non drastic innovation} \end{cases}.$$

It can be easily checked from above that $V^m < V^e$ for drastic innovations, and it has been demonstrated by Arrow that this inequality still holds for non drastic innovations. Arrow thereby formalizes the intuition behind John Hicks (1935)'s assertion that "[the] best of all monopoly is a quiet life". Indeed a firm that is already enjoying market power and the resulting profits has less incentives to lower its costs than another firm which starts from nothing. Put differently, the new entrant's additional incentive to innovate corresponds to a business stealing effect, by which the entrant merely steals the incumbent's profits. In the case of drastic innovations, this effect clearly reveals the over-incentives to innovate triggered by Schumpeterian "creative destruction". Indeed the entrant's incentive to innovate V^e is the sum of the incremental profit V^m created by the innovation and the former incumbent's initial profit $\pi^m(p^m(\bar{x}))$ that is simply redirected to the new entrant.

Thus Arrow's pattern suggests that when patents confer exclusivity on the leading technology, a monopoly has less incentives to innovate than a new entrant because the

latter can benefit from a business stealing effect. This result is straightforward for drastic innovations, which are close to Schumpeter's view of "creative destruction". It also holds for non drastic ones, although in that case the entrant cannot steal the whole business of the former monopoly.

3.1.2 The incentives to preempt

Gilbert and Newberry (1982) propose a different approach of the "winner takes all" pattern which refines Arrow's approach and modifies his result. Indeed, Arrow's interpretation of this pattern is simply that the reward of innovating is an exclusive use of the invention. He does not consider the possibility of a competition for the patent, such as a patent race. The strategic dimension of innovation, especially its effect on the loser's profit, is not taken into account.

By contrast, the model proposed by Gilbert and Newberry focuses precisely on the strategic incentive to preempt the patent. As only one patent is granted for one innovation, they do not measure the incentive to innovate by comparing a firm's profit before and after innovating. They rather compare a firm's profit if it innovates with the same firm's profit if it is one of its competitors that innovates instead. They use an auction model to measure the incentives to innovate of an incumbent monopoly and a new entrant, while Arrow (1962) considers an incumbent monopoly and initial competition as two separate cases.

Their key result is that an incumbent monopoly is always able to preempt a patent on a non drastic innovation. To demonstrate it, Gilbert and Newberry have revisited Arrow (1962)'s definition of non drastic innovations. Instead of defining a price \bar{x} set by the innovator to exclude competitors from the market, they consider that innovation by

the entrant yields a duopoly competition between this entrant and the monopolist¹. Let $\pi^d(\underline{x}, \bar{x})$ and $\pi^d(\bar{x}, \underline{x})$ denote respectively the profits of the entrant and the incumbent, whose unit cost remains \bar{x} . For simplicity let also the profit of a monopoly with cost \underline{x} be $\pi^m(\underline{x})$, instead of the previous notation $\pi^m(p^m(\underline{x}))$.

In an auction setting where the firms bids correspond to their R&D expenses, preempting the patent yields a value equal to the difference between the bidder's profit if it wins the auction and its profit if it loses. Finally:

$$V^i = \pi^m(\underline{x}) - \pi^d(\bar{x}, \underline{x}) \text{ for the incumbent monopoly, and}$$

$$V^e = \pi^d(\underline{x}, \bar{x}) \text{ for the challenger}$$

It is then easy to show that $V^i > V^e$ is always true, so that the incumbent systematically preempts the patent. Indeed, the rent dissipation induced by competition necessarily implies that:

$$\pi^m(\underline{x}) > \pi^d(\underline{x}, \bar{x}) + \pi^d(\bar{x}, \underline{x}),$$

$V^i - V^e$ is the measure of this rent dissipation:

$$V^i - V^e = \pi^m(\underline{x}) - [\pi^d(\bar{x}, \underline{x}) + \pi^d(\underline{x}, \bar{x})] > 0$$

It follows directly that $V^i > V^e$.

Gilbert and Newberry show that the incumbent's incentive to develop a non drastic innovation is higher because it can prevent the dissipation of rents through competition. In this setting, the incumbent may even preempt the innovation if it is less efficient in R&D than the entrant. Consider indeed that R&D inefficiency is measured by an extra cost Δ incurred by the incumbent only. As the maximum R&D bid of the challenger

¹Gilbert and Newberry (1982)'s setting may thus also include product innovation, while Arrow's model was only about process innovations. For simplicity, we however keep considering process innovations here.

is $V^e = \pi^d(\underline{x}, \bar{x})$, the incumbent is still able to preempt the patent by bidding $V^e + \Delta$ provided that $\Delta < V^i - V^e$ holds. The persistence of monopoly is then socially inefficient in two ways: it maintains market powers, and it induces inefficient R&D investments.

By suggesting that patents rather favour the persistence of monopoly, Gilbert and Newberry's result contradicts Arrow (1962)'s conclusion of . It is refined by Chen (2000) who shows that the incentive to preempt a new product actually depends on whether this innovation and the product initially sold by the incumbent are strategic complements or substitutes. The incumbent is more likely to preempt and to dominate both products if they are strategic complements. Conversely, the entrant has more incentive to win the auction if the products are strategic substitutes. Note also that Gilbert and Newberry (1962)'s results do not hold for drastic innovations, because such innovations increase the total industry profits. In their framework, the incumbent and its challenger become symmetric: both earn $\pi^m(\underline{x})$ in case they patent, and nothing otherwise. Thus $V^i = V^e = \pi^m(\underline{x})$, so that the incumbent and the entrant have the same incentives to innovate.

3.1.3 The incumbent's dilemma

The incumbent's preemption strategy highlighted by Gilbert and Newberry (1982) strongly relies on their bidding model. Indeed, such a setting does not capture the uncertainty inherent to R&D. It supposes implicitly that innovation is immediate and that the innovator is always the firm that invests more in R&D. A more realistic model should also take into account that the R&D investment outcome is stochastic, so that the smaller bidder may nevertheless win the patent race. Reinganum (1983, 1985) has developed such models, in which the firms' R&D investments determine both the probabilities of winning the race,

and the time when the innovation will be achieved. By contrast with Gilbert and Newberry (1982)'s model, this setting implies that firms care about how R&D investments affects their profits in the period preceding the innovation. What is at stake now is not only who will win or lose the patent race, but also how long the initial profits will last until one firm innovates.

Introducing stochastic R&D is nearly neutral for the new entrant, because it will make a profit only if it wins the patent race. Therefore the single difference with the model of Gilbert and Newberry is that the entrant can try to shorten the race by investing more in R&D. Stochastic innovation is however more problematic for the incumbent firm. As it already makes a profit $\pi^m(\underline{x})$ before the innovation has been achieved, the incumbent faces a trade-off between increasing the probability to win the race by investing more in R&D, and jeopardizing its current profits by accelerating the race. This trade-off echoes Arrow's model in which the incumbent has a lower incentive to innovate because its benefit from innovation is only incremental. So that Reinganum's models reconcile the diverging contributions of Arrow (1962) and Gilbert and Newberry (1982).

	- <i>Size of innovation</i> +	
	<i>Non drastic</i>	<i>Drastic</i>
<i>winner vs statu quo (Arrow, 1962)</i>	Entrant prevails	Entrant prevails
<i>winner vs loser (Gilbert & Newberry, 1982)</i>	Incumbent prevails	Neutral
<i>stochastic R&D (Reinganum, 1983)</i>	Incumbent prevails	Entrant prevails

Table 3.1: Exclusive patents and persistence of the incumbent: summary of the results

Their results are summarized in the table above. In Gilbert and Newberry (1982)'s model the incumbent and the entrant have equal incentives to develop a drastic innovation. It is therefore not surprising that with stochastic innovation the incumbent's additional

incentive to slow down the race finally results in higher incentives to invest for the entrant than for the incumbent. Furthermore Reinganum shows that the entrant keeps investing more in R&D for non drastic innovations when they are valuable enough. In case innovation by the entrant would result in a duopoly competition, she indeed shows that which firm invests more depends on the market share conquered by the entrant. She shows the existence of a threshold of expected market share above which the entrant invests more in R&D than the incumbent. And conversely the incumbent is more likely to preempt the non drastic innovations that would capture a market share below this threshold. So that preemption prevails for minor innovations only. In that way, Arrow's initial intuition is upheld despite the validity of Gilbert and Newberry's critics: the exclusivity created by patents tends to promote innovation by entrants rather than by incumbents².

Some authors also discuss Reinganum's assumption on the R&D technology. While Reinganum uses a neutral and memoryless Poisson model to capture the stochastic R&D process, Harris & Vickers (1985a,b) and Lippman and McCardle (1987) argue that the incumbent firm may actually have some knowledge advantages over its competitor. By signaling that it is more likely to win the race, the incumbent firm could then have the challenger drop out.

3.1.4 Conclusion and comments

I can conclude from this discussion that the exclusivity created by patents rather favours innovation by new entrants. Bearing aside a better innovation capability that may

²While her 1983 model focuses on process innovations only, Reinganum (1985) shows that it can also be extended to product innovations, provided the new products capture a sufficiently large market share. Otherwise, a closer competition between the former and the new products requires introducing product differentiation in the models. And the results then become difficult to interpret.

benefit to the incumbent (Harris & Vickers, 1985a,b; Lippman and McCardle, 1987), the main factor behind this result is the business stealing effect. Indeed a new entrant that replaces an incumbent monopoly enjoys both the incremental profit from innovation and part of the incumbent's former profit. This always ensures higher incentives for the entrant when innovation is drastic. And the entrant remains more likely to develop an innovation when it is non drastic but valuable. So that preemption by the incumbent only prevails for patents on small incremental innovations.

This conclusion is upheld if I partly relax the assumption of exclusivity. Indeed the pattern of competition between the incumbent and a new technological leader could be extended to several new entrants with different innovations. Then there are different opportunities to innovate, and a challenger's incentive to invest in one innovation depends on how many innovations are preempted by the incumbent. Several authors explore this situation and show that it finally favours the erosion of the incumbent's market power (Lewis, 1993; Kamien & Zang, 1990; Krishna, 1993). In particular, Krishna (1993) develops a model where an incumbent monopoly and an entrant bid for units of capacity - equivalent to non drastic innovations - that come sequentially. He shows that the preemption of a unit of capacity by the incumbent makes the following units all the more attractive for a new entrant. As a result the incumbent has fewer chances to persist when several threats of entry come sequentially.

A recent empirical test realized on German manufacturing firms from 1992 to 1995 confirms that challengers invest more into R&D to enter a new market than incumbents do (Czarnitzki & Kraft, 2004). The authors do not distinguish between drastic and non

drastic innovations, nor do they derive their study from one particular incumbent/entrant model. Their method consists of testing whether firms undertaking R&D to enter a new market have a higher R&D/sales ratio than firms undertaking R&D to preserve or extend their market share (the incumbents). Their econometric results validate this assumption. Absent any distinction between drastic and non drastic innovations, these 'average' results rather match Reinganum's conclusion that new entrants are more likely to innovate than incumbents. By contrast they rather contradict Gilbert and Newberry prediction that incumbents can preempt non drastic innovations. Czarnitzki & Kraft (2004) obtain another result which upholds Reinganum's synthetic model. Indeed they build a new variable by weighing the "incumbent" dummy variable with the firm's market share. Then they show that this new variable has a significant negative impact on the R&D/sales. Hence the incumbents' incentives to innovate are lower the larger their market share and, conversely, the business stealing effect can explain that new entrants have more incentives to innovate because they can expect to reap the incumbent's business.

3.2 Using patent as a tool for trade

Besides creating exclusivity on a final product market, patents also allow to trade technologies on a specific, upstream market for R&D. Indeed, patents are property rights that can be sold. Furthermore they provide a legal basis for contracting on licensing agreements. In the latter case, exclusive licensing is equivalent to selling the patent: it simply transfers the patent exclusivity. But the patentee can also grant several licenses, which results in relaxing the patent exclusivity by sharing the innovation with other firms. All

these possibilities of technology transfer create strategic opportunities for the patentee. By selling or licensing its patent, an innovator can modify the structure of the product market. I show in this part that such possibilities may facilitate the persistence of dominant firms when innovations are not drastic.

A patentee and a licensee will strike a licensing agreement if this transaction is profitable for both. This actually requires that the transaction increases the contracting parties' total surplus and that they can share this surplus in a way that makes it profitable for both.

In this perspective, I review several ways by which a dominant firm can trade patents to stay in place when innovations are non-drastring. A first direct way is for an incumbent monopoly to buy the new entrant's patent (Salant, 1984). Conversely, and more surprisingly, the incumbent monopoly can also license its own patent to select its future competitors (Rockett, 1990). A similar licensing strategy can be used by the leader in an asymmetric duopoly. Although it is not directly profitable to grant a license to a weak challenger (Katz and Shapiro, 1985), it may be a way to avoid a patent race and thereby to limit the risk of being replaced if the follower innovates (Gallini, 1984; Gallini & Winter, 1985).

3.2.1 Buying the entrant's patent

A first way for an incumbent monopoly to persist is merely to buy its challenger's innovation ex post. This strategy is described by Salant (1984) in a comment on Gilbert and Newberry's (1982) model. Salant shows that once a new entrant has patented a non drastic innovation, the former monopoly is still able to buy this patent or - which is equivalent

- an exclusive license on this patent. Consistently with Gilbert and Newberry (1982)'s argument, the entrant can indeed increase its profit by selling its innovation because the monopoly resulting from the transaction yields higher industry profits than the former duopoly. Using the previous notations about Gilbert and Newberry's (1982) model, the incumbent can buy the patent ex post at a price V such that

$$\pi^d(\underline{x}, \bar{x}) < V < \pi^m(\underline{x}) - \pi^d(\bar{x}, \underline{x})$$

This result is stronger than Gilbert and Newberry (1982)'s result in that it does not require the assumption of deterministic innovation. Indeed the competitors bid to buy an asset - the patent - that does already exist. They do not bid ex ante for an innovation that does not exist yet, like in Gilbert and Newberry's model.

Such a deal may however yield transaction costs, which I denote by T . In this case the surplus S from trading the patent corresponds to the difference between monopoly and duopoly industry profits, minus the transaction costs:

$$S = \pi^m(\underline{x}) - [\pi^d(\bar{x}, \underline{x}) + \pi^d(\underline{x}, \bar{x})] - T$$

Salant shows that the incumbent's choice between preempting the innovation and buying the patent ex post depends on the comparison between the transaction cost T , and the incumbent's eventual R&D inefficiency, which is measured by an additional R&D cost Δ incurred by the incumbent only. Indeed the incumbent chooses a preemption strategy if $\Delta < T$, which includes the particular case where the incumbent and the challenger have the same R&D technology (so that $\Delta = 0$). However Salant argues that in most cases the incumbent's R&D disadvantage is larger than the transaction cost of transferring the patent. So that one can expect the incumbent to buy the entrant's patent ex post rather

than investing in R&D ex ante.

This strategy has an important implication on the efficiency of R&D. By contrast with Gilbert and Newberry's initial result, the least efficient firm - the incumbent - does not invest in R&D and the innovation is developed by the most efficient firm - the challenger. One can thus still expect new entrants to invest more in R&D than the incumbents, yet without jeopardizing the persistence of the incumbent monopoly. So that empirical evidence that challengers invest more in R&D (Czarnitzki & Kraft, 2004) does not contradict the persistence of monopoly.

In a reply to Salant, Gilbert and Newberry (1984) argue that instead of buying the entrant's patent, the incumbent could as well negotiate ex ante - in markets for R&D inputs - with a more efficient challenger. They show that the incumbent's optimal strategy depends on the relative transaction costs of the ex ante and ex post negotiation strategies. This argument limits the scope of the patent trading strategy. I can however expect the transaction costs to be higher ex ante than ex post, because there is much more uncertainty and asymmetric information before the R&D investments have been undertaken. Therefore the ex post strategy is more likely to prevail.³

Note finally that Salant's argument about preemption has the same weakness as Gilbert and Newberry (1983)'s one when there are more than one potential entrant. As I have explained while discussing the effect of patent exclusivity, different models indeed show that such a setting favours the erosion of the incumbent's market power (Krishna, 1993),

³Another remark of Gilbert and Newberry (1984) should be noticed. They argue that any bargaining solution could end up indifferently with either the incumbent or the challenger remaining alone on the product market, and transferring part of its profit to the other firm. Though the identity of the monopoly may change, this does not affect the impact of patent trading on market structure, namely the persistence of "a" monopoly.

by making it more difficult for the incumbent to suppress all the competitive threats. The persistence of monopoly may however be easier in that the incumbent just has to buy those innovations that are actually patented, instead of preempting all potential innovations.

3.2.2 Choosing the next competitor

Besides buying the entrant's patent, the incumbent can also sell its own intellectual property to its challenger. Paradoxically, such a strategy may indeed be a way for a dominant firm to persist. Rockett (1990) gives a first example of this in the case of an incumbent monopoly expecting the entry of a new competitor when its patent ends up. She indeed shows that the incumbent monopoly can use licensing to select a weak competitor for the time after the patent has expired.

She builds a model with two periods - before and after the monopoly's patent expires - and assumes that in the first period the incumbent is able to set a licensing contract such that it can (i) keep earning the whole monopoly profit in period 1 and (ii) draw the licensee's profit of period 2. Hence licensing is neutral in period 1. It only matters in the second period, as it affects the conditions of entry for new competitors.

Rockett assumes that there are two potential entrants, a strong one and a weak one, with symmetric entry costs. Absent any licensing contract in the first period, the strongest firm enters first and the weak one stays out. However, the incumbent can grant a license to the weak firm during the first period. Then the resulting transfer of know how reduces the licensee's entry cost, and allows it to enter first in the second period. As a result the strong firm stays out and the former monopoly faces a weaker competitor in the second period.

Rockett shows that such a strategy is possible only if several cumulative conditions are met. Firstly, the total industry profit should be higher when the weak firm is active than when the strong one is active. Otherwise it would be more profitable for the incumbent to select the strong firm. Second, the industry must support only a limited number of firms. Indeed, facilitating the entry of a weak competitor would be worthless if the strong firm would nevertheless enter in period 2. Third, the incumbent must care sufficiently about its future profits to justify the short-run sacrifice that licensing entails. Although Rockett's model does not capture it, it is an important factor which may vary upon different industries. These conditions allow to identify industries in which such licensing strategies are likely. In particular, Rockett gives three examples from chemicals - namely polyester, cellophane, and nylon - in which Du Pont, in the role of the incumbent, has licensed its basic patents to a weak partner in order to increase the industry capacity and thereby deter the entry of more aggressive competitors.

As stated by Rockett (1990), another version of this licensing strategy consists in licensing a patent to avoid the risk of losing an infringement suit. Here the problem of the incumbent monopoly is still to limit the entry of strong competitors. But the threat of entry comes from the patent invalidation by a court, not from its natural expiration. Following Rockett's insight, the incumbent could thus prevent the first infringement by crowding the market with low royalties licensing contracts⁴.

⁴Choi (1998) has developed a similar argument. In his model, the patentee does however not grant a license to the first infringer. It simply does not sue it for infringement, in order not to risk to reveal the actual weakness of its patent to other potential entrants. The incumbent can thereby keep on benefiting from asymmetries of information about its patent's strength. An additional difference with the licensing strategy evidenced by Rockett (1990) is here that in Choi's model, the patentee cannot choose its infringer.

3.2.3 Licensing to followers

Before examining how licensing can be a strategy for a dominant firm to persist, I shall review as a first step what are the general incentives for such a dominant firm to license its leading technology. The most intuitive way of contracting on a license is when the patentee shares its technology so as to improve the industry efficiency. However such a transaction may not be profitable for the patentee, especially if it is a dominant firm facing a challenger. This point is made by Katz and Shapiro (1985). They focus on an asymmetric duopoly with homogenous products, and assume that the firms initially have different production costs. By considering that one of the firms holds a patent on the lowest cost technology, they can study the leader's incentives to license this patent to the follower. The leader has to trade-off the license revenue with the loss of its competitive cost advantage.

Katz and Shapiro (1985) distinguish two types of contract. First, they show that the leader can always draw a net benefit from licensing if it can set a complex licensing contract comprising both variable royalties and a fixed fee. Indeed such contracts allow the licensor (i) to control the price set by its competitor and (ii) to appropriate the whole industry surplus from licensing. If variable royalties cannot be enforced, they however show that the set of profitable licensing contracts is limited to some small innovations. This is so because pure fixed fees do not allow the licensor to monitor the price set by the licensee, nor to appropriate the whole surplus from the contract. Then the fixed license fee has to outweigh the profit loss due to additional price competition for the licensing contract to be profitable. This is possible only if licensing the efficient technology increases the total industry profits. Katz and Shapiro show that this condition is met when the two firms are

nearly symmetric, on condition that the industry marginal revenue curve is downward sloping at the equilibrium level of total output. Otherwise fixed fee licenses cannot increase the total industry profits, so that the leader chooses to exclude the follower from its technology. This is therefore consistent with Gilbert and Newberry (1982)'s preemption result.

Katz and Shapiro (1985)'s model is useful to identify the incentives to license in static, asymmetric competition. They however do not really take into account the dynamic nature of innovation, and how licensing may affect it. Gallini (1984) and Gallini and Winter (1985) bridge the gap by focusing on a dynamic competition between a technological leader and a follower, where innovations consist of cost reductions. Gallini (1984) can thereby shed light on a specific incentive for the leader to license its technology, which is to slow down the R&D race between the two firms by reducing the follower's incentive to innovate. Indeed the follower's incentive to catch up is higher the broader the technologic gap with the leader, and the threat of innovation by the follower in turn pushes the leader to invest in R&D to keep its leading position. In Gallini's 1984 model, the leader can transfer part of its monopoly profit to the follower through a cooperative licensing contract with a fixed fee. As a result the follower has less incentive to develop a new innovation. So that, in counterpart to this lost profit, the leader can save the R&D cost that would have been necessary to keep up in a patent race for the next innovation.

While Gallini (1984) obtains this result for particular cases of R&D competition between an incumbent monopoly and a new entrant, Gallini and Winter (1985) generalize it into an asymmetric duopoly competition in which a leader licenses its patent to a follower for per unit royalties. They consider two types of licensing contracts, with per unit royalties in

each case. First, the firms can strike a licensing agreement before investing in R&D. Under this ex ante agreement, the contractors agree that the firm with the best ex ante technology will license it to its competitor. The per unit royalty paid by the licensee is then equal to the difference between the ex ante unit costs of the firms. Gallini and Winter furthermore introduce the possibility for the firms to strike a licensing agreement after one of them has become the leader by developing a new technology. This form of ex post licensing is close to the one studied by Katz and Shapiro (1985). The licensor sets a royalty equal to the difference between the firms' per unit costs, so as to keep the market price constant. Thus, in accordance with Katz and Shapiro (1985)'s prediction, the firms always strike an ex post agreement.

Gallini and Winter (1985) show that ex post agreements increase the firms' incentives to innovate. It is so because licensing generalizes to both competitors the use of the best technology, which benefits to the licensor. The profit from licensing is then higher the closer the firms' initial costs. By contrast, a follower with a large initial cost disadvantage cannot expect an important royalty revenue if it innovates, because it is unlikely that its innovation leapfrogs significantly the leader's technology.

In turn, Gallini and Winter find that the firms will sign an ex ante agreement if their initial costs are sufficiently asymmetric. Then the firms do not invest in R&D, so that ex ante licensing actually suppresses the R&D race between a weak follower trying to catch up and a leader replying by investing more in R&D. These results thus clarify how the insights of Katz and Shapiro (1985) and Gallini (1984) articulate. In an asymmetric duopoly, how licensing affects innovation depends on the initial production costs. The prospect of

licensing the most efficient technology increases the firms' incentives to innovate when their costs are initially symmetric. While when the initial costs are asymmetric, the leader has a strong incentive to license so as to suppress the R&D competition and, thereby, to persist. In this way, patent licensing finally favours both the creation of technological leader (when there is a neck and neck competition initially) and their persistence (by limiting the R&D competition).

3.2.4 Conclusion

Whereas focusing on patent exclusivity suggests that challengers are more likely to innovate than incumbent monopolies, introducing the possibility of trading this exclusivity on a market for R&D balances this conclusion as regards non drastic innovations. Technological leaders can preserve their monopoly by buying patents on innovations that have been developed by new entrants (Salant, 1984). They can also license their own patents to select a weak competitor for the period after these patents expire (Rockett, 1990). They can at last prevent patent races by licensing their patents to their challengers (Gallini, 1984; Gallini & Winter, 1985), and thereby preserve their technological leadership. In all cases trading technology thanks to patents facilitates the persistence of monopoly.

An important remark must be noticed here. Indeed, the persistence of monopoly thanks to patent trading does not reverse the respective incentives to innovate of the challenger and the incumbent. The incumbent can buy the entrant's patent precisely because it can propose a price that is higher than the innovation entrant's market profit. And the possibility to buy patents ex post may furthermore reduce the incumbent's incentive to innovate. Also, sharing the leading technology with the challengers simply reduces these

incentives for both competitors, but it does not reverse the follower's higher incentive to innovate and catch up. Thus the theoretical results on patent trading strategies do not contradict Czarnitzki & Kraft (2004)'s empirical finding that entrants invest more in R&D than incumbents. Simply, this finding does not necessarily imply that dominant firms will not persist.

3.3 Leveraging cumulative patents

Instead of one single patent, an innovation is often protected by a bundle of patents. It is especially true in industries like semi-conductors, software or biotechnologies, where innovations are strongly cumulative. This situation is similar to the "single patent" one in so far as all patents belong to the same innovator. It however raises specific issues when a single innovation is based on several patents owned by different firms. The firms that operate on the product market have then to buy all the licenses that they need on the market for R&D. Even when they hold their own patents, they may have to engage into cross-licensing strategies in order to secure an access to their competitors' blocking patents. In this context, holding blocking patents may be a very effective way for a dominant firm to stay in place. I show as a first step that the important literature on cumulative innovation provides important arguments in this way. In particular, it appears that patents on cumulative innovation can protect an incumbent even against drastic innovations. As a second step, I review the empirical literature on patent portfolio strategies, to show that they uphold and extend the theoretical predictions on the persistence of monopoly. Then I come back to the theoretic literature to investigate how dominant firms can trade licenses

or patents on cumulative innovations to persist.

3.3.1 Cumulative patents as barriers to entry: theoretical elements

Several papers on cumulative innovations consider the case where one challenger innovates upon a basic patent owned by an incumbent monopoly (Green & Scotchmer, 1995; Van Dijk, 1998; Denicollo, 2000). Obviously, a monopoly will persist if the entrant's innovation infringes the incumbent's patent, be this innovation drastic or not. The entrant's incentives to innovate will then depend on how its own innovation is protected.

If the subsequent innovation is not patentable, the incumbent can claim exclusivity on it, which totally deters the entrant from investing in R&D. If the innovation is patentable, both the entrant and the incumbent have a right on it, and they have to bargain. The incumbent can then use its initial monopoly as a threatpoint in the negotiation. So that the entrant's profit is only a fraction α of the remaining surplus $\pi^m(\underline{x}) - \pi^m(\bar{x})$. In this way, cumulative patents suppress the profit from business stealing, be the innovation drastic or not. They even reduce the entrant's incentive to innovate below the actual incremental value of the innovation. This may eventually deter the entrant from developing some valuable innovations which costs c verifies $\alpha [\pi^m(\underline{x}) - \pi^m(\bar{x})] < c < \pi^m(\underline{x}) - \pi^m(\bar{x})$ (Green & Scotchmer, 1995). From a complete welfare viewpoint, this under-incentive to innovate may however be efficient if several entrants run a patent race for the cumulative innovation (Denicollo, 2000). Indeed it will limit the entrants' excessive investments in R&D.

Green and Scotchmer (1995) argue that the incumbent can both persist and monitor the entrant's incentive to innovate by signing an ex ante agreement with the entrant.

In this case, the entrant invests only after the agreement has been signed, and its incentive to innovate is a fraction α of the incremental surplus $\pi^m(\underline{x}) - \pi^m(\bar{x}) - c$. If the transaction costs are not too high, such agreements therefore permit that any valuable innovation be developed, and that the incentives to develop it be in line with the incumbent's profits.

3.3.2 Patent portfolios as barriers to entry: empirical elements

The empirical literature confirms that the accumulation of cumulative patents by dominant firms creates barriers to entry. Lerner (1995) shows for example that new U.S. biotechnology firms with high costs of litigation generally avoid to invest in the technological areas where other firms already have patents.

The actual contrast between the numerous patents that a dominant firm is able to accumulate and the narrow patent portfolio of new entrants accentuates the theoretic conclusions mentioned above. Lanjouw and Schankerman (2001, 2004) find that a patent holder has a greater incentive to sue a competitor for infringement if it can thereby build a reputation vis-à-vis other innovators. This finding sheds light on an important asymmetry between incumbent firms and new entrants. Indeed large firms with important portfolios have an additional incentive to have an aggressive patent strategy vis-à-vis potential infringers, because it sends a signal to the other entrants who may infringe any patent of this portfolio. By contrast, a new entrant with a narrow portfolio will have fewer opportunities to leverage a reputation of tough litigator in other patent trials.

When several firms have built large patent portfolios, the new products infringe a large number of patents (Cohen, Nelson & Walsh, 2000) and the competitors may have to cross-license their patents. In such cases, the firms may engage into strategic patenting to

block their competitors and use their patents as bargaining chips. This reinforces the entry barriers for new competitors because the firms have to invest in such a patent portfolio prior to settling cross-licensing agreements (Barton, 2002; FTC, 2003). Hall and Ziedonis (2001) explore these mechanisms in the case of the U.S. semiconductor industry between 1975 and 1996. They show that the firms have doubled their patent propensity - e.g. the number of patents per million dollar of R&D - over the period in order to build patent portfolios. One result of this strategy is that new entrants in the industry have to spend \$100 millions to \$200 millions to buy licenses on second order patents. These entry barriers finally favour a vertical division of the industry, where some firms specialize in upstream R&D and license their innovations to the large manufacturing firms (Hall and Ziedonis, 2001).

Graham and Mowery (2003) obtain similar results regarding the software industry. They show that the patent propensities of the largest U.S. software firms has significantly increased between 1990 and 1997. They also compare, during the same period, the patent propensities of the firms that they consider respectively as entrants and incumbents. The resulting graph is reproduced below. It suggests that software patentability has more benefited to the first generation of innovators, who have accumulated patent portfolios that may now deter the entry of new competitors. Indeed, the incumbents' patent propensity is steadily increasing while the entrants' propensity is unchanged or even decreasing between 1992 and 1994.

3.3.3 Contracting on cumulative innovations

The generalization of cross-licensing strategies that can be observed in some industries justifies further comments on the licensing contracts based on cumulative patents. Van

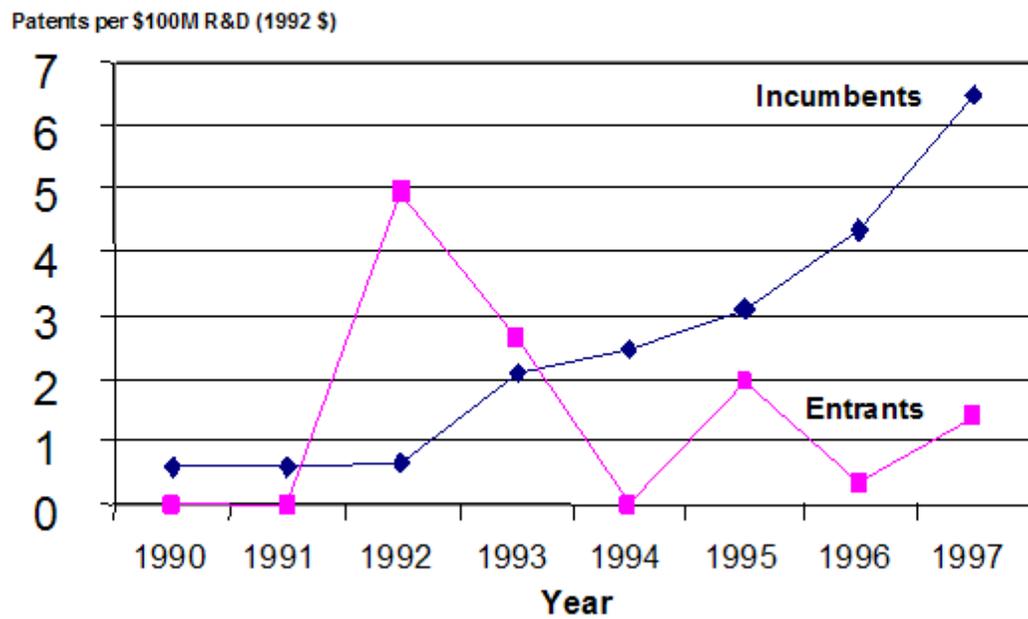


Figure 3.1: Patent propensities of software "Incumbents" and "Entrants" (source: Graham and Mowery, 2003)

Dijk (1998) focuses on the grantback clauses that may be added to a licensing contract by which an incumbent monopoly shares its technology with a challenger. Such clauses require the licensee to license back improvements upon the licensor's patent. The contract described by Van Dijk (1998) introduces on the one hand a new competitor on the product market, which reduces the incumbent's profit market. On the other hand, it reduces the challenger's incentives to innovate. Van Dijk first shows that a simple license without grantback clause is profitable for the incumbent if the two firms' goods are sufficiently differentiated for the licensing contract to enlarge the market. In this case, the entrant's incentive to innovate is reduced because the replacement effect partly disappears. Van Dijk however finds that the firms' R&D investments are excessive because they engage in a patent race for the next innovation. As a second step he introduces a grantback clause that compels the licensee to license back any improvement to the licensor. He shows that this clause reduces the entrant's incentives to innovate by suppressing the exclusivity on the R&D output. As a result the firms invest less in R&D, although there may still be overinvestment in some cases. Finally, Van Dijk analyses mutual exchange clause, by which each firm accepts to license any improvement to each other. This clause totally suppresses the exclusivity on innovation. As a result, the patent race totally disappears and the firms under-invest in R&D. Van Dijk (1998)'s model is therefore comparable to Gallini (1984) and Gallini and Winter (1985). By licensing its technology to the challenger, the leader can indeed preserve its position and compensate lower market profits with reduced R&D investments. Van Dijk however shows that the cumulative nature of innovation reinforces the negative effect of licensing. Cumulative patents offer the legal basis to clauses that suppress the protection of

subsequent innovations, and thereby comfort the initial leader.

3.3.4 Buying upstream patents

Blocking subsequent innovations or contracting on them is an effective way for a dominant firm to persist, provided this firm owns the required patent. If the dominant firm has not patented the upstream innovation, it still has the possibility to buy it on the market for R&D. This possibility has not been discussed extensively in the economic literature. Before exploring it further in the next chapter, I mention here an isolated and interesting contribution. Yi (1995) shows indeed that if a downstream innovation is enabled by an upstream patent, an incumbent monopoly is able to preempt this patent even if it has not developed it by itself.

To demonstrate this, Yi (1995) transposes Reinganum (1983)'s model into a cumulative context. Recall that in Reinganum' model the two firms engage into a patent race with stochastic R&D technology. Each firm has the same R&D technology and the final innovation may be drastic or not. The incumbent has a specific incentive to delay the innovation so as to preserve its initial monopoly position. As a result, the incumbent invests less in R&D, and the entrant is generally more likely to win the race. Yi (1995)'s model is different in that only the incumbent has a R&D technology at the beginning of the game. To enter the patent race, the entrant has to buy its own R&D technology. Yi furthermore assumes that a patent on a R&D technology is auctioned by a research lab. This technology, which is as efficient as the incumbent's one, introduces a cumulative aspect in Reinganum (1983)'s model. The technology auctioned by the research lab can indeed be interpreted as a research tool, which enables innovation downstream. In Yi (1995)'s model,

the upstream patent is however not blocking. Both available R&D technologies enable the same downstream innovation, which does not infringe any upstream patent.

Yi shows that in this setting the incumbent will always buy the auctioned patent. By keeping the exclusivity on both R&D technologies, the incumbent can indeed maximize the industry profit, and thus propose the highest bid. This is so because the incumbent anticipates only the incremental profit from innovation, so that its R&D investments are optimal for the industry. If, by contrast, the entrant had the R&D technology, the business stealing effect would induce it to invest excessively. And the resulting patent race would reduce the industry profit. Yi (1995) reports that the same result holds true if initially the incumbent has no R&D technology. Even in this case, only the incumbent invests so as to maximize the industry profits.

Yi (1995) can thus reverse Reinganum's result by introducing an initial auction for the R&D technology. Upstream preemption by the incumbent happens even if the innovation is drastic, while Reinganum predicts that the entrant is more likely to prevail. This result therefore emphasizes again the power of patent trading as a means to persist. By enabling negotiated agreements, patents open the way to solutions that maximize the joint surplus of the negotiators. If the negotiation takes place sufficiently early for patent races and business stealing effects to be internalized, then the persistence of monopoly emerges as the natural solution to maximize the industry profits.

3.3.5 Conclusion on blocking patents

Focusing on cumulative technologies reveals that patents strongly protect the incumbent and may seriously weaken the entrant's incentives to innovate. Cumulative patents

allow an incumbent monopoly to block entry even to a drastic innovation. They provide their holders with a legal instrument that allow them either to exclude or control the entrants, so as to align their incentives with their own goals. All these possibilities explain that in industries like semi-conductors or software, the dominant firms have built large patent portfolios, thereby raising barriers to the entry of new competitors. In comparison with the mere strategic use of patents on the market for R&D, the use of cumulative patents by dominant firms reduces further the entrants' incentives to innovate. These incentives may indeed shift below the innovation's incremental profit for the incumbent, therefore reversing the conclusion of the first part in some industries. Similar results may be obtained even if the incumbent does not own an upstream patent initially. Yi (1995) indeed shows that an incumbent is able to preempt a research tool on a drastic innovation, precisely because it can internalize the business stealing effect, and therefore ensure that R&D investments maximize the downstream industry profit.

3.4 Conclusion

Focusing on patent strategies opens a rich and insightful perspective on the relation between innovation and monopoly persistence. In particular, patents allow an incumbent monopoly or a technological leader to preserve its position in the market.

I have first shown that focusing on the exclusivity conferred by patents on a product market leads to the conclusion that an entrant generally has more incentives to innovate than an incumbent monopoly. Indeed, the challengers always have greater incentives to innovate than the incumbent firms, excepted for low value, non-drastic innovations (Reinganum,

1983).

I have however argued in the following parts that this result must be taken cautiously. An effective way to persist is for the incumbent to use patents as tools for trading technology. The incumbent can buy the patent on its challenger's innovation (Salant, 1984). It can also use a license to select a weak competitor for the time after the patent has expired. The technological leader can finally license its technology to its challenger so as to slow down the R&D race (Gallini, 1984; Gallini & Wright, 1985). All these cases show that the incumbent firm can finally lessen or prevent the threat of non-drastic innovations, but not drastic ones. It can furthermore reduce the entrants' incentives to innovate, but not eliminate their superior incentives to innovate.

Cumulative innovations create another set of strategies for the incumbent. Blocking patents may ensure the persistence of a monopoly even against a subsequent drastic innovation. Their multiplication and aggregation make it more costly and less profitable for new entrants to innovate. More generally, empirical works emphasize how the generalization of strategic patent portfolios and their cross-licensing between competitors create barriers to the entry of new innovators. In this case, the entrants' incentives to innovate are further reduced so that dominant firms may finally end up with superior incentives. Then patents not only favour the persistence of dominant firms, but also eliminate the replacement effect which Arrow (1962), echoing Schumpeter (1934)'s "destructive creation", describes as one engine of the innovation.

Chapter 4

Cumulative Patents, drastic Innovation and the Persistence of Monopoly

In this section, I develop a model showing how an incumbent monopoly can leverage its initial position to buy a basic patent that could otherwise enable a challenger to develop a cumulative and drastic innovation. I present the model in a first part. Then I solve it and discuss in a third part its effect on the incentives for R&D firms to develop basic innovations. I conclude by discussing the contribution of the model to the literature on the persistence of monopoly.

4.1 The model

I consider a drastic innovation that can be achieved and patented by either an incumbent monopoly or a new entrant. I furthermore suppose that this innovation is cumulative in that it builds upon a first basic innovation. That upstream innovation is patented too. It belongs to a third firm specialized in R&D that therefore holds a right on the subsequent drastic innovation. As both upstream and downstream patents confer a right on the drastic innovation, the agreement of each patent owner is required to use it. Put differently, each patent owner has the possibility to block the use of the drastic innovation. The motives of the patent owners however differ. In this context, the incumbent's initial profit confers him an interesting bargaining position, while a new entrant makes zero profit if she cannot use the drastic innovation.

Let M denote the incumbent monopoly. Given its variable cost \bar{x} , M sets a monopoly price $p^m(\bar{x})$ and makes a profit $\pi(\bar{x})$. The upstream R&D firm is denoted by R . The basic patent owned by R enables the achievement of a downstream patentable innovation that would reduce the variable cost from \bar{x} to \underline{x} , with $p^m(\underline{x}) < \bar{x}$ (the innovation is drastic). For simplicity, I will note $\pi = \pi(\bar{x})$ and use the parameter $\alpha > 1$ such that $\pi(\underline{x}) = \alpha\pi$.

I assume that R is specialized in basic research and that it does not have the capacity to develop itself the downstream innovation. Only the incumbent M or a potential entrant E have the capability to do it, each at a fixed cost c . Therefore, R has to transfer the exclusive right on its basic innovation in order to derive a profit from it. R can decide to do it either ex ante - that is before the cumulative innovation has been achieved - or

ex post - once the downstream innovation has been achieved by M or E . Note that the R&D firm could also strike a contract ex ante with M and E in order to co-ordinate more efficiently the R&D efforts (Scotchmer, 1996). I let this possibility aside for the moment. But I will introduce and analyse the possibility of such ex ante contracts at the end of the Chapter, for some specific subcases.

If R decides not to sell its patent ex ante, it will have to bargain ex post with the owner of the downstream innovation patent. I suppose that R can auction ex ante either the patent itself, or an exclusive license to develop the cumulative innovation - which is actually equivalent. As the investment c necessary to develop the cumulative innovation is fixed and the same for M and E , each of them has a probability $\frac{1}{2}$ to obtain the downstream patent if both invest. Thus the competitors do not bid for the innovation itself - in that matter they decide only to invest c or not. They actually compete for the right to hold it up by controlling the basic patent.

An extensive form of this game is proposed in Figure 4.1. The corresponding timing of the firms' decisions deserves two remarks.

First, the research firm R decides at the very beginning of the game whether to sell its upstream patent ex ante or ex post. Thus, the decision to sell the patent ex ante is irreversible: it is not possible for R to wait and sell the patent ex post in case it is not satisfied with the ex ante bids of M and E . Such a timing implies that M and E do not anticipate the possibility that the patent could be sold ex post when they bid to buy it ex ante. This makes the game clearer in that their bids only reflect the expected profit of owning the upstream patent before investing downstream.

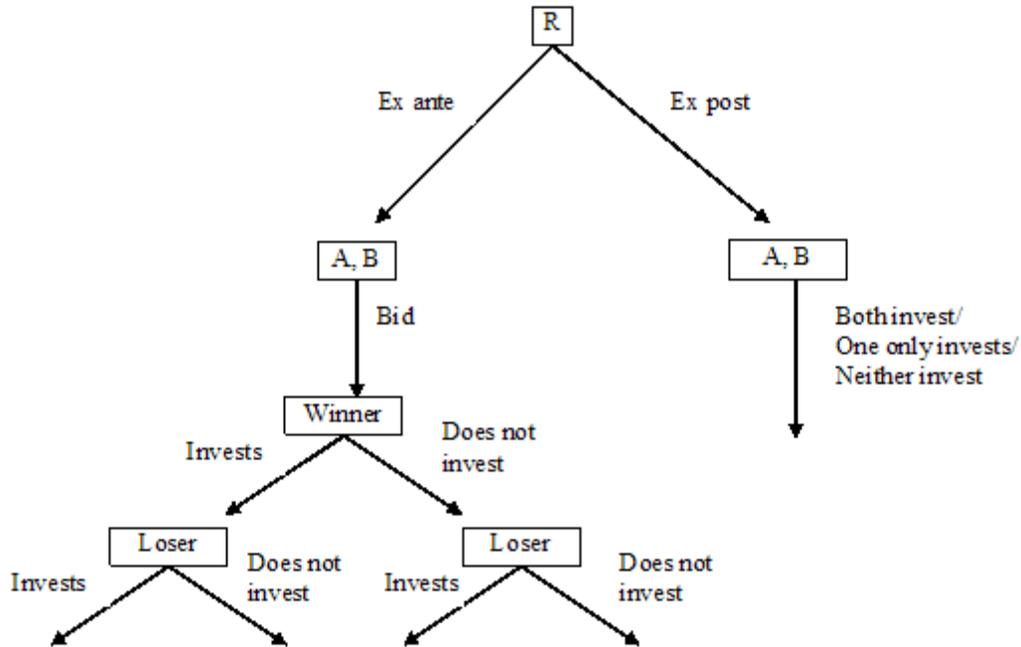


Figure 4.1: Timing of the game

The other remark corresponds to a hypothesis about the investment decisions by M and E once the upstream patent has been sold ex ante. In this case, I consider that the firms do not decide simultaneously whether to invest or not, but that the patent rather confers a first mover position to its buyer. This time order matters when simultaneous decisions would trigger two Nash equilibria in pure strategies. Indeed, the sequentiality of the decisions allows the patent buyer to choose the most favourable Nash equilibrium. The underlying hypothesis is that it is common knowledge among the firms that the patent buyer will choose the strategy corresponding to its most favourable Nash equilibrium.

4.2 Solving the model

I proceed by backward induction to solve the model. I therefore consider first the different subgames where M and E have to decide whether to invest in the downstream innovation or not. In a first case, M has already bought the patent ex ante, while in the second case it is E that has bought it ex ante. The third possible case is when R has decided to not sell its patent ex ante. In all of these subgames, the respective strategies (m_M, m_E) of M and E are the probability that they invest c to try to patent the drastic innovation. If the upstream patent has been sold ex ante, the decisions of the firms are sequential, so that the set of strategies of each firm is $\{0, 1\}$. If the patent is sold ex post, the decisions of the firms are simultaneous. Here the set of strategies of each firm becomes $[0, 1]$ and I must look for all possible Nash equilibria in mixed strategies.

After having identified the Nash equilibria in these subgames, I turn to the decision of R at the beginning of the game, namely whether to sell the patent ex ante or ex post. I need therefore to analyze first which firm of M and E will win the auction in case the patent is sold ex ante, and at which price.

4.2.1 M has bought the patent ex ante

Suppose first that M has bought the upstream patent ex ante at a price p . Each firm can then decide either to invest in the downstream innovation or not.

If both M and E invest c , each of them has a probability $\frac{1}{2}$ to obtain the downstream patent. If M obtains it, it will enjoy the whole profit from the drastic innovation, while E will get zero profit. If E gets the downstream patent, then M and E will have

to bargain in order to use the drastic innovation. I use here the Nash bargaining solution. Thus each of them will add half of the surplus $(\alpha - 1)\pi$ to their respective threat points, that is π for M and 0 for E . Finally the expected profits of M and E in case both invest are respectively $(1 + 3\alpha)\frac{\pi}{4} - c - p$ and $(\alpha - 1)\frac{\pi}{4} - c$.

If only M invests, it surely obtains the downstream patents and enjoys the whole monopoly profit from the drastic innovation, that is $\alpha\pi - c - p$. The expected profit of E is of course 0. The situation is different in case only E invests. Indeed E also gets the downstream patent, but M is then able to use the upstream patent to block it. Thus M and E will have to bargain in order to use the drastic innovation. Each of them will add half of the surplus $(\alpha - 1)\pi$ to their respective threat points, namely to π for M and to 0 for E . Finally the expected profits of M and E if only E invests are respectively $(1 + \alpha)\frac{\pi}{2} - p$ and $(\alpha - 1)\frac{\pi}{2} - c$.

The last possible case is that neither M nor E invests. Then M keeps its former monopoly profit π minus the price of the upstream patent, while E makes zero profit. The resulting expected profits are presented in Table 4.1 below:

	Expected profit of M	Expected profit of E
M and E invest	$(1 + 3\alpha)\frac{\pi}{4} - c - p$	$(\alpha - 1)\frac{\pi}{4} - c$
only M invests	$\alpha\pi - c - p$	0
only E invests	$(1 + \alpha)\frac{\pi}{2} - p$	$(\alpha - 1)\frac{\pi}{2} - c$
no firm invests	$\pi - p$	0

Table 4.1: Expected profits of M and E when M has bought the upstream patent ex ante.

This subgame has three Nash equilibria in pure strategies, depending on the innovation value α and the amount of investment c required to achieve the downstream innovation.

Lemma 4.1 (i) if $c \leq (\alpha - 1) \frac{\pi}{4}$, the single Nash equilibrium is $(1, 1)$

(ii) if $(\alpha - 1) \frac{\pi}{4} \leq c < (\alpha - 1) \pi$, the single Nash equilibrium is $(1, 0)$

(iii) if $(\alpha - 1) \pi \leq c$, the single Nash equilibrium is $(0, 0)$.

Part (i) of Lemma 4.1 shows that both firms invest if $\frac{\pi}{c}$ is greater than $(\alpha - 1)$, which means that the innovation is profitable enough. Below this threshold, firm E does not invest so that M can develop and patent the innovation in a secure position (Part (ii)). This result is due to the assumption that the owner of the upstream patent can play as a first mover in the downstream investment game. In Part (iii), the innovation is not profitable enough even for M to invest downstream alone.

4.2.2 E has bought the patent ex ante

Suppose now that E has bought the upstream patent ex ante at a price p . Each firm can still decide either to invest in the downstream innovation or not.

If both M and E invest c , each of them has a probability $\frac{1}{2}$ to obtain the downstream patent. If E obtains it, it will enjoy the whole profit from the drastic innovation, while M will get zero profit. If M gets the downstream patent, then M and E will have to bargain in order to use the drastic innovation. According the Nash bargaining solution, each of them adds half of the surplus $(\alpha - 1) \pi$ to their respective threat points, that is π for M and 0 for E . Finally the expected profits of M and E in case both invest are respectively $(1 + \alpha) \frac{\pi}{4} - c$ and $(3\alpha - 1) \frac{\pi}{4} - c - p$

If only E invests, it surely obtains the downstream patent and enjoys the whole monopoly profit from the drastic innovation, that is $\alpha\pi - c - p$ - while the expected profit

of M is 0. The situation is different in case only M invests. Indeed E is then able to use the upstream patent to block it. Thus M and E will have to bargain in order to use the drastic innovation. Each of them will add half of the surplus $(\alpha - 1)\pi$ to their respective threat points, that is π for M and 0 for E . Finally the expected profits of M and E if only M invests are respectively $(1 + \alpha)\frac{\pi}{2} - c$ and $(\alpha - 1)\frac{\pi}{2} - p$.

The last possible case is that neither M nor E invests. Then M keeps its former monopoly π , while E makes a loss corresponding to the price p paid for the upstream patent.

The resulting expected profits are presented in Table 4.2 below:

	Expected profit of M	Expected profit of E
M and E invest	$(1 + \alpha)\frac{\pi}{4} - c$	$(3\alpha - 1)\frac{\pi}{4} - c - p$
only M invests	$(1 + \alpha)\frac{\pi}{2} - c$	$(\alpha - 1)\frac{\pi}{2} - p$
only E invests	0	$\alpha\pi - c - p$
no firm invests	π	$-p$

Table 4.2: Expected profits of M and E when E has bought the upstream patent ex ante.

This subgame has three Nash equilibria in pure strategies, depending on the innovation value α and the amount of investment c required to achieve the downstream innovation.

Lemma 4.2 (i) if $c \leq (\alpha + 1)\frac{\pi}{4}$, the single Nash equilibrium is $(1, 1)$

(ii) if $(\alpha + 1)\frac{\pi}{4} \leq c < \alpha\pi$, the single Nash equilibrium is $(0, 1)$

(iii) if $\alpha\pi \leq c$, the single Nash equilibrium is $(0, 0)$.

This Lemma is similar to Lemma 4.1. Indeed both M and E invest if the innovation is profitable enough (i). Below a certain profitability threshold on $\frac{\pi}{c}$, only E invests downstream (Part (ii)). At last part (iii) shows that no firm invests if $\frac{\pi}{c}$ is too low. Con-

trary to Lemma 4.1, it is E and not M that stays alone in some cases, because this time it is E that, as owner of the basic patent, can act as a first mover. The result is however not totally symmetric with Lemma 4.1. Indeed the thresholds on $\frac{\pi}{c}$ are higher in Lemma 4.2 than in Lemma 4.1.

4.2.3 R sells the patent ex post

Suppose finally that R has not sold the upstream patent ex ante. Each firm must decide either to invest in the downstream innovation or not. The eventual owner of the downstream patent will then share equally the innovation profit with firm R .

It is therefore straightforward to derive the firms' expected profits depending on which firms invest downstream. If both firms invest, each firm can get the downstream patent with a probability $\frac{1}{2}$. Thus the expected profits are $(1 + \alpha) \frac{\pi}{4} - c$ for M , $\alpha \frac{\pi}{4} - c$ for E , and $(2\alpha - 1) \frac{\pi}{4}$ for R . If only M (respectively E) invests, the expected profits are $(1 + \alpha) \frac{\pi}{2} - c$ (respectively 0) for M , 0 (respectively $\alpha \frac{\pi}{2} - c$) for E , and $(\alpha - 1) \frac{\pi}{2}$ (respectively $\alpha \frac{\pi}{2}$) for R . If no firm invests, M keeps its former monopoly profit π , while E and R make zero profit.

These expected profits are presented in Table 4.3:

	Expected profit of M	Expected profit of E	Expected profit of R
M and E invest	$(1 + \alpha) \frac{\pi}{4} - c$	$\alpha \frac{\pi}{4} - c$	$(2\alpha - 1) \frac{\pi}{4}$
only M invests	$(1 + \alpha) \frac{\pi}{2} - c$	0	$(\alpha - 1) \frac{\pi}{2}$
only E invests	0	$\alpha \frac{\pi}{2} - c$	$\alpha \frac{\pi}{2}$
no firm invests	π	0	0

Table 4.3: Expected profits of M , E and R when the upstream patent is sold ex post.

Contrary to the subgames considered previously, this subgame is simultaneous.

Therefore I will look here for the Nash equilibria in mixed strategies.

Lemma 4.3 (i) if $c < \alpha \frac{\pi}{4}$, the single Nash equilibrium is $(1, 1)$

(ii) if $Max \left\{ \alpha \frac{\pi}{4}; (\alpha - 1) \frac{\pi}{2} \right\} \leq c < (\alpha + 1) \frac{\pi}{4}$, the single Nash equilibrium (in mixed strategies) is $\left(2 - \frac{4c}{\alpha\pi}, \frac{2(1-\alpha)\pi+4c}{(3-\alpha)\pi} \right) \equiv (m_M^*, m_E^*)$

(iii) if $\alpha \frac{\pi}{4} \leq c < Min \left\{ (\alpha - 1) \frac{\pi}{2}; (\alpha + 1) \frac{\pi}{4} \right\}$, the single Nash equilibrium is $(1, 0)$

(iv) if $Max \left\{ (\alpha + 1) \frac{\pi}{4}; (\alpha - 1) \frac{\pi}{2} \right\} \leq c < \alpha \frac{\pi}{2}$, the single Nash equilibrium is $(0, 1)$

(v) if $(\alpha + 1) \frac{\pi}{4} \leq c < \alpha \frac{\pi}{2}$, there are two Nash equilibria in pure strategies and one Nash equilibrium in mixed strategies, namely $(1, 0)$, $(0, 1)$, and $\left(2 - \frac{4c}{\alpha\pi}, \frac{2(1-\alpha)\pi+4c}{(3-\alpha)\pi} \right) = (m_M^*, m_E^*)$

(vi) if $\alpha \frac{\pi}{2} \leq c$, the single Nash equilibrium is $(0, 0)$.

4.3 First node

I resolve now the model at its first node. In order to identify the research firm's decision to sell its patent ex ante or ex post, I must compare its expected profits in both cases. Therefore I need to determine first which firm will win the auction in case the patent is sold ex ante, and at which price. As the patent is auctioned, the willingness to pay of M (respectively of E) corresponds to the difference between its expected profit in case it wins the auction and in case it is E (respectively M) that wins the auction. Let us denote them by \overline{p}_M and \overline{p}_E respectively. The auction winner is the firm with the highest willingness to pay for the patent, and the price it will pay equals the loser's willingness to pay. Here I must distinguish between several cases depending on the different possible subgame equilibria. The different cases are presented in Figure 4.2, and the firms' corresponding willingness to

pay for the patent are presented in Table 4.4.

Once the auction winner has been identified, I must compare its bid with the expected profit of R if it sells the patent ex post, that I denote \underline{p}_R . The subgame where the patent is sold ex post may have different outcomes, which has also been taken in account in Figure 4.2. Of course the research firm will decide how to sell the upstream patent so as to maximize its expected profit.

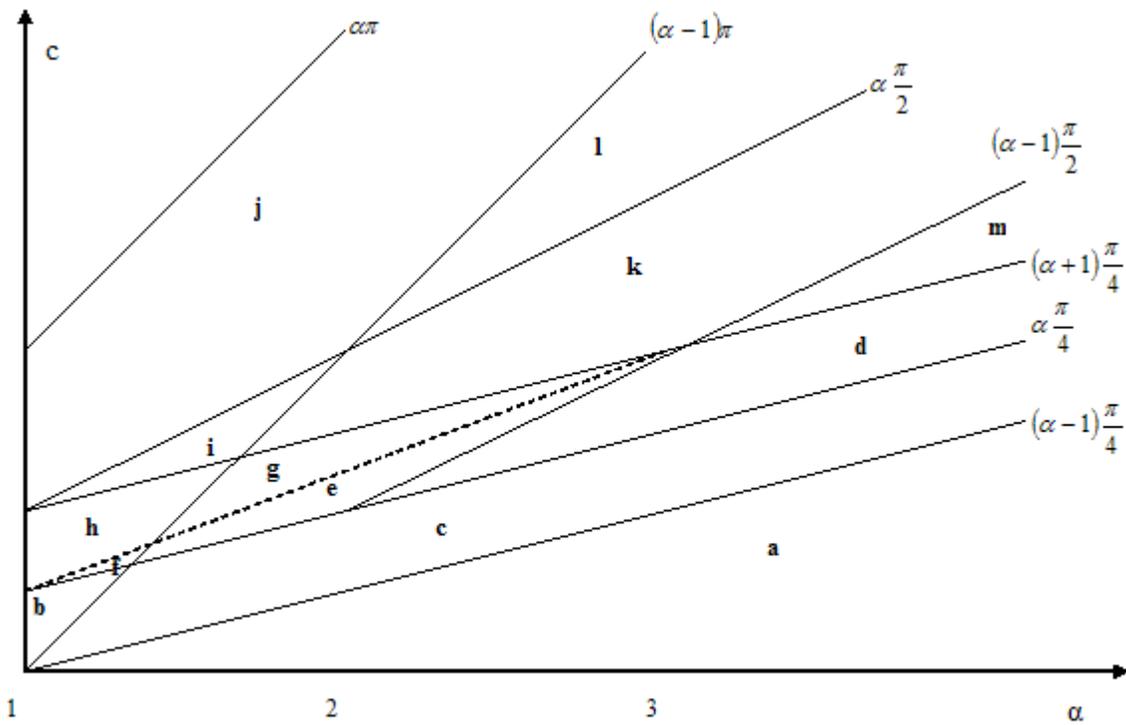


Figure 4.2: Outcomes of the auction

All cases are presented in Table 4.4. Each row describes one particular case, which correspondence with Figure 4.2 is given in Column 1. For each case, the maximum en

ante bids \overline{p}_M and \overline{p}_E are given respectively in Columns 2 and 3. Column 4 presents the expected profit of R incase it sells the upstream patent ex post. By comparing \overline{p}_M and \overline{p}_E , I can deduce which firm will be the auction winner. By comparing the winning bid, that is $Min(\overline{p}_M, \overline{p}_E)$, with \underline{p}_R I can in turn deduce whether R will sell the patent ex ante or ex post. If $\underline{p}_R \leq Min(\overline{p}_M, \overline{p}_E)$, the patent will be auctioned ex ante and the auction winner is given in Column 5. Note that in some cases M and E have the same willingness to pay. Then both have equal chances to win the auction so that both are mentioned in Column 5. If $\underline{p}_R > \min(\overline{p}_M, \overline{p}_E)$, R will wait for the firms to invest and sell the patent ex post. In this case the cell of Column 5 is empty.

Knowing how the upstream patent will be sold, I can also deduce which firm(s) will invest to patent the drastic innovation. This is presented in Column 6.

Cases e , f , g , h and m deserve some additional explanations. In cases e , f , g and h , there is a Nash equilibrium in mixed strategies, namely (m_M^*, m_E^*) , if the patent is sold ex post. Thus \underline{p}_R is equal to:

$$m_M^* m_E^* (2\alpha - 1) \frac{\pi}{4} + m_M^* (1 - m_E^*) (\alpha - 1) \frac{\pi}{2} + (1 - m_M^*) m_E^* \frac{\pi}{2} \equiv \tilde{p}$$

As in these cases I have $\overline{p}_M = \overline{p}_E = (3\alpha - 1) \frac{\pi}{4} - c$, the condition for R to sell the patent ex ante is:

$$\tilde{p} < (3\alpha - 1) \frac{\pi}{4} - c$$

It is shown in Appendix 2.1 that this condition can be reformulated into:

$$c < F(\alpha) \pi$$

Area	$\overline{p_M}$	$\overline{p_E}$	$\underline{p_R}$	Ex ante buyer	Investment
<i>a</i>	$\alpha \frac{\pi}{2}$	$\alpha \frac{\pi}{2}$	$(2\alpha - 1) \frac{\pi}{4}$	<i>M</i> or <i>E</i>	<i>M</i> and <i>E</i>
<i>b</i>	$(3 - \alpha) \frac{\pi}{4} + c$	$(3\alpha - 1) \frac{\pi}{4} - c$	$(2\alpha - 1) \frac{\pi}{4}$	<i>M</i>	-
<i>c</i>	$(3\alpha - 1) \frac{\pi}{4}$	$(3\alpha - 1) \frac{\pi}{4} - c$	$(2\alpha - 1) \frac{\pi}{4}$	<i>M</i>	<i>M</i>
<i>d</i>	$(3\alpha - 1) \frac{\pi}{4}$	$(3\alpha - 1) \frac{\pi}{4} - c$	$(\alpha - 1) \frac{\pi}{2}$	<i>M</i>	<i>M</i>
<i>e</i>	$(3\alpha - 1) \frac{\pi}{4}$	$(3\alpha - 1) \frac{\pi}{4} - c$	\tilde{p}	<i>M</i>	<i>M</i>
<i>f</i>	$(3\alpha - 1) \frac{\pi}{4}$	$(3\alpha - 1) \frac{\pi}{4} - c$	\tilde{p}	<i>M</i>	-
<i>g</i>	$(3 - \alpha) \frac{\pi}{4} + c$	$(3\alpha - 1) \frac{\pi}{4} - c$	\tilde{p}	-	(m_M^*, m_E^*)
<i>h</i>	$(3 - \alpha) \frac{\pi}{4} + c$	$(3\alpha - 1) \frac{\pi}{4} - c$	\tilde{p}	-	(m_M^*, m_E^*)
<i>i</i>	π	$\alpha\pi - c$	$\alpha \frac{\pi}{2}$	<i>M</i>	-
<i>j</i>	π	$\alpha\pi - c$	0	<i>M</i>	-
<i>k</i>	$\alpha\pi - c$	$\alpha\pi - c$	$\alpha \frac{\pi}{2}$	<i>M</i> or <i>E</i>	<i>M</i> or <i>E</i>
<i>l</i>	$\alpha\pi - c$	$\alpha\pi - c$	0	<i>M</i> or <i>E</i>	<i>M</i> or <i>E</i>
<i>m</i>	$\alpha\pi - c$	$\alpha\pi - c$	\hat{p}	<i>M</i> or <i>E</i>	<i>M</i> or <i>E</i>

Table 4.4: Equilibria of the game.

where:

$$F(\alpha) = \frac{1}{8} (2\alpha - 1)^{-1} \left(5\alpha^2 - 3\alpha - 4 + \sqrt{4\alpha + \alpha^2 - 2\alpha^3 + \alpha^4 + 16} \right)$$

$F(\alpha)\pi$ is represented dotted in Figure 4.2. As it is a continuously increasing (and nearly linear) function of α from $[1, 3]$ into $[\frac{\pi}{2}, \pi]$, it separates areas *e* and *f* on the one hand, and areas *g* and *h* on the other hand. Thus the patent is sold ex ante (respectively ex post) in areas *e* and *f* (respectively *g* and *h*). In cases *g* and *h*, *M* and *E* will invest with probabilities m_M^* and m_E^* respectively, which is mentioned in Column 6.

The last is *m*. It is particular in that there are three Nash equilibria if the patent is sold ex post. Thus I cannot determine the profit \hat{p} that *R* could expect by selling the patent ex post. It can however be checked easily that $\overline{p_M} = \overline{p_E}$ is higher than any possible value of \hat{p} . Therefore the patent will be sold ex ante, to either *M* or *E*.

The main results are presented successively below.

Proposition 4.1 describes the research firm's decision about how to sell its patent.

It is represented in Figure 4.3.

Proposition 4.1 (i) if $c > \alpha\pi$, the research firm cannot sell its patent,

(ii) if $c < (\alpha - 1) \frac{\pi}{4}$ or $(\alpha + 1) \frac{\pi}{4} \leq c < (\alpha - 1) \pi$, the research firm sells its patent ex ante to either E or M ,

(iii) if $(\alpha - 1) \frac{\pi}{4} \leq c < \text{Min} \{F(\alpha); (\alpha - 1) \frac{\pi}{4}\}$ or $\text{Max} \{F(\alpha); (\alpha - 1) \pi\} \leq c < \alpha\pi$, the research firm sells its patent ex ante to M ,

(iv) if $F(\alpha) \leq c < (\alpha + 1) \frac{\pi}{4}$, the research firm sells its patent ex post.

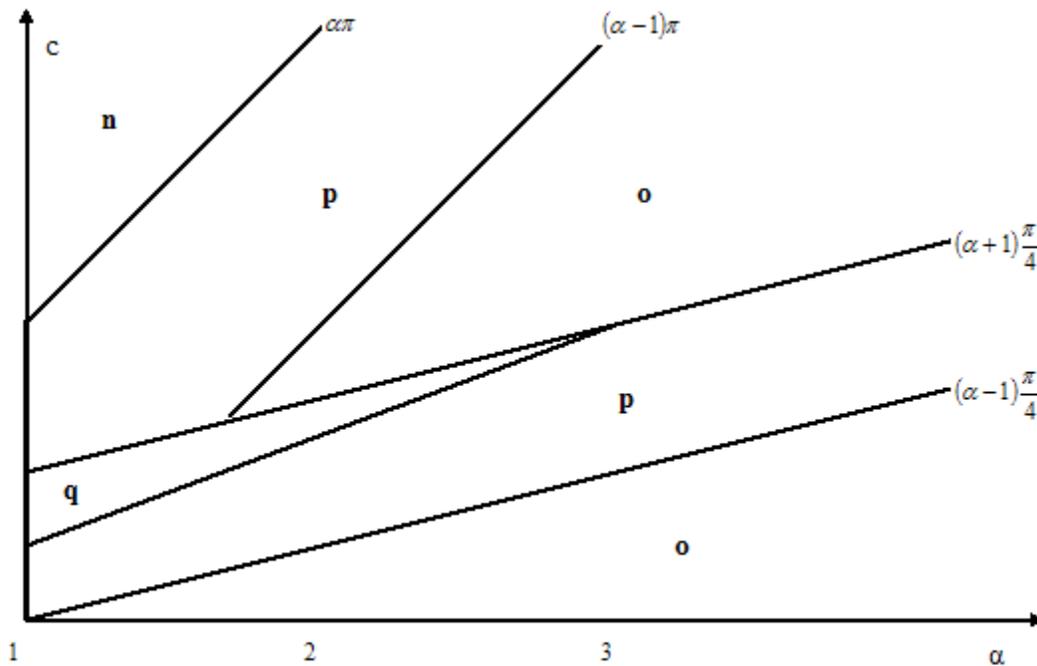


Figure 4.3: Allocation of the basic patent and persistence of the incumbent

Part (i) of the Proposition corresponds to the case in which the drastic innovation is not profitable at all (area n). Here firm R cannot sell its patent because developing the

drastic innovation would not be profitable even for a new entrant enjoying the full profits from it.

Parts *(ii)* and *(iii)* (respectively areas *o* and *p*) mean firstly that in most cases the research firm would benefit from the rivalry between *M* and *E* by selling the upstream patent ex ante. They however also differ regarding the outcome of the ex ante auction. The result presented in part *(ii)* (area *o* on Figure 4.3) is consistent with the usual understanding of drastic innovations as being neutral: the incumbent and the new entrant have the same willingness to pay for the upstream patent ex ante. Therefore either *M* or *E* can indifferently win the auction and buy the patent. In both cases, only the winner of the auction invests downstream. Finally the research firm always gets a profit $\alpha\pi - c$, which is the sum of the net incremental profit from innovation $(\alpha - 1)\pi - c$ and the incumbent's initial profit π .

By contrast, the firms willingness to pay for the patent differ in part *(iii)* (area *p*), where the incumbent's maximum bid is not equal but superior to the entrant's one. This actually corresponds to two different cases. The first one is represented by the upper part of area *p*. Here the innovation is not profitable per se for the industry, but only insofar as it allows the entrant to steal the incumbent's business. Thus the incumbent is able to propose a higher bid than the entrant because it will not invest in the downstream innovation. By buying the patent ex ante, it internalizes the wasteful creative destruction and maximizes the industry surplus. The second case is represented by the lower part of area *p*. It corresponds to the situation where *E* does not invest if *M* buys the patent ex ante, while *M* still invests if *E* buys the patent. This asymmetry is a consequence of the greater bargaining power of *M*, along with the assumption that the patent buyer becomes

the first mover in the investment game. It creates a superior incentive for M to preempt the patent and keep its monopoly.

Part (iv) is an exception to this rule. It corresponds to a case in which the firms invest randomly if the patent is not sold ex ante (area q). Here R chooses to sell the patent ex post because the probability for M to invest is relatively lower than that of E . Thus R can reasonably expect to bargain on an even basis with E rather than on a disadvantageous basis with M . Conversely, note that R prefers to sell the patent ex ante when the firms invest randomly if $c < F(\alpha)$. This is because M would otherwise patent the drastic innovation with a higher probability than E .

Proposition 1 therefore strongly contradicts the idea that a new entrant is more likely to develop a drastic innovation than an incumbent monopoly because it can benefit from the replacement effect. When innovation is cumulative, the firms' incentives to develop and patent an innovation rather derive from their ability to leverage blocking patents in a bargaining setting. All the results of Proposition 1 must be understood in this framework. And in this game, the incumbent has a better position than an entrant, precisely because it can expect less surplus from the drastic innovation.

4.4 Incentives to develop the upstream patent

I focus now on the research firm's revenue and incentive to invest in the upstream patent. I compare as a first step the expected profit that R derives from its basic patent with the aggregate expected profits that the industry derives from the drastic innovation. I discuss as a second step some possibilities for the research firm to strike an ex ante contract

with E and M in order to improve its profit.

4.4.1 Incentives for R to develop the upstream innovation

In this subpart, I compare the expected profit that R derives from selling its patent with the aggregate profits that the industry derives from the drastic innovation. These industry profits include the aggregate revenues created by the innovation for R , M and E , as well as the total investment costs. The difference Δ between the profits of R and the industry incremental profits from innovation reflects the excessive (if $\Delta > 0$) or insufficient (if $\Delta < 0$) incentive for R to develop and patent the upstream innovation.

Proposition 4.2 *Let v denote the expected profit that the research firm R derives from the upstream patent,*

Let w denote the total expected profit that the industry derives from the upstream patent,

Let $\Delta = v - w$.

- $$(i) \Delta < 0 \text{ if } \begin{cases} (\alpha - 1) \frac{\pi}{4} \leq c < (\alpha + 1) \frac{\pi}{4} \\ \alpha > 3 \end{cases}$$
- $$(ii) \Delta < 0 \text{ if } c < \text{Min} \left\{ (\alpha - 2) \frac{\pi}{2}; (\alpha - 1) \frac{\pi}{4} \right\}$$
- (iii) $\Delta > 0$ in all other cases.

Proof. See Appendix 3.2. ■

The results are represented in Figure 4.4 below. The R&D firm has an underincentive ($\Delta < 0$) to develop the upstream patent when its value/cost ratio α/c is high, while it has an excessive incentive ($\Delta > 0$) to develop it when the ratio α/π is low. The research firm cannot collect the whole innovation surplus when this surplus is relative high. Both

the entrant and the incumbent have then an incentive to invest downstream, and their bids reflect the uncertainty about who will innovate first. As the probability to win is equal to $1/2$ for each firm, the R&D firm can only expect to get $1/2$ of the innovation's market value. The excessive reward of R when α/c is low stems from the business stealing effect that motivates the entrant E . In order to persist, M has to compensate this effect, by transferring a part of its incumbent profits to the R&D firm. This strategic incentive dominates when the innovation surplus is minor with regards to the incumbent's initial profit. Therefore the incumbent's preemption strategy changes the nature of the research firm's incentives to innovate. For R , the value of the upstream innovation derives not only from its social value but also from the threat that it represents for M . The research firm has insufficient incentives to develop the most valuable innovations. By contrast it is profitable for it to develop low value innovations provided they represent a threat for the incumbent.

4.4.2 Ex ante contracts between the three firms

Before concluding, I introduce now the possibility for the R&D firm to propose a joint venture contract to the other firms instead of selling its patent ex ante through an auction. I apply this possibility to three specific subcases, in order to highlight how such joint venture agreements affect the profits of the R&D firm. I show that they improve the efficiency of the R&D investments when the auction system would lead to cost duplication, and that they reinforce the capacity of the R&D firm to extract the initial monopoly rent of the incumbent.

The contract is specified in a similar way as Scotchmer (1996). R offers a contract simultaneously to the two other firms, each of which can answer "yes", or "no". R has the

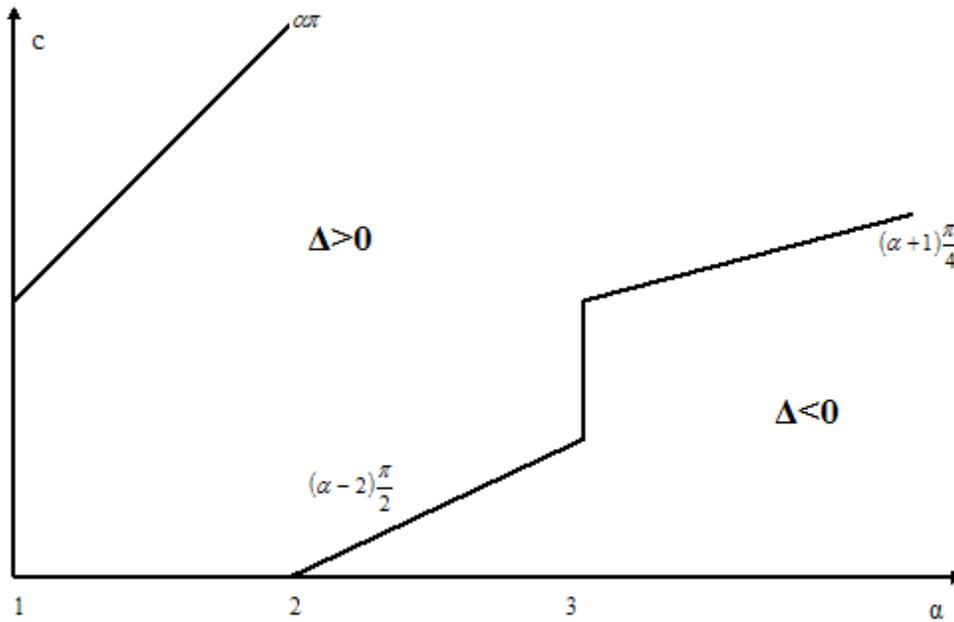


Figure 4.4: Over and under incentives for the research firm to develop the basic innovation responsibility to bear the research costs once it has contracted with at least one of the two firms. The contract offered to each firm specifies the payment they will receive, and which firm will undertake the research project. A firm accepts a contract if it provides at least its reservation payoff.

The first case corresponds to subcase a in Table 4.4 and Figure 4.2. It is a situation where the incremental value of the drastic innovation, namely $(\alpha - 1)\pi$, is high with respect to the R&D cost c . I have shown in Section 4.3 that in this case E and M make the same bid $\alpha\pi/2$, so that any of them can win the auction, and that both invest downstream whoever wins the auction. I show now that R can propose a contract that will be accepted by M and E , and that increases R 's profit by c , namely the R&D cost saved by avoiding a patent race.

Proposition 4.3 *When $c < (\alpha - 1) \frac{\pi}{4}$, the following contract proposed by R will be accepted by M and E .*

(i) R gets $\frac{\alpha\pi}{2} + c$

(ii) M gets $(\alpha + 1) \frac{\pi}{4} - c$

(iii) E gets $(\alpha - 1) \frac{\pi}{4} - c$

Proof. (i) *By declining the contract, firms M and E can assure themselves at least $(\alpha + 1) \frac{\pi}{4} - c$ and $(\alpha - 1) \frac{\pi}{4} - c$ respectively. If no other firm invests, M (respectively E) can get $(\alpha + 1) \frac{\pi}{2} - c$ (respectively $(\alpha - 1) \frac{\pi}{2} - c$) by investing. If the other firm or the joint venture invests, M (resp. E) also invests. M (resp. E) has then a probability $1/2$ to win and its expected profits is $(\alpha + 1) \frac{\pi}{4} - c$ (resp. $(\alpha - 1) \frac{\pi}{4} - c$ for E).*

(ii) *The payoffs written in the cells of Table 4.5 represent the contract offered by R where ϵ is a very small number. I shall show that the equilibrium is (y, y) . The cell (n, n) contains the expected payoffs of M and E in the auction setting analyzed in subsection 4.3. Consider cells (y, n) and (n, y) , meaning respectively that only M or E participates in the joint venture. We already know that the non-participant will invest. Furthermore, the joint venture will invest in both cases with expected payoffs of $(3\alpha + 1)\pi/4 - c$ and $(3\alpha - 1)\pi/4 - c$ respectively, by contrast with $(\alpha + 1)\pi/4$ and $(\alpha - 1)\pi/4$ if it does not invest. On this expected payoffs the contractual payment is $(\alpha + 1) \frac{\pi}{4} - c + \epsilon$ to M and $(\alpha - 1) \frac{\pi}{4} - c + \epsilon$ to E . The contract payoffs in (y, y) are specified in the contract and R will designate one firm to invest. Since the equilibrium of the game in Table 4.5 is (y, y) , and since R will designate only one firm to invest, the equilibrium payoffs are those specified in*

Proposition 4.3. ■

		firm E	
		<i>yes</i>	<i>no</i>
firm M	<i>yes</i>	$(\alpha + 1) \frac{\pi}{4} - c + \epsilon, (\alpha - 1) \frac{\pi}{4} - c + \epsilon$	$(\alpha + 1) \frac{\pi}{4} - c + \epsilon, (\alpha - 1) \frac{\pi}{4} - c$
	<i>no</i>	$(\alpha + 1) \frac{\pi}{4} - c, (\alpha - 1) \frac{\pi}{4} - c + \epsilon$	$(\alpha + 1) \frac{\pi}{4} - c, (\alpha - 1) \frac{\pi}{4} - c$

Table 4.5: Joint venture contract: case 1

The second case corresponds to subcases c , d and e in Table 4.4 and Figure 4.2. It is a situation where the incremental value of the drastic innovation is higher than the R&D cost c , although in a lower proportion than in the previous case. In these cases M makes a higher bid than E , and M remains the sole downstream investor. I show below that R can propose a contract that will be accepted by M and E , and that increases its profit by an amount c . Indeed R can get a payoff of $(3\alpha - 1) \frac{\pi}{4}$ through the contract while in the auction the winning bid is only equal to $(3\alpha - 1) \frac{\pi}{4} - c$.

As only M would invest c if the patent were auctioned, the additional payoff to R does not correspond R&D costs savings. Rather, the contract allows R to extract a higher share of the incumbent's initial profit. This is so because the joint venture increases the credibility of the threat that E invests downstream. The proof of Proposition 4.4 shows that a joint venture including E will invest downstream, while E alone would not invest after M has bought the upstream patent. The only way M can prevent E from investing is then to participate in the joint venture, which requires transferring more of its monopoly rent to R .

Proposition 4.4 *When $(\alpha - 1) \frac{\pi}{4} < c < \text{Min} \{(\alpha - 1) \pi; F(\alpha); (\alpha + 1) \frac{\pi}{4}\}$, the following*

contract proposed by R will be accepted by M and E .

(i) R gets $(3\alpha - 1) \frac{\pi}{4}$

(ii) M gets $(\alpha + 1) \frac{\pi}{4} - c$

(iii) E gets 0

Proof. (i) By declining the contract, firms M and E can assure themselves at least $(\alpha + 1) \frac{\pi}{4} - c$ and 0 respectively. If no other firm invests, M (respectively E) can get $(\alpha + 1) \frac{\pi}{2} - c$ (respectively $(\alpha - 1) \frac{\pi}{2} - c$) by investing. If the other firm or the joint venture invests, M (resp. E) can get $(\alpha + 1) \frac{\pi}{4} - c > 0$ (respectively $(\alpha - 1) \frac{\pi}{4} - c < 0$) by investing. Hence only M will invest in that case.

(ii) The payoffs written in the cells of Table 4.6 represent the contract offered by R where ϵ is a very small number. I shall show that the equilibrium is (y, y) . The cell (n, n) contains the expected payoffs of M and E in the auction setting analyzed in subsection 4.3. Consider cell (y, n) meaning that only M participates in the joint venture. We already know that in this case E will not invest. Then the joint venture will invest with expected payoff of $\alpha\pi - c$ instead of π if it does not invest. Consider cell (y, y) meaning that only M participates in the joint venture. We know that E will invest if the joint venture does not invest. But the best answer of the joint venture to E investing is also to invest since $(3\alpha + 1)\pi/4 - c > (\alpha + 1)\pi/4$. We also know that E will not invest if the joint venture invests. Then, the joint venture will invest with expected payoff of $\alpha\pi - c$ instead of π if it does not invest. Thus at equilibrium only the joint venture invests. The contractual payment to M is then $(\alpha + 1) \frac{\pi}{4} - c + \epsilon$, while E gets 0. Consider now cell (n, y) meaning that only

E participates in the joint venture. We know that in this case *M* will invest. Then, the joint venture will also invest with expected payoff $(3\alpha - 1)\pi/4 - c$ instead of $(\alpha - 1)\pi/4$ if it does not invest. On this expected payoffs the contractual payment is $0 + \epsilon$ to *E*, while the expected payoff of *M* is $(\alpha + 1)\frac{\pi}{4} - c$. The contract payoffs in (y, y) are specified in the contract and *R* will designate one firm to invest. Since the equilibrium of the game in Table 4.6 is (y, y) , and since *R* will designate only one firm to invest, the equilibrium payoffs are those specified in Proposition 4.4. ■

		firm <i>E</i>	
		<i>yes</i>	<i>no</i>
firm <i>M</i>	<i>yes</i>	$(\alpha + 1)\frac{\pi}{4} - c + \epsilon, 0 + \epsilon$	$(\alpha + 1)\frac{\pi}{4} - c + \epsilon, 0$
	<i>no</i>	$(\alpha + 1)\frac{\pi}{4} - c, 0 + \epsilon$	$(\alpha + 1)\frac{\pi}{4}, 0$

Table 4.6: Joint venture contract: case 2

The last case I study corresponds to subcases *k*, *l* and *m* in Table 4.4 and Figure 4.2. It is a situation where the incremental value $(\alpha - 1)\pi$ of the drastic innovation is low with respect to the R&D cost c , although $(\alpha - 1)\pi - c$ remains positive. I have shown in Section 4.3 that *E* and *M* make the same bid $\alpha\pi - c$, and that only the auction winner will invest downstream. The winning bid is equal to the total industry profits $\alpha\pi - c$, including the incremental profit from the drastic innovation $(\alpha - 1)\pi - c$, and *M*'s initial profit π . As *R* already gets the total industry surplus through the auctioning of its patent, I show below that it can propose a contract that grants it the same payoff as the auction.

Proposition 4.5 *When $(\alpha + 1)\frac{\pi}{4} < c < (\alpha - 1)\pi$, the following contract proposed by *R**

will be accepted by M and E .

(i) R gets $\alpha\pi - c$

(ii) M gets 0

(iii) E gets 0

Proof. (i) By declining the contract, firms M and E can assure themselves at least 0. If no other firm invests, M (respectively E) can get $(\alpha + 1)\frac{\pi}{2} - c$ (respectively $(\alpha - 1)\frac{\pi}{2} - c$) by investing. If the other firm or the joint venture invests, M (resp. E) can get $(\alpha + 1)\frac{\pi}{4} - c < 0$ (respectively $(\alpha - 1)\frac{\pi}{4} - c < 0$) by investing. Hence neither firm will invest in that case.

(ii) The payoffs written in the cells of Table 4.7 represent the contract offered by R where ϵ is a very small number. I shall show that the equilibrium is (y, y) . The cell (n, n) contains the expected payoffs of M and E in the auction setting analyzed in subsection 4.3. Consider cell (y, n) meaning that only M participates in the joint venture. We know that E will not invest if the joint venture does invest. The best answer of the joint venture to E investing is also to invest since $(3\alpha + 1)\pi/4 - c > (\alpha + 1)\pi/4$. And the joint venture invests as well if E does not invest, since $\alpha\pi - c > \pi$. Thus at equilibrium only the joint venture invests. Then the contractual payment to M is $0 + \epsilon$, while E gets 0. Consider now cell (n, y) meaning that only E participates in the joint venture. We know that M will not invest if the joint venture does invest. The best answer of the joint venture to M investing is also to invest since $(3\alpha - 1)\pi/4 - c > (\alpha - 1)\pi/4$. And the joint venture invests as well if M does not invest, since $\alpha\pi - c > \pi$. Thus at equilibrium only the joint venture invests.

Then the contractual payment to E is $0 + \epsilon$, while M gets 0. The contract payoffs in (y, y) are specified in the contract and R will designate one firm to invest. Since the equilibrium of the game in Table 4.7 is (y, y) , and since R will designate only one firm to invest, the equilibrium payoffs are those specified in Proposition 4.5. ■

		firm E	
		<i>yes</i>	<i>no</i>
firm M	<i>yes</i>	$0 + \epsilon, 0 + \epsilon$	$0 + \epsilon, 0$
	<i>no</i>	$0, 0 + \epsilon$	$0, 0$

Table 4.7: Joint venture contract: case 3

These three cases of ex ante "joint venture" contracts show how such contracts can modify the payoffs to the R&D firm R . When the upstream patent is auctioned ex ante, I have shown that R is under-rewarded for the most valuable innovations (those exhibiting a high α/c ratio) because they trigger a patent race which uncertain outcomes are reflected in the bids. In this case, a joint venture allows to delegate the R&D investment to only one firm. It thereby increases the efficiency of the R&D investments and suppresses the uncertainty of their outcome. Therefore ex ante contracts increase both social efficiency and the profits of the upstream firm. However, in many cases, the auctioning of the upstream patent does not trigger a patent race. I have shown that ex ante contracts may nevertheless be possible and profitable for the research firm. Indeed they allow it to extract a bigger share of the initial rents of the incumbent firm. This is possible insofar as a joint venture contract can transform investment by an entrant into a credible threat. Finally, the auction and joint

venture contracts are equivalent when the incremental value of the drastic innovation is low (but positive). In both cases, the research firm is able to appropriate the total industry surplus, including the initial profit of the incumbent.

4.5 Conclusion and discussion

I have developed in this Chapter a model in which an incumbent monopoly and a new entrant run to patent a cumulative and drastic innovation. This simple model adds in two ways on the literature on the persistence of monopoly which I reviewed in the previous Chapter.

The model firstly sheds light on a setting where the incumbent can prevent an entrant from developing a drastic innovation although it does not own any blocking patent initially. If an R&D firm owns a patent that enables the development of a drastic innovation, the incumbent may indeed be able to buy it before the drastic innovation has been patented. The research firm generally prefers to sell its patent *ex ante*, because it can then benefit from the competition between the incumbent and the entrant, rather than having to bargain *ex post* with the owner of the drastic innovation patent. In this case, the incumbent monopoly can derive a greater value from a patent that allows it to hold-up the drastic innovation if it is developed and patented by a new entrant. The incumbent would still earn its former monopoly if the drastic innovation were not marketed, while a new entrant would make no profit at all. As a result, the incumbent has at least an equal willingness to pay for the upstream patent than the entrant. In particular, the incumbent is able to preempt the upstream patent if the downstream innovation is not profitable *per se*, or if it can exclude

the entrant from the downstream market thanks to its greater bargaining power.

This result is close to Yi (1995) who concludes that an incumbent monopoly will always buy an upstream patent enabling a downstream innovation, be it drastic or not. However the underlying insights differ so that the models rather complete each other. In Yi's model the upstream patent enables its owner to develop a downstream innovation, but it does not confer a right on this innovation. In this context the incumbent is able to pay a higher price than the entrant for the upstream patent, because it will then invest in R&D in a way that maximizes the industry profit. In my model, a competitor does not need to own the upstream patent to be able to develop and patent the downstream innovation. However, the upstream patent confers a right to block the use of the downstream innovation. In this context I do not focus primarily on the R&D investments. The incumbent's ability to buy the upstream patent rather stems from its bargaining power in case each competitor owns one blocking patent. This power is indeed superior to the entrant's one, because the incumbent makes a profit even if the negotiation fails.

The overall advantage of the incumbent firm as regards the preemption of drastic cumulative innovations in turn affects the incentives to develop the upstream patents. Indeed, the research firm's incentive to develop the upstream patent depends both on the net incremental value of the drastic innovation $(\alpha - 1)\pi - c$ and on the potential threat that it creates for the incumbent. I have shown that when it auctions the patent, the research firm has under-incentives to invest in high value innovations, and excessive incentives to invest in low value ones. In the first case, the payoff to R is limited by the uncertainty on the bidders profits. When the incremental value of the drastic innovation is relative low, R

can by contrast extract a part of the incumbent's initial monopoly rent. In some cases, R is even able to extract the total industry profit, including the incumbent's whole monopoly rent. As a result, its incentives to develop the upstream innovation then reflect the entire business stealing power of the drastic innovation.

At the end of Chapter, I have introduced the possibility for the firms to strike joint venture agreements before developing the drastic innovation. I have shown in two different cases that such contracts allow the upstream firm to increase its profits and, hence, its incentive to innovate. When the net value of the drastic innovation is high, joint ventures are a way to avoid the cost duplications due to patent race. The upstream firm can then benefit directly from the efficiency improvement. In other cases, a joint venture can also be a way for the upstream firm to extract more of the incumbent's monopoly rent. This is true when, in the auction system, the entrant would have dropped out of the market after having lost the auction. A joint venture agreement with the entrant can then provide credibility to the threat that the entrant invests in R&D. To prevent this, the incumbent has no choice but to enter into the joint venture and abandon a larger share of its monopoly rent to the upstream firm. Hence the joint venture agreement also reinforces the upstream firm's overincentive to invest in the less valuable innovations.

Appendix

Appendix 2.1

The condition for R to sell the patent ex ante is:

$$c < (3\alpha - 1) \frac{\pi}{4} - \tilde{p}$$

Knowing that

$$\left\{ \begin{array}{l} \tilde{p} = m_M^* m_E^* (2\alpha - 1) \frac{\pi}{4} + m_M^* (1 - m_E^*) (\alpha - 1) \frac{\pi}{2} + (1 - m_M^*) m_E^* \frac{\pi}{2} \\ m_M^* = \frac{2\alpha\pi - 4I}{\alpha\pi} \\ m_E^* = \frac{2(\alpha-1)\pi - 4I}{(\alpha-3)\pi} \end{array} \right. ,$$

the right part of this condition can be reformulated as follows:

$$(-16)(2\alpha - 1)c^2 + 4\pi(5\alpha^2 - 3\alpha - 4)c + \alpha\pi^2(\alpha + 1)(5 - 3\alpha)$$

This expression is a second degree polynomial in c that admits two real roots for $\alpha \neq \frac{1}{2}$:

$$\left\{ \begin{array}{l} c_1 = \frac{\pi}{8}(2\alpha - 1)^{-1} \left(5\alpha^2 - 3\alpha - 4 - \sqrt{4\alpha + \alpha^2 - 2\alpha^3 + \alpha^4 + 16} \right) \\ c_2 = \frac{\pi}{8}(2\alpha - 1)^{-1} \left(5\alpha^2 - 3\alpha - 4 + \sqrt{4\alpha + \alpha^2 - 2\alpha^3 + \alpha^4 + 16} \right) \end{array} \right.$$

For any $\pi > 0$ and $1 \leq \alpha \leq 3$, the roots c_1 and c_2 furthermore verify:

$$\left\{ \begin{array}{l} c_1 < \text{Min} \left\{ (\alpha - 1) \frac{\pi}{2}; \alpha \frac{\pi}{4} \right\} \\ (\alpha - 1) \frac{\pi}{4} \leq c_2 < \text{Max} \left\{ (\alpha - 1) \frac{\pi}{2}; \alpha \frac{\pi}{4} \right\} \end{array} \right.$$

Therefore, only c_2 intersects with the area of (α, π) where (m_M^*, m_E^*) is the subgame Nash equilibrium if the patent is sold ex post.

By reformulating c_2 into $F(\alpha)\pi$, where

$$F(\alpha) = \frac{1}{8}(2\alpha - 1)^{-1} \left(5\alpha^2 - 3\alpha - 4 + \sqrt{4\alpha + \alpha^2 - 2\alpha^3 + \alpha^4 + 16} \right)$$

is a continuously increasing (and nearly linear) function of α from $[1, 3]$ into $\left[\frac{\pi}{2}, \pi\right]$, I can conclude that R prefers to sell its patent ex ante if:

$$c < F(\alpha)\pi.$$

Appendix 2.2: Proof of Proposition 4.2

I prove successively (i) and (ii).

$$(i) \text{ If } \begin{cases} (\alpha - 1) \frac{\pi}{4} \leq c < (\alpha + 1) \frac{\pi}{4} \\ \alpha > 3 \end{cases}$$

Then M buys the basic patent ex ante at a price $v = (3\alpha - 1) \frac{\pi}{4} - c$,

And M invests in the downstream patent so that $w = (\alpha - 1) \pi - c$.

Thus I have:

$$\Delta = (3 - \alpha) \frac{\pi}{4}$$

Which is negative because $\alpha > 3$.

(ii) Consider the case when $c < \text{Min} \{(\alpha - 2) \frac{\pi}{2}; (\alpha - 1) \frac{\pi}{4}\}$.

Here M or E buys the basic patent ex ante and develops the drastic innovation.

I have:

$$v = \alpha \frac{\pi}{2}$$

$$w = (\alpha - 1) \pi - c$$

Thus $\Delta = c - (\alpha - 2) \frac{\pi}{2} > 0$

(iii) Consider first the case when $\text{Max} \{(\alpha + 1) \frac{\pi}{4}; (\alpha - 1) \pi\} < c < \alpha \pi$.

Here M buys the basic patent ex ante and does not develop the drastic innovation.

I have:

$$v = \alpha \pi - c$$

$$w = 0$$

Thus $\Delta > 0$.

Consider the case when $(\alpha + 1) \frac{\pi}{4} < c < (\alpha - 1) \pi$.

Here M or E buys the basic patent ex ante and develops the drastic innovation.

I have:

$$v = \alpha\pi - c$$

$$w = (\alpha - 1)\pi - c$$

Thus $\Delta = \pi > 0$.

Consider the case when $F(\alpha) < c < (\alpha + 1) \frac{\pi}{4}$.

Here R sells the basic patent ex post so that $v = \tilde{p}$

As M and E adopt mixed strategies of investment, I have:

$$w = m_M^* m_E^* (A - c) + m_M^* (1 - m_E^*) A + (1 - m_M^*) m_E^* A$$

with $A = (\alpha - 1)\pi - c$.

Recall that $\tilde{p} > (3\alpha - 1) \frac{\pi}{4} - c$, which is the maximum price R would have got by selling its patent ex ante.

As $v = \tilde{p}$ and $0 \leq m_M^*, m_E^* \leq 1$, it follows directly that:

$$v > [m_M^* m_E^* + m_M^* (1 - m_E^*) + (1 - m_M^*) m_E^*] \left[(3\alpha - 1) \frac{\pi}{4} - c \right],$$

Furthermore I have

$$(3\alpha - 1) \frac{\pi}{4} - c - A = (3 - \alpha) \frac{\pi}{4} > 0,$$

Thus $(3\alpha - 1) \frac{\pi}{4} - c > A$ and:

$$v > [m_M^* m_E^* + m_M^* (1 - m_E^*) + (1 - m_M^*) m_E^*] A$$

Thus:

$$v > m_M^* m_E^* (A - c) + m_M^* (1 - m_E^*) A + (1 - m_M^*) m_E^* A$$

Which is equivalent to $v > w$ and $\Delta > 0$.

Consider the case when
$$\left\{ \begin{array}{l} (\alpha - 1) \frac{\pi}{4} \leq c < F(\alpha) \\ \alpha < 3 \end{array} \right.$$
.

Here M buys the basic patent ex ante and develops the drastic innovation.

I have:

$$\begin{aligned} v &= (3\alpha - 1) \frac{\pi}{4} - c \\ w &= (\alpha - 1) \pi - c \end{aligned}$$

Thus $\Delta = (3 - \alpha) \frac{\pi}{4} > 0$.

Consider finally the case when $(\alpha - 2) \frac{\pi}{2} \leq c < (\alpha - 1) \frac{\pi}{4}$.

Here M or E buys the basic patent ex ante and develops the drastic innovation.

I have:

$$\begin{aligned} v &= \alpha \frac{\pi}{2} \\ w &= (\alpha - 1) \pi - c \end{aligned}$$

Thus $\Delta = c - (\alpha - 2) \frac{\pi}{2} > 0$

Part III

Patent Agreements between Competitors

This part of the thesis is derived from a joint paper with Sarah Parlane (Ménière & Parlane, 2004). I develop a model that captures R&D competition between two symmetric firms. I use this model to study the effect of blocking patents that the firms may use against each other. I consider the formation of ex ante cross-licensing agreements between the firms, and the incentives for the firms to accumulate patent portfolios.

Chapter 5

Blocking patents and R&D investments

5.1 Introduction

In industries where innovations are cumulative and complementary, a patent on an early innovation grants its owner more than a mere protection against copies or illegal use of its innovation. A patent owner may be in a position to block the access of other innovations to market, and thereby to gather a revenue from licensing agreements (Scotchmer, 1991; Green & Scotchmer, 1995; Shapiro, 2001). As shown in several surveys and empirical investigations, this blocking power of patents has led firms in many industries to build up large patent portfolios (Cohen, Nelson and Walsh, 2000; Hall & Ziedonis, 2001; Bessen & Hunt, 2004), which they use strategically against competitors.

In this chapter I focus at blocking patents and consider their implications for

R&D investments. I develop a simple setting that allows me to shed light successively on the firms' incentives to sign cross licensing agreements at an early stage of R&D, and on their incentives to accumulate blocking power by building patent portfolios.

I consider two competitors that innovate independently but can use their patents to sue each other. I assume that patents not only protect against imitation, but also give their holder an odds to block the competitor's product. I use this model to study the strategic use of blocking patents at the industry level. I show that the firms' R&D investments are decreasing in the blocking power of patents, and that their expected profits are an inverse-U-shaped function of the blocking power of patents. Indeed the threat of hold up is a way to reduce the intensity of R&D competition when the blocking power is initially low, but as it increases it also triggers a free riding effect by which each firm excessively relies on its competitor's R&D efforts.

I discuss extensively in Section 2 how my approach articulates to the literature. The rest of the chapter is made of two sections focusing respectively on early cross licensing agreements and on the accumulation of patent portfolios by the firms.

I consider in section 3 that the patent breadth is exogeneous in order to study the effects of cross licensing agreements signed at an early stage by competitors. My setting indeed captures as a particular case the possibility that the firms succeed in blocking each other so that their patents become legal complements. It therefore provides a probabilistic definition of complementarity which is new in the literature (Shapiro, 2001, Lerner & Tirole, 2004). My findings corroborate the fact that cross licensing agreements are welfare improving when and only when patents exhibit high levels of legal breadth, because they

are then most likely to be blocking. Yet I obtain this result in a setting of dynamic R&D, while the other models are purely static and focus only on multiple marginalization issues. I contrast this result with a compulsory licensing regime, and show that such a regime would favour the creation of cross licensing agreements, be they pro- or anti-competitive.

Section 4 presents a version of the model in which the blocking power of patents is endogenously chosen by the firms. My setting explains why the firms accumulate blocking patent portfolios in industries with low R&D costs, and not in industries with high R&D costs. In the first case, the threat of hold up is indeed a means to reduce the intensity of R&D competition, which is not necessary in the second case. I also show that a more stringent policy of patent offices and courts vis-à-vis patent holders is a way to improve social welfare and, in some cases, firms' profits.

Section 5 concludes.

5.2 A review of the literature

5.2.1 Cumulative innovation and patent breadth

Blocking patents have been mostly analyzed in terms of cumulative innovations, where the owner of one upstream patent may hold up a subsequent innovator (Scotchmer, 1991; Green & Scotchmer, 1995; Denicolò, 2000). An important result of this literature is that ex post licensing contracts between upstream patent holders and downstream innovators may not provide enough incentives for the latter to innovate, because the R&D costs are already sunk when the licensing contract is negotiated. Thus ex ante licensing agreements are more efficient to provide incentives to innovate when upstream patents are

blocking (Green & Scotchmer, 1995). In this chapter, I introduce cumulative innovation by considering that the firms invest first in patentable innovations upon which they develop marketable products as a second step. I moreover take into account the hold up issue by considering that an upstream patent can block a downstream product. I however depart from the literature on cumulative innovation by focusing on competitors that develop innovations independently, instead of focusing on vertical relationships between subsequent innovators (Green & Scotchmer, 1995).

This contrast is reflected in my definition of the blocking power of patents. In Green and Scotchmer (1995), the upstream innovation enables by definition the downstream innovation, and the question is whether the downstream innovation should be within the scope of the upstream patent. By contrast, I consider that a firm can develop a product without using the technology of its competitor, and assume that the first firm's product can nevertheless fall within the scope of the second firm's patent. In this perspective I define patent breadth in a way that is closer to Gilbert and Shapiro (1991) and Klemperer (1991), that is as the power to exclude substitute products. Unlike them, I however do not aim to define an optimal patent breadth, but rather consider patent breadth as an exogenous legal parameter (in Section 3) or as the result of the firms' strategies (in Section 4).

My model is actually developed in such a way that the optimal patent breadth is zero, so that the firms can innovate freely. I thereby build a bridge with the notion of independent invention defense (Maurer & Scotchmer, 1998). The notion consists in arguing that social efficiency requires that innovations should not be deemed infringing if they have been developed without the knowledge disclosed in the infringed patent.

5.2.2 Complementary patents, cross licensing and R&D investments

The pattern where one final product is blocked by several complementary but non-sequential patents has been focused on by Shapiro (2000), Gilbert (2002) and Lerner and Tirole (2004). This approach has especially been privileged to analyze cross licensing and patent pool agreements. One hardship in this approach is to define the complementarity between patents. In a seminal paper, Shapiro (2001) considers innovations that are perfect complements. This enables him to match the antitrust definition of "essential patents" as patents that have no substitutes. Neither essentiality nor pure complementarity do however capture all possibilities of combining innovations with each other. Lerner and Tirole (2004) especially emphasize that complementary patents at time t may become substitutes at time $t+1$ if both enable the development of competing subsequent innovations. Lerner and Tirole thus go back to the more general definition of substitutability and complementarity, namely that goods A and B are substitutes (respectively complements) if increasing the price of A increases (respectively decreases) the demand for B . They propose a model where patents are complements for low prices - because increasing the price of one patent increases the price of the whole bundle - and substitutes for high prices - because beyond a price threshold the technology user will only buy one patent (and, for instance, invent around the second one).

The way I define blocking patents in this chapter implies another interpretation of complementarity which is closer to the legal definition of a patent. I consider that courts ultimately decide whether patents are essential inputs of the allegedly infringing products. This requires for each patent that the court rules (*i*) that the patent scope includes the

product, so that an infringement claim is valid, and (ii) that the patent itself is not invalid, e.g. that it satisfies all patentability requirements. An important consequence of this definition is that complementarity does no more depend on the technology underlying the patents, nor on the prices and demands for other patents as in the Lerner and Tirole (2004) model, but on the probability that a patent is held infringed by a court. The definition therefore builds upon Shapiro (2003) and Shapiro and Lemley (2004) who emphasize the probabilistic nature of patents but do not explicitly derive the probabilistic nature of patent complementarity. It is similar to the definition used by Choi (2002) in his analysis of the incentives to form patent pools and cross-licensing agreements "in the shadow of litigation".

The economic problem raised by complementary patents has been so far formulated in terms of multiple marginalization due to a decentralized pricing. Shapiro (2001), Choi (2002), Lerner and Tirole (2004) and Kim (2004) show that cross-licensing or pooling the patents raise welfare because they are a way to coordinate the pricing of complementary patents. By contrast, cross licensing or pooling substitute patents harm welfare, hence the antitrust requirement that only essential patents should be pooled. Lerner and Tirole also demonstrate that requiring that the members of a pool have the possibility to license their patents independently is sufficient to screen out inefficient pools. Lerner and alii (2002) valid empirically these results regarding the efficiency (respectively, inefficiency) of pooling complementary (respectively, substitute) patents, as well as the independent licensing requirement. By contrast with these papers, my model ignores the multiple marginalization issue. Rather than on prices, it focuses on R&D investments within a vertically integrated industry.

Shapiro (2001), Choi (2002) and Lerner and Tirole (2004) consider a basic framework where patent owners and patent users are perfectly separated. Lerner and Tirole however propose extensions of their static model. They consider especially the case of two patent owners competing on the same downstream market. Interpreting patents as differentiation factors, they show especially that making cross royalties illegal per se would impeach the creation of welfare increasing patent pools. I similarly consider two patents owners who compete on the same market. Thanks to my probabilistic definition of complementary patents, I can however assume that the downstream products are perfect substitutes, and thereby have a simpler specification of the product market.

Few theoretic papers study the dynamic impact of blocking patents and cross-licensing agreements on R&D investments. Fershtman and Kamien (1992) develop a model in which two firms engage in a patent race for two complementary patents. They use it especially to evaluate the impact of cross-licensing agreements that may take place if each firm has patented one different complementary innovation. They show first that cross-licensing agreements do not allow a perfect coordination of firms' R&D efforts. Although it takes more time to achieve both innovations if cross-licensing is forbidden, such agreements indeed do not match the R&D efficiency that a centralized coordination would achieve. This is due to inefficient strategic behaviors by the firms, who tend to retard the development of the technology in which they have a cost advantage, and seek to patent first the other technology in order to deter their competitor. Fershtman and Kamien (1992) also shed light on the social trade-off underlying cross-licensing agreements. On the one hand cross-licensing improves the efficiency of the R&D investments by eliminating the duplication of

efforts. But on the other hand, it favours collusion between the firms.

My model captures a similar trade-off, but it differs from Fershtman and Kamien (1992) in several important aspects. Firstly, the complementarity between patents is probabilistic. In that respect pure complementarity becomes a particular case, and I can explore further how probabilistic complementarity may determine the firms' cooperation and investment strategies. Secondly, my R&D race setting includes not only a stage of research investment for the patents, but also a stage of product development upon the patents. I thereby introduce in the analysis a dimension of R&D investments which has often been neglected in the literature, namely the follow-on investments that need to be done until a new technology is commercialized. This allows to capture how firms can use cross-licensing agreements to control the intensity of R&D competition. By contrast with Fershtman and Kamien (1992)'s model, such agreements do not always improve the efficiency of R&D. As I show below, they may also be a way for the firms to collude on lower investments.

5.2.3 Surveys and empirical studies

The fourth section of the chapter focuses on the accumulation of blocking patent by the firms. It provides a theoretical explanation for the findings of several surveys and empirical studies by explaining the motives and effects of patent portfolio strategies.

In a survey of 1478 R&D labs in the U.S. manufacturing sector, realized in 1994, Cohen, Nelson and Walsh show that the ranking of the motives to patent may vary between industries. They draw a distinction between "discrete" and "complex" technologies. When the technology is "discrete", as in pharmaceuticals or chemicals, a marketable product or process comprises relatively few patentable elements. In this case preventing copying is

the main motive for patenting innovations. By contrast, when a technology is "complex", a marketable product or process comprises relatively numerous patentable elements. This corresponds to sectors such as telecommunications equipment, semiconductors, software or biotechnology. Here firms often do not have control over all the patented components of the technology that they are developing. They need to secure an access to other firms' patents, which requires especially preventing suits and negotiating licenses. As shown by Cohen, Nelson and Walsh, blocking patents may then provide useful bargaining chips for this purpose.

Hall and Ziedonis (2001) show also that in the US semi-conductor industry, the need to cross-license complementary patents has led the firms to engage into strategic patenting, which may finally be detrimental to competition and innovation. Testing a theoretical model developed by Bessen (2003), Bessen and Hunt (2004) show that a weak enforcement of patent requirements in the software industry leads to similar strategies of patent portfolio building and cross-licensing. They find that strategic patenting has a negative effect on innovation, because it does not correspond to real innovation, and it raises the cost of innovation for other firms.

My model provides theoretic explanations for these empirical findings. By separating the decisions on patenting and on R&D investments in Section 5.4, I show that firms tend to accumulate blocking power to hold up their competitor, which reduces R&D investments. I also propose a theoretical distinction between industries that matches Cohen and alii (2000)'s distinction between "discrete" and "complex" technologies, although it does not rely on the same premisses. Indeed, I find that firms have an incentive to accumulate

patent portfolios only when it is profitable to reduce the intensity of R&D competition. The fragmentation of "complex" technologies into numerous patents would therefore be the result of such incentives. By contrast firms have no incentives to file additional blocking patents when R&D is expensive and innovation is uncertain. As a result innovations would be protected by one or few patents as in Cohen and alii (2000)'s definition of "discrete" technologies. My model finally upholds Bessen and Hunt (2004)'s argument that a weak enforcement of the patentability requirements fosters the accumulation of patent portfolios to the detriment of innovation and social welfare, and even in some cases to the detriment of the firms' profits.

5.3 Exogeneous blocking patents and ex ante licensing agreements

5.3.1 The model

I consider a situation where two symmetric firms (referred to as firm A and firm B) sequentially invest in R&D. Figure 5.1, presented below, gives an extensive form representation of the game I will analyze.

Initially, both firms invest in R&D to create a basic innovation that is necessary to develop a new product at the second stage. Each firm can achieve a basic innovation with a probability x at a cost $c(x)$. When achieved, the first stage innovations are granted a patent. The power this patent grants is discussed after the description of the timing.

Besides the technical information disclosed in patents, the basic innovations also consist in knowledge that is protected by trade secret. I consider that both this secret

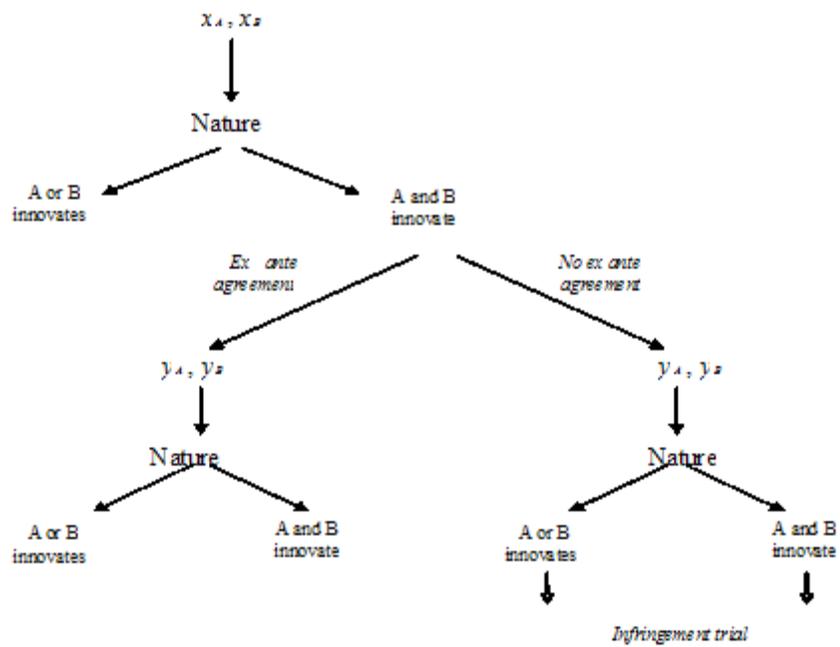


Figure 5.1: Timing of the model.

knowledge and the information disclosed in the patents are necessary to develop a patent upon the basic innovation. This assumption is consistent with the reality of some industries, such as computer hardware and semiconductors, where "the disclosure of information through patents is seldom sufficient for a rival to replicate the innovation" (FTC, 2003). Therefore, I consider that a firm can be successful at stage 2 only if it was successful at stage 1.

In the second stage, each patent owner invests $c(y)$ and develops a product with a probability y . I assume that there are no additional production cost. The demand for a final product comes from a mass of consumer that is set equal to 1, with a willingness to pay equal to 1 for either product. Thus a monopoly price on the product market grants a profit equal to 1. If both firms are successful, I assume that they compete à la Bertrand on the product market. This very simple setting does not take into account any deadweight loss effect, so that the dynamic effects that the model exhibits are independent from the multiple margins issue.

For a better exposition and in order to reach explicit results I assume that the cost function is such that $c(t) = \frac{\delta}{2}t^2$, with $t = x, y$ and $\delta > 1$. (Results hold for different cost parameters δ_t at stages 1 and 2 or under more general convex functions.)

I now define how I have incorporated the concept of blocking patents. I assume that each patent confers a perfect protection against imitation. Moreover, and more importantly, I consider that patents can be used to block the competitor's product although it has been developed independently. I define firm i 's patent breadth (denoted i , $i = 1; 2$) as the probability that firm j 's product is held infringing firm i 's patent. Let

$$\phi_i = \phi + \tilde{\varepsilon}_i, i = A, B.$$

where ϕ reflects the patent breadth set by the policy in vigor and $\tilde{\varepsilon}_i$ is a realization of a random variable $\tilde{\varepsilon}$ with mean zero. According to this formalization the firms are symmetric as each patent has the same breadth on average.

As for the consequences of infringing, I consider two possible settings. The first referred to as "unrestricted patent" reflects patent protection in its most general form. Patents permit to rule out any infringing product from the market so as to make monopoly profits. The second setting aims to capture the concept of compulsory licensing. I refer to it as "restricted patent". In that case, firms must compete à la Bertrand even when a patent is held infringed. When infringing a firm must pay a royalty to the patent holder. Thus, firms may have different marginal cost depending on whether their product infringes their opponent's patent.

Note that the parameter ϕ provides a proxy of the complementarity between the firms' basic patents. Indeed, as a Court holds one firm's patent essential to its competitor's product, which occurs with probability ϕ , it acknowledges a complementarity between this patent, as a legal input, and the infringer's basic patent, as a technical input. Moreover, if each patent is held essential to the competitor's product, which happens with probability ϕ^2 , then the patents become perfect legal complements for all the industry.

5.3.2 Downstream investments

In this section, I focus at the downstream investments. As a first step, I quickly describe what happens if only one firm has innovated at stage 1. I then compare as a second

step unrestricted and restricted patents in case the two firms have innovated at stage 1. I finally consider early cross licensing agreements between the firms.

Single patent owner

When a single firm owns a patent after stage 1, it is the only one who can innovate downstream and will be a monopolistic seller if it succeeds. Therefore whether an agreement has been signed or not is irrelevant in this case and the firm always invests y^m such that

$$y^m \in \arg \max_y y - c(y).$$

This leads to $y^m = \frac{1}{\delta}$ and generates a profit $\Pi^m = \frac{1}{2\delta}$. Second period investments will differ as I consider situations where both firms were initially successful. For each possible scenario I now evaluate second period investments when both firms are patent owners.

Two patent owners, no agreement

Assume, simply for notation purpose, that ϕ_A and ϕ_B are common knowledge before the firms invest. Let π_i^j with $i, j = A, B$ denote firm j 's profit when firm i only succeeded downstream. Let π_{AB}^i denote firm i 's profit when both firms succeeded downstream.

The case of unrestricted patents When firm i is the only successful firm downstream, I have:

$$\begin{aligned}\pi_i^i &= (1 - \phi_j) + \frac{\phi_j}{2}, \\ \pi_i^j &= \frac{\phi_j}{2}.\end{aligned}$$

When only firm i ($i = A, B$) succeeds at stage 2, firm j , $j \neq i$, can use its patent to sue i for infringement. If the Court rejects the infringement claim, firm i is a monopoly.

If the Court upholds the claim firm j 's patent is essential and firm i cannot sell its product without j 's agreement. In that case, firms i and j share equally the monopoly profits¹.

Assume now that both firms succeed at stage 2. I then have:

$$\pi_{AB}^i = \phi_i (1 - \phi_j) + \phi_i \phi_j \frac{1}{2}, \quad i = A, B.$$

Both firms can use their initial patent to sue their competitor for infringement. If both claims are rejected, the firms have no choice but compete à la Bertrand and get no profit in equilibrium. If both patents are held essential then the firms are entitled to extract and share equally the monopoly profit. If only one patent is held essential, the firm with the essential patent can exclude its opponent from the market and extract the monopoly profit.

Given the above, I can express firm i 's expected profit in the second stage as

$$\Pi_2^U = y_i (1 - y_j) \left(1 - \frac{\phi_j}{2}\right) + y_i y_j \phi_i \left(1 - \phi_j \frac{1}{2}\right) + (1 - y_i) y_j \frac{\phi_i}{2} - \frac{\delta}{2} y_i^2, \quad i = A, B, i \neq j. \quad (1)$$

Since ϕ_A and ϕ_B are equal on expectation, I have a symmetric equilibrium investment such that:

$$y^U = \frac{1 - \frac{1}{2}\phi}{1 + \delta - \phi + \frac{1}{2}\phi^2}.$$

(I use the upper-script U to refer to unrestricted patent.)

The case of restricted patents Let r denote the royalty that a firm must pay if it held infringing by a court. If firms decide on the royalty to be paid, I will assume that it corresponds to the Nash bargaining outcome and I have $r = \frac{1}{2}$. Alternatively, the royalty

¹Equal sharing corresponds to the Nash bargaining solution.

could be set by a regulatory agency so as to maximize total welfare. Assume that only firm i ($i = A, B$) succeeds at stage 2. I have:

$$\begin{aligned}\pi_i^i &= (1 - \phi_j) + \phi_j(1 - r), \\ \pi_i^j &= \phi_j r.\end{aligned}$$

If a single firm succeeds, competition does not come into play and payoffs are the same as those achieved under unrestricted patent for $r = 1/2$. Assume that both firms succeed at stage 2. There are now 2 products on the market and firms compete à la Bertrand. Whether a firm's patent is essential determines its opponent's marginal cost. I have

$$\pi_{AB}^i = \phi_i(1 - \phi_j)r + \phi_i\phi_j\frac{r}{2} \text{ with } i = A, B \text{ and } j \neq i.$$

If no patent is essential, then marginal cost equals zero for firms compete away their profits. If both patents are essential then both firms must pay each other a royalty and marginal cost equals r for both and in equilibrium $p = r$, each firm sells to half of the market. All the firms earn is the royalty revenue. Finally, if one patent only is essential firms become asymmetric with one firm with zero marginal cost (the one with the valid patent) and one firm with a marginal cost equal to r . The Bertrand model predicts that $p = r$ and both sell $q = 1/2$. The firm without essential patent makes no profit, while the firm with the essential patent gets r .

Firm i ($i = A, B$) expects:

$$\Pi_2^R = y_i(1 - y_j)(1 - \phi r) + (1 - y_i)y_j\phi r + y_i y_j \phi r \left(1 - \phi \frac{1}{2}\right) - \frac{\delta}{2} y_i^2, \quad i = A, B, i \neq j. \quad (2)$$

In equilibrium I have:

$$y^R = \frac{1 - r\phi}{1 + \delta - r\phi + \frac{r}{2}\phi^2}.$$

Comparative statics

Proposition 5.1 *Downstream investments are strictly decreasing (and concave) with the expected patent breadth ϕ . Under restricted patents, y^R decreases with the royalty r . (The proof is obvious and thus omitted.)*

The firms will free ride on each other's investments. Expression $(1 - y_i) y_j \frac{\phi_i}{2}$ in equation (1) and expression $(1 - y_i) y_j \phi r$ in equation (2) are the free riding benefit. As Patent breadth increases, these revenues increase (provided $r > 0$) which deters the firms' incentives to invest in R&D.

The fact that increased patent protection systematically lowers R&D investments may seem surprising. Recall however that the parameter ϕ only captures the likelihood that a product infringes while it has been developed upon a different basic innovation. By contrast, I have assumed that patent protection is perfect vis-à-vis imitations. Thus, proposition 1 puts in perspective the free riding behavior that prevails when patents give their owners the right to grasp part of some value created independently and separately and which would have arisen whether or not the patent owner had been successful upstream.

Proposition 5.2 The second period expected profit under unrestricted patents is inverse

U shaped with respect to ϕ .

The second period expected profit under restricted patents is such that

- for any $\delta > 1$, there exists a range of royalties $[0; \hat{r}]$ with $\hat{r} < \frac{1}{2}$ such that for any $r \in [0, \hat{r}]$, Π_2^W reaches a maximum at $\phi = 1$. As the cost of investment increases, this interval shrinks as \hat{r} decreases (but it never disappears).

- for any $\delta > 1$, and any $r > \hat{r}$, the second period expected revenue is inverse U shaped with respect to ϕ .

Proof. See Appendix 5.1. ■

Lower levels of patent breadth are associated with higher investments. Firms are then more likely to succeed and compete away their profits since infringement claims will most likely be rejected. Thus expected profits are low for narrow patents. Higher levels of patent breadth are associated with low investments (provided r is sufficiently high). Firms are more unlikely to succeed as each counts on the free riding revenue. I face a situation comparable to under-provision of a public good in which both firms hope that the other will invest to generate some value. As a result both invest too little and the expected revenue is small. By implementing small enough royalties a regulatory agency has the possibility to counteract the free riding incentive. Notice in particular that setting $r = 0$ wipes out any free riding revenue and transforms the game into a single winner takes all patent race.

Ex ante agreement

I now investigate how the presence of an ex ante agreement can affect the firms' investments at stage 2. Assume that the firms have the possibility to sign an arrangement before investing in the second period. This agreement consists in fixing a royalty per unit of output conditional on developing the downstream product. The firms then commit not to sue each other for infringement afterwards.

This type of agreements are conform with the antitrust guidelines regarding patent pools. They especially rule out the possibility of contingent royalties that would allow the

firms to share the monopoly profits even if both develop a new product. I also consider that the firms cannot collude by renegotiating the agreements ex post if both have developed a new product.

If a single firm succeeds in developing the product I have:

$$\begin{aligned}\pi_i^i &= 1 - \psi, \\ \pi_i^j &= \psi.\end{aligned}$$

The successful firm gets the monopoly profit minus the royalty which is paid to the non successful firm.

If both firms succeed, they compete à la Bertrand and each firm's marginal cost is equal to ψ . Thus I have:

$$\pi_{AB}^i = \frac{\psi}{2}, i = A, B.$$

Expected profits for the second period are then given by:

$$\Pi_2^A = y_i(1 - y_j)(1 - \psi) + y_i y_j \frac{\psi}{2} + (1 - y_i)y_j \psi - \frac{\delta}{2} y_i^2, i = A, B, i \neq j.$$

In equilibrium each firm invests

$$y^A = \frac{1 - \psi}{1 + \delta - \frac{\psi}{2}}.$$

Proposition 5.3 *When an ex ante agreement is settled, the second period investment is decreasing in royalty ψ . (The proof is obvious and therefore omitted.)*

A higher royalty only encourages investment when both firms succeed and each gathers rents through the royalty. In any other case a higher royalty either means lower rents or greater free riding revenue. Thus overall the investment decreases with the royalty.

Proposition 5.4 *If an ex ante agreement is settled, the expected payoff is inverse U shaped with respect to ψ and there exists a unique $\hat{\psi} = \underset{\psi}{\text{ArgMax}} \Pi_2^A(\psi)$.*

Proof. *See Appendix 5.2. ■*

Though the structure of the payoffs differs from the case without ex ante agreement, these results therefore establish that the main features of the competition that were valid without ex ante agreement remain valid. The patent royalties induce a free riding, which reduces their investment efforts. This has first a positive effect on the firms' expected payoffs when the royalties are low, but the effect on the expected payoffs becomes negative when the royalties are too high. I can deduce from that the firms will settle on the royalty rate $\hat{\psi}$ that maximizes their expected payoffs at stage 2.

5.3.3 Comparing the scenarios

Investment in R&D

The socially optimal level of downstream investment is given by

$$y^* = \underset{y}{\text{ArgMax}} \left[1 - (1 - y)^2 \right] - 2c(y)$$

It maximizes the expected generated surplus minus the cost of obtaining this surplus. Formally, I have

$$y^* = \frac{1}{1 + \delta}$$

The table below summarizes my findings in terms of downstream investments.

No ex-ante agreement Unrestricted patent	Ex ante agreement	No ex-ante agreement restricted patent
$y^U = \frac{1 - \frac{1}{2}\phi}{1 + \delta - \phi + \frac{1}{2}\phi^2}$	$y^A = \frac{1 - \psi}{1 + \delta - \frac{\psi}{2}}$	$y^R = \frac{1 - r\phi}{1 + \delta - r\phi + \frac{r}{2}\phi^2}$

Table 5.1: Downstream investment under the three scenarii.

Proposition 5.5 *In absence of an ex-ante agreement, downstream investments are suboptimal (provided $r > 0$) for any positive level of patent breadth ($\phi > 0$). An ex-ante agreement will always fail to reach the socially optimal investments.*

Proof. Recall that y^U and y^R , and y^A are decreasing in ϕ and ψ respectively (provided $r > 0$). I have $y^T = y^*$ with $T = U, R, A$ if and only if $\phi = 0$ for $T = U, R$ and $\psi = 0$ for $T = A$. Thus for any $\phi, \psi > 0$, I have $y^T < y^*$, for $T = U, R, A$. The fact that ex-ante agreement will always fail to lead to socially optimal investment stems from the fact that $\left. \frac{d\Pi^A}{d\psi} \right|_{\psi=0} > 0$. Thus firms will always set a strictly positive royalty. ■

The above result does not imply that no protection of innovation is optimal. It just captures the effect of patent protection as a legal mean for the firms to hold up products that have been developed independently by their competitor. The above result states that the ability given by patents to obtain rights of such independent products, that would have been developed even without the patent holder's innovation, is detrimental to innovation.

Lemma 5.1 *A regulatory agency can implement efficient investments by imposing compulsory free licensing (set $r = 0$).*

When patents owners are in a position to legally block infringing innovations, they are tempted to free ride on their competitor's investments. By imposing free licensing a

regulatory body can inhibit free riding and restore efficient investments. A similar remark can be made as regards the ex ante agreement. An ex ante agreement with $\psi = 0$ is equivalent to a case where the firms cannot use their patents to block their rival and simply compete without being threatened by imitators. This case too appears to trigger optimal downstream investments. Introducing a positive royalty would indeed reduce the profit of a successful innovator, and thereby lower the incentives to innovate.

Agreement versus non-agreement

For any given cost of investment, the firms decide to settle ex-ante if and only if $\Pi_2^A(\hat{\psi}) \geq \Pi_2^T(\phi)$ with $T = U, R$. I can rewrite the second period profits as

$$\Pi_2^U = \frac{\phi}{2}y^U + \frac{\delta}{2}(y^U)^2,$$

and

$$\Pi_2^R = r\phi y^R + \frac{\delta}{2}(y^R)^2,$$

and

$$\Pi_2^A = \psi y^A + \frac{\delta}{2}(y^A)^2, \tag{5.1}$$

I have, for any $r \geq 0$ and $\delta > 1$,

$$\Pi_2^U|_{\phi=0} = \Pi_2^R|_{\phi=0} = \Pi_2^A|_{\psi=0}.$$

Proposition 5.6 *For any cost parameter $\delta > 1$, there exists $\underline{\phi}^U < 1$ and $\bar{\phi}^U > \underline{\phi}^U$ such that firms settle ex-ante in either cases:*

- when patents are weak (that is $\phi \in [0, \underline{\phi}^U]$) so as to save on otherwise high investments and escape competition.

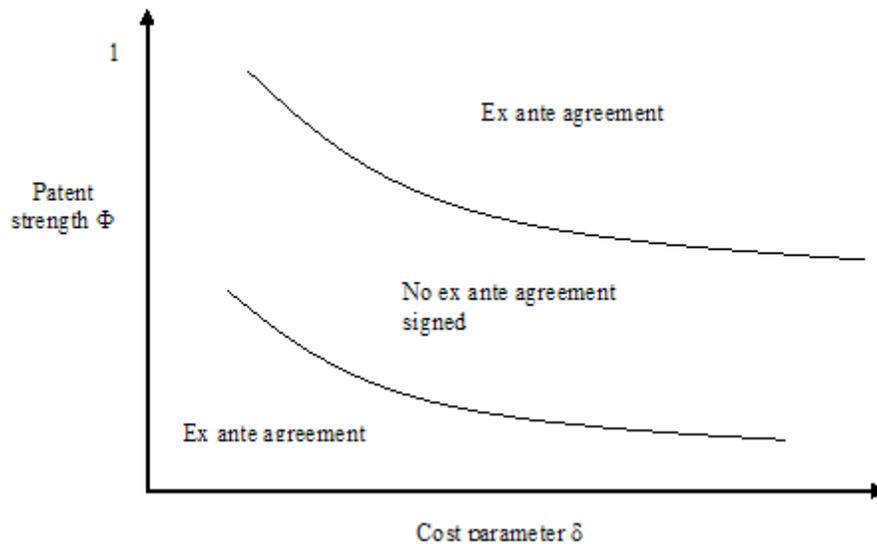


Figure 5.2: Decision to sign ex ante agreements.

- when patents have a strong blocking capacity (that is $\phi \geq \min \left\{ \frac{-U}{\phi}, 1 \right\}$) to overcome the free riding issue and settle on low royalties.

Proof. See appendix 5.3 ■

Figure 5.2 gives a visual representation of the above proposition.

Firms may settle for two, very distinct, reasons. The first is to pool blocking patents (characterized by a high patent breadth parameter ϕ) when downstream investment is costly. This corresponds to the northeast region of the graph. This motive is pro-competitive. Indeed, firms prefer to settle on (lower) royalties and overcome the free riding issue that deters investment. The second motive is to seize an opportunity to collude when patents are unlikely to be held essential and investment in R&D is not expensive. Without an ex ante agreement investment in R&D would be high and firms would compete away

their profits. The ex ante agreement leads to lower investments and limits the probability of competing away their profits. This second motive is rather anti-competitive.

Lemma 5.2 *If compulsory licensing is implemented and firms settle on a royalty $r = 1/2$ (corresponding to the Nash bargaining solution) then the set of parameters δ and ϕ for which firms settle shrinks as it appears in figure 3.*

If compulsory free licensing is implemented then firms will always settle ex-ante.

Proof. The second statement is obvious since $\Pi_2^R(0) = \Pi_2^A(0) < \Pi_2^A(\hat{\psi})$. The first statement relates to the previous proposition and stems from the fact that for $r = 1/2$, I have

$$\Pi_2^R(\phi) \leq \Pi_2^U(\phi) \text{ for all } \phi, \text{ with equality at } \phi = 0 \text{ only.}$$

■

To reach efficient investments, a regulatory authority should implement compulsory free licensing. Setting $r = 0$ is optimal for any level of patent breadth. Unfortunately, such a policy would result in firms systematically agreeing ex-ante, and therefore would be ineffective. Basically, for any $r < \hat{r}$ will always choose to sign an ex-ante agreement to save on otherwise high investments and to escape the dramatic consequences of the Bertrand competition leading to a revenue at most equal to r . Thus, the royalty must be sufficiently high to prevent firms resorting to systematic ex-ante agreement.

5.3.4 Upstream investment and welfare

I now move to the first stage. A first question consists in analyzing the determinants of the upstream investment. Let the variable γ refer to either ϕ or ψ . The expected

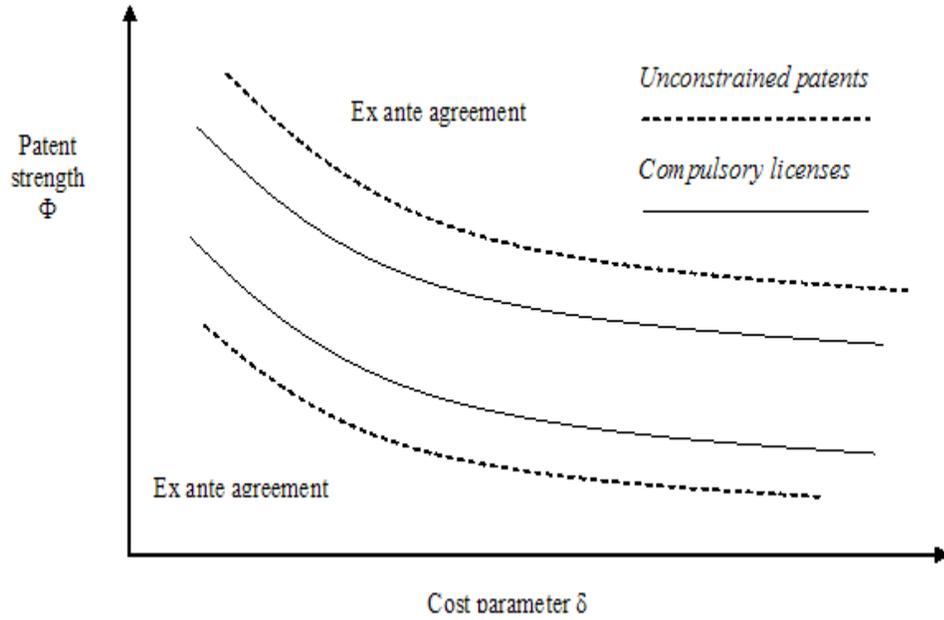


Figure 5.3: Effect of compulsory licensing on ex ante agreements.

profit from the first stage investment is given by:

$$\Pi_1(\gamma) = x_i(1 - x_j) \frac{1}{2\delta} + x_i x_j \Pi_2^T(\gamma) - \frac{\delta}{2} (x_i)^2, i = A, B, j \neq i, T = U, R, A.$$

If a firm succeeds while its opponent fails it has no competitor in the second period. In that case it invests y^m and gathers $\Pi_2^M = \frac{1}{2\delta}$ in the second period. If both firms succeed, the expected profit is given by $\Pi_2^T(\gamma)$ with $T = U, R, A$ depending on what regime prevails in the second period.

A firm selects the investment level non-cooperatively, the Nash solution is symmetric and is given by:

$$x(\gamma) = \frac{\Pi_2^M}{\delta + \Pi_2^M - \Pi_2^T(\gamma)}$$

Given that $\Pi_2^T(\gamma) < \Pi_2^M$ for any $T = R, U, A$, I have $x(\gamma) \in [0, 1]$.

Lemma 5.3 1) *The upstream investment $x(\gamma)$ is inverse U shaped with respect to γ .*

2) *Under ex ante agreement, the royalty $\hat{\psi}$ set by the firms maximizes the upstream investment $x(\psi)$.*

3) *Under ex ante agreement, the royalty maximizes the firms' profits over the two periods.*

4) *The total profits $\Pi_1(\phi)$ are higher than $\Pi_1(\hat{\psi})$ when the firms decide not to settle ex ante.*

(The Proof is obvious and thus omitted.)

As one could expect the impact of either a royalty or a patent breadth increase on upstream investments is contingent on the impact it has on future expected profit. It follows directly that, as $\Pi_2^T(\gamma)$, $x(\gamma)$ first increases and then decreases with γ . An important consequence is that when the firms sign an ex ante agreement, they set the royalty at the level $\hat{\psi}$ that maximizes the upstream investment. It can be checked easily that this royalty level also maximizes the firms' profits $\Pi_1(\psi)$ over the two periods.

The main question is now to evaluate the social efficiency of the investments $(x(\gamma), y(\gamma))$. Let $W(\gamma)$ denote the total welfare. After some simplifications, I have

$$W(\gamma) = 2x(\gamma)(1-x(\gamma))\frac{1}{2\delta} + (x(\gamma))^2 \left[1 - (1-y(\gamma))^2 - \delta y(\gamma)^2 \right].$$

Proposition 5.7 *Total welfare is decreasing in both ϕ and ψ (for any $r > 0$).*

Proof. *See Appendix 5.4* ■

Granting firms a legal possibility to block innovations deters welfare. Besides, offering firms the possibility to pool potentially blocking patents will not restore efficiency.

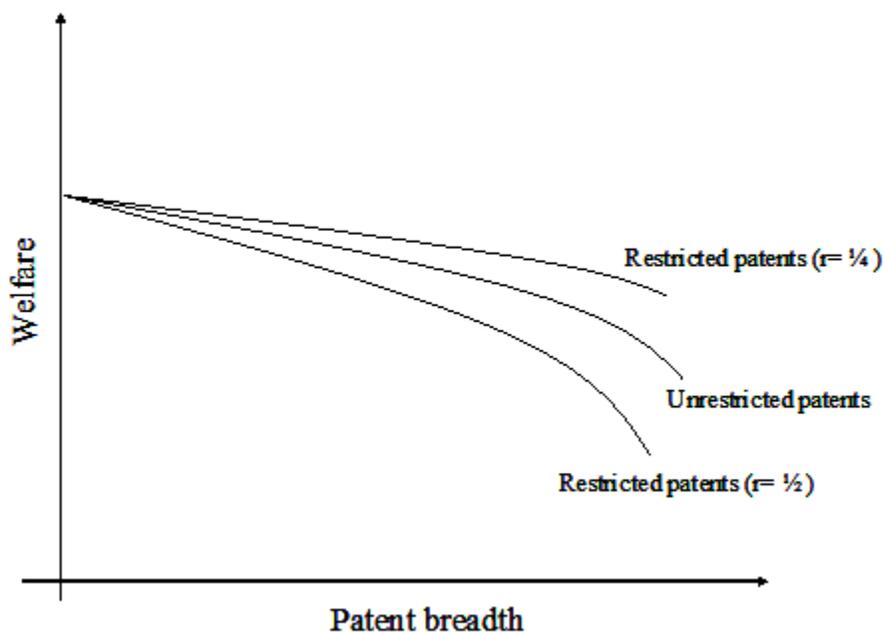


Figure 5.4: Total welfare in function of the patent breadth.

This result suggests that the only form of protection that would lead to efficient investment is one against copies. The narrower the patents, the better.

Figure 5.4 illustrates this last point. It represents total welfare under unrestricted patents and compares it with the one reached under restricted patents $r = 1/2$ and $r = 1/4$.

As one can see in the graph above, compulsory licensing can be welfare improving if the regulatory body can impose of low royalty.

Lemma 5.4 1) *Any strictly positive level of cooperative royalties will always fail to maximize total welfare.*

2) *Compulsory licensing will also fail to maximize total welfare. At best, if $r = 0$ and if no ex-ante settlements are permitted it will restore second period efficiency but lead to under investment in the first period.*

3) There exists ϕ^U such that for all $\phi < \phi^U$ welfare is higher without ex-ante settlements and for all $\phi > \phi^U$ welfare is higher with ex-ante settlements. This corroborates the finding according to which it is best for the firms to settle only when patents are very likely to be blocking.

Proof. Point 1 and point 3 are obvious as welfare decreases with ψ and with ϕ and I have $W^A(0) = W^U(0)$. Thus, there exists a unique ϕ^U such that $W^U(\phi) > W^A(\widehat{\psi})$ if and only if $\phi < \phi^U$.

Point 2: Let (x^*, y^*) denote the socially optimal level of investments. The maximization of welfare leads to

$$y^* = \frac{1}{1 + \delta},$$

$$x^* = \frac{1 + \delta}{2}.$$

One can easily verify that $x^R(r = 0) = \frac{(\delta + 1)^2}{2\delta(\delta + 2\delta^2 + \delta^3 + 1) + 1} < x^*$, while $y^R(r = 0) = y^*$. ■

A scenario of compulsory licensing with $r = 0$ does not maximize welfare. Indeed only the downstream investment is then optimal, while the upstream investment is lower than optimal. This is because at the first stage, the firms do not internalize the consumers welfare in case both of them succeed at stages one and two and, as a result, compete away their innovation surplus. This result suggests that, in a second best world, allowing innovators to use their patents to block each other could be a way to internalize this consumer surplus.

Figure 5.5 illustrates the last point in the above Lemma. It shows the values of ϕ above which setting an agreement is welfare improving and contrasts it with the regions for

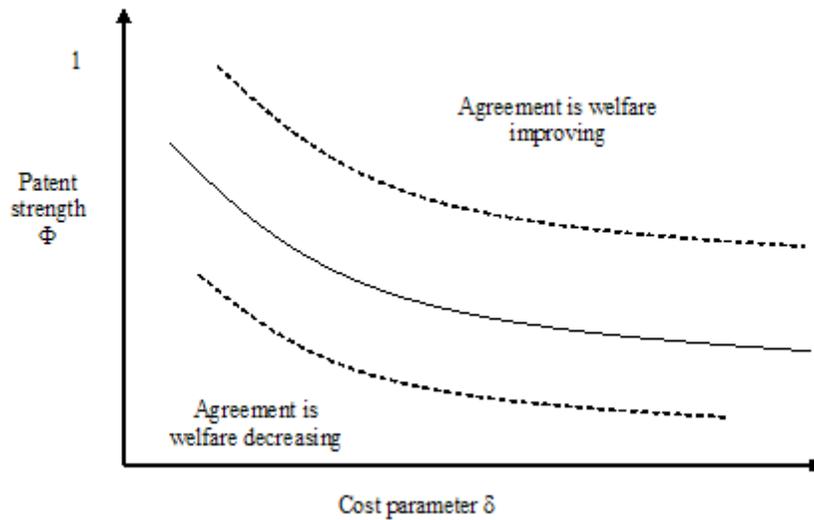


Figure 5.5: Social efficiency of the ex ante agreement.

which the firm would set an ex-ante agreement. Within the two blue lines the firm would not sign an ex-ante agreement.

5.4 Endogeneous blocking patents

In this section I consider that ϕ is endogeneous. There are two ways of interpreting this new assumption. A first interpretation is that the firms can decide on the formulation of the patent claims. This is what I do in the subsection 4.2, by assuming that increasing ϕ_i is costless for firm i . In subsection 4.3, a second interpretation is used as I consider that the firms can accumulate patents so as to increase the blocking power ϕ of their patent portfolio. As filing a patent is costly, this interpretation implies that increasing ϕ_i is costly for firm i . Unfortunately, solving for strategic patent breadths is complex in the model

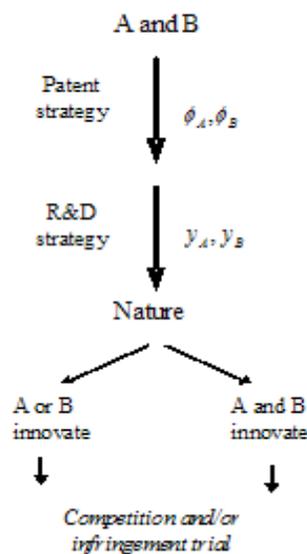


Figure 5.6: Timing of the model.

I have used so far. Thus, I first propose a simplified version of my model and then use simulations to reach some conclusions.

5.4.1 The model

The initial model is amended by assuming that, in the 1st stage, firms set their own patent breadth (non-cooperatively) instead of investing in an upstream innovation. The model has the following timing:

The variable ϕ_i ($i = 1, 2$) is verifiable. The patents are of the most common type: unrestricted. The time order between stages 1 and 2 can be justified as follows. The R&D and patenting process actually begin at the same time. However the firms have to adopt a patenting strategy very quickly (e.g. with the first R&D results) and this strategy is

observable by the competitor as patents are filed and granted. By contrast, the intensity of the R&D efforts is spread over the whole R&D period and can be adjusted during the period.

5.4.2 Endogeneous patent breadth

I consider the case in which increasing ϕ is not costly. At the symmetric equilibrium, the marginal benefit for firm i to increase ϕ_i must be zero. Assume a symmetric equilibrium exists² and let ϕ^* denote a non-cooperative solution. It must be such that:

$$\left. \frac{d\Pi_2^i}{d\phi_i} \right|_{\phi_i=\phi_j=\phi^*} = \frac{\partial\Pi_2^i}{\partial y_j} \frac{\partial y_j}{\partial\phi_i} + \left. \frac{\partial\Pi_2^i}{\partial\phi_i} \right|_{\phi_i=\phi_j=\phi^*} = 0. \quad (5.2)$$

It is straightforward to show that $\frac{\partial\Pi_2^i}{\partial\phi_i} > 0$, and that $\frac{\partial y_j}{\partial\phi_i} < 0$. Since $\left. \frac{\partial\Pi_2^i}{\partial y_j} \right|_{\phi_i=\phi_j=0} < 0$, I will always have $\phi^* > 0$. Finally one can verify that

$$\left. \frac{d\Pi_2^i}{d\phi_i} \right|_{\phi_i=\phi_j=1} = \frac{1}{2} \left(\frac{1}{4\delta^2 - 1} \right) [(4\delta^2 - 1)y(1) + 2\delta(y(1) - 1)] < 0$$

so that $\phi^* < 1$. I have simulated the marginal benefit for firm i to increase ϕ_i for different values of the R&D cost parameter δ ($\delta \in \{1.001; 1.01; 1.2; 1.5; 2; 5; 10\}$). In all the simulations it appears that $f(\phi)$ is continuous and decreasing in ϕ on $[0, 1]$ so that the symmetric equilibrium is unique. It is also interesting to compare it with the breadth $\hat{\phi}$ that maximizes the firms' joint profits.

Conjecture 5.1 *At the symmetric equilibrium the firms choose a level of patent breadth*

$\phi^ > 0$ that exceeds the level $\hat{\phi}$ that maximizes their expected profits.*

²Given that the strategy spaces are non-empty and compact sets, and given that the profit functions are continuous the existence of a Nash equilibrium is not at stake. Whether it is in pure strategies is more difficult to prove. Simulations show existence for the specific forms used.

	$\delta = 1.001$	$\delta = 1.01$	$\delta = 1.2$	$\delta = 1.5$	$\delta = 2$	$\delta = 5$	$\delta = 10$
$\hat{\phi}$	0.751	0.750	0.723	0.685	0.633	0.451	0.316
ϕ^*	0.921	0.922	0.943	0.962	0.978	0.996	0.999

Table 5.2: Simulations of the model with different research costs.

Besides fixing a positive and hence socially inefficient patent breadth, the firms also fix an excessive patent breadth with respect to the profit maximizing level. Hence at equilibrium, it would be both welfare and profit improving that they reduce their patents' breadth.

Whether firms fix an excessive patent's breath is not trivial. While equation (5.2) holds at the non cooperative solution, the parameter $\hat{\phi}$ is such that:

$$\left. \frac{d\Pi_2^i}{d\phi} \right|_{\phi=\hat{\phi}} = \frac{\partial\Pi_2^i}{\partial y_j} \frac{\partial y_j}{\partial\phi} + \left. \frac{\partial\Pi_2^i}{\partial\phi} \right|_{\phi=\hat{\phi}} = 0. \quad (5.3)$$

Note first that $\frac{\partial\Pi_2^i}{\partial\phi_i} > \frac{\partial\Pi_2^i}{\partial\phi}$, meaning that in a non-cooperative setting, firms only consider the direct impact of their own patent breadth on profits and disregard the fact that an increase in the competitor's patent breadth would reduce their gains. Hence they have an incentive to fix an excessive patent breadth. Since $\left| \frac{\partial y_j}{\partial\phi_i} \right| > \left| \frac{\partial y_j}{\partial\phi} \right|$, firm i moreover has an over- or under-incentive to raise ϕ_i ³ (everything else being equal) depending on whether it can benefit from its competitor's investment. At equilibrium, $\frac{\partial\Pi_2^i}{\partial y_j} > 0$, so that firm i can expect a benefit if firm j innovates, because of the hold up profits. Then the second effect reduces its incentive to raise ϕ_i . Simulations however show that it does not compensate the direct over-incentive to raise its patent breadth.

³Both of these derivatives are negative.

5.4.3 Costly patenting

Let us study now the case where increasing the blocking power $\phi_i, i = A, B$ of the firms' patents is costly. This corresponds to a case in which an innovator can file additional patents in order to increase the blocking power of its patent portfolio. Filing a new patent is costly and any additional patent is likely to have a weaker blocking power than the previous one. I thus assume that the cost for firm i to have a probability ϕ_i to block firm j 's product is given by $G(\phi_i)$, where $G(\phi_i)$ is increasing and convex and $G'(0) > 0$. Then the firms will set their blocking power $\phi_i, i = A, B$ by comparing its marginal cost and benefit.

Conjecture 5.2 *There is a threshold $\bar{\delta}$ of the R&D cost parameter such that*

- *If $\delta > \bar{\delta}$ firms do not invest in patent portfolios.*
- *If $\delta < \bar{\delta}$ firms invest in patent portfolios, and there exists a unique non-cooperative size of patent portfolio ϕ^* .*

According to the simulations, let us assume that the marginal revenue $\frac{\partial \Pi_2^i}{\partial \phi_i}$ is decreasing over $[0, 1]$. Two types of equilibria arise if patenting is costly.

- If $\left. \frac{\partial \Pi_2^i}{\partial \phi_i} \right|_{\phi=0} < G'(0)$ firms do not invest in patent portfolios, and $\phi^* = 0$.
- If $\left. \frac{\partial \Pi_2^i}{\partial \phi_i} \right|_{\phi=0} > G'(0)$, firms invest in patent portfolios, and there exists a unique

equilibrium ϕ^* .

Since $\left. \frac{\partial \Pi_2^i}{\partial \phi_i} \right|_{\phi=0}$ is decreasing in the R&D cost parameter δ , the first situation arises

in industries where R&D costs are high, whereas the second portraits low R&D industries.

This distinction has a good explanation power. In industries such as pharmaceuticals, where R&D is both expensive und uncertain, blocking strategies are indeed seldom. In this case reducing R&D investments by accumulating blocking power principally decreases the

probability of developing at least one innovation. By contrast, developing a new product is relative easy and cheap in an industry like software. As a result the probability is high that, absent any blocking patents, the competitors develop and market substitute products and have to compete neck and neck. In this case building a patent portfolio is a profitable strategy for the firms. Finally note that in such a setting with costly patent breadth it is possible that $\phi^* < \widehat{\phi}$.

Conjecture 5.3 *A uniform increase of the cost of patenting from $G(\phi_i)$ to $G(\phi_i) + \Delta$*

- *reduces the R&D cost threshold $\bar{\delta}$ above which firms do not invest in a patent portfolio, which is welfare improving.*
- *reduces the size ϕ^* of the equilibrium portfolio if $\delta < \bar{\delta}$, which is welfare improving and can be profit improving if $\phi^* > \widehat{\phi}$ or profit decreasing if $\phi^* < \widehat{\phi}$.*

A more severe policy of patent offices and courts vis-à-vis patent holders would trigger an increase in the cost of accumulating blocking power. This is welfare improving in that it reduces the patent portfolio strategies. Interestingly, it can also be profit improving for the firms in industries where R&D costs are low enough for the equilibrium portfolio ϕ^* to be beyond the profit maximizing level $\widehat{\phi}$.

5.5 Conclusion

This chapter focuses on a duopoly where the firms invest in R&D to develop products independently. I introduce the possibility for the firms to use their patents to hold up their competitor's product.

I consider first the case where the blocking power of the patents is an exogenous consequence of the patent policy, in order to study the incentive for the firms to sign ex ante licensing agreements and the welfare effects of their strategy. I show that allowing the firms to use their patents to block their competitors yields a free riding behavior as regard the development of new products. Indeed, the broader the patents, the lower the firms' investments in new products. As a result, the firms' expected payoffs if both have patented basic innovations is an inverse U shaped function of the patent breadth.

If the firms settle an ex ante agreement before developing new products, the level of the royalty has a similar effect to that of the patent breadth. The firms thus choose to settle ex ante on the level of royalty in two different cases. First the firms will settle if the patents are broad, while the creation of new products requires important investments. In this case setting a relatively low ex ante royalty is a way to cope with the free riding issue and to foster investments. But the firms will also settle ex ante in the opposite case, that is if the patents are narrow while creating new products is cheap. In this case, the firms would indeed invest in excess and compete away the profit from innovation. Thus they use relative high ex ante royalties in order to collude on lower investments and reduce the risk of competing neck and neck on the product market.

My model also predicts that the firms will not sign some agreements that would be welfare improving if the R&D cost and patent breadth are not important enough. I show however that introducing a duty to grant compulsory licenses on essential patents, is a way to foster the signing of an ex ante agreement. Indeed patent restriction lower the firms' profits and the social welfare if no agreement is signed, so that the firms have additional

incentives to organize the development of new products through ex ante agreements. I warn however that a policy of patent restriction through compulsory licences would favour both pro- and anti-competitive agreements.

I show that in any ex ante agreement that is signed, the royalty set by the firms will maximize their overall profits. Yet any positive royalty, as well as any possibility to use a patent to block a competitor, is detrimental to social welfare. Indeed the investments will be insufficient. A second best equilibrium can then be obtained if the patents only protect against pure imitation (minimal patent breadth), and if there is no royalty under ex ante agreement.

In the second part of the paper, I adapt the model to the case where the firms can decide the blocking power of their patents. I show first that if the firms can freely choose the breadth of their patents, they will fix it beyond the level that maximizes their joint profits. The firms increase the blocking power of their patents in order to reduce the intensity of R&D competition at the expense of social welfare, but they also fail to coordinate on the profit maximizing equilibrium.

I capture patent portfolio strategies as a second step by introducing a cost of patenting. I show that the strategies of the firms depend on the cost of R&D. In sectors where innovation is very costly and risky, such as pharmaceuticals, the firms will not build patent portfolios because there is no real problem of R&D competition. By contrast, the firms will accumulate patent portfolios in sectors such as software in which developing new products is easy. Indeed they can thereby reduce the intensity of R&D competition and increase their expected profits, at the expense of consumers. In that case, strengthening

the severity of the courts and patent offices is a way to prevent the accumulation of socially detrimental patent portfolios.

Appendix

5.5.1 Appendix 5.1: proof of Proposition 5.2

- Consider first the case of unrestricted patents:

By combining the expressions of $y^U(\phi)$ and $\Pi_2^U(y^U(\phi))$ I obtain:

$$\Pi_2^U = \frac{(2 - \phi)(2\delta + 2\phi + \delta\phi - 2\phi^2 + \phi^3)}{2(2\delta - 2\phi + \phi^2 + 2)^2}$$

It can be checked that:

$$\frac{d\Pi_2^U}{d\phi} = \frac{12\delta - 8\phi - 22\delta\phi + 6\phi^2 - 2\phi^3 + 12\delta\phi^2 - 2\delta^2\phi - 3\delta\phi^3 + 4}{(2\delta - 2\phi + \phi^2 + 2)^3}$$

$$\frac{d\Pi_2^U}{d\phi}(0) = \frac{12\delta + 4}{(2\delta + 2)^3} > 0$$

and

$$\frac{d\Pi_2^U}{d\phi}(1) = -\frac{\delta}{4\delta + 4\delta^2 + 1} < 0$$

Let us assume now that there exists at least one $\hat{\phi}$ such that $\frac{d\Pi_2^U}{d\phi}(\hat{\phi}) = 0$. The problem is unicity. Since $\frac{d\Pi_2^U}{d\phi}$ is continuous, $\hat{\phi}$ is unique if and only if $\frac{d^2\Pi_2^U}{d\phi^2}(\hat{\phi}) < 0$.

The sign of $\frac{d^2\Pi_2^U}{d\phi^2}(\hat{\phi}) < 0$ is the same as the sign of

$$-8 - 22\delta - 2\delta^2 + 12\phi(1 + 2\delta) - 3\phi^2(3\delta + 2)$$

which is the derivative of the numerator of $\frac{d\Pi_2^U}{d\phi}$. Since I care about the derivative at $\widehat{\phi}$, I need not worry about the rest which is 0 at $\widehat{\phi}$. The function

$$H(x) = -8 - 22\delta - 2\delta^2 + 12x(1 + 2\delta) - 3x^2(3\delta + 2)$$

is concave in x . I have $H(0) < 0$ and $H(1) < 0$. Moreover it maximizes at

$$x^* = \frac{2 + 4\delta}{2 + 3\delta} > 1$$

Thus for any $x < 1$, I have $H(x) < 0$. Thus I have $\frac{d^2\Pi_2^U}{d\phi^2} < 0$ at any $\widehat{\phi}$ such that $V_2'(\widehat{\phi}) = 0$.

Thus $\widehat{\phi}$ is unique.

It follows that for all $\phi < \widehat{\phi}$ I have $\frac{d\Pi_2^U}{d\phi} > 0$ and for all $\phi > \widehat{\phi}$ I have $\frac{d\Pi_2^U}{d\phi} < 0$. Thus there is only one value of $\widehat{\phi}$ maximizing Π_2^U , and $\Pi_2^U(\phi)$ is inverse-U-shaped on $[0; 1]$.

- Consider now the case of restricted patents:

Concavity of $y^R(\phi)$.

I have

$$\frac{dy^R}{d\phi} = r \left[\left(\frac{1 - \phi}{1 + \delta - r\phi + \frac{r}{2}\phi^2} \right) y^R(\phi) - \frac{1}{1 + \delta - r\phi + \frac{r}{2}\phi^2} \right]$$

Using the fact that $\frac{dy^R}{d\phi} < 0$, and given the above expression I have $\frac{d^2y^R}{d\phi^2} < 0$.

I can rewrite the expected profit as

$$\Pi_2^R = y^R - (y^R)^2 \left[1 + \frac{\delta}{2} - r\phi + \frac{r}{2}\phi^2 \right].$$

I have

$$\left. \frac{d\Pi_2^R}{d\phi} \right|_{\phi=0} = \frac{r(1+2\delta)}{(1+\delta)^3} > 0,$$

and

$$\left. \frac{d\Pi_2^R}{d\phi} \right|_{\phi=1} = \frac{\left. \frac{dy^R}{d\phi} \right|_{\phi=1}}{1+\delta-\frac{r}{2}} \left[r\delta + \frac{r}{2}\phi - (1-r)^2 \right].$$

The terms in brackets it negative for some $r < \hat{r}$ with $\hat{r} > 0$ and decreasing in δ . Given that the function $\Pi_2(\phi)$ is continuous, and continuously differentiable there exists at least one $\hat{\phi} \in (0, 1)$ such that $\left. \frac{d\Pi_2^W}{d\phi} \right|_{\phi=\hat{\phi}} = 0$ for $r > \hat{r}$. I will prove that it is unique by showing that the second derivative at such a point is always negative. The first order condition leads to:

$$2y(\hat{\phi}) \left(1 + \frac{\delta}{2} - r\hat{\phi} + \frac{r}{2}\hat{\phi}^2 \right) = 1 + \frac{r(1-\hat{\phi})y^2(\hat{\phi})}{y'(\hat{\phi})}.$$

The second derivative at $\hat{\phi}$ can be expressed as

$$\left. \frac{d^2\Pi_2^R}{d\phi^2} \right|_{\phi=\hat{\phi}} = y''(\hat{\phi}) - 2y''(\hat{\phi})y(\hat{\phi}) \left(1 + \frac{\delta}{2} - r\hat{\phi} + \frac{r}{2}\hat{\phi}^2 \right) + \Delta(\hat{\phi}).$$

with $\Delta(\hat{\phi}) < 0$. Using the first order condition I get

$$\left. \frac{d^2\Pi_2^R}{d\phi^2} \right|_{\phi=\hat{\phi}} = -\frac{r(1-\hat{\phi})y^2(\hat{\phi})}{y'(\hat{\phi})}y''(\hat{\phi}) + \Delta(\hat{\phi}) < 0.$$

Thus $\hat{\phi}$ is unique and I have $\frac{d\Pi_2}{d\phi} > 0$ for $\phi < \hat{\phi}$ and $\frac{d\Pi_2}{d\phi} < 0$ for $\phi > \hat{\phi}$.

Appendix 5.2: proof of Proposition 5.4.

By combining the expressions of $y^A(\psi)$ and $\Pi_2^A(y^A(\psi))$ I obtain:

$$\Pi_2^A = \frac{2(\psi^2 - 2\psi - \delta\psi - \delta)(\psi - 1)}{(\psi - 2\delta - 2)^2}$$

It can be checked that:

$$\frac{d\Pi_2^A}{d\psi} = \frac{2(10\psi - 6\delta + 16\delta\psi - 6\psi^2 + \psi^3 - 6\delta\psi^2 + 4\delta^2\psi - 4)}{(\psi - 2\delta - 2)^3}$$

$$\frac{d^2\Pi_2^A}{d\psi^2} = \frac{4(2\psi - \delta - 4)(2\delta + 1)^2}{(\psi - 2\delta - 2)^4} < 0$$

$$\frac{d\Pi_2^A}{d\psi}(0) = \frac{(3\delta + 2)}{2(\delta + 1)^3} > 0$$

and

$$\frac{d\Pi_2^A}{d\psi}(1) = -\frac{2}{2\delta + 1} < 0$$

Thus $\Pi_2^A(\psi)$ is inverse-U-shaped on $[0; 1]$, and there is only one value of $\hat{\psi}$ maximizing Π_2^A .

Appendix 5.3: proof of Proposition 5.6

The profit maximizing royalty $\hat{\psi}$ solves

$$2(1 + \delta) - \psi^3 + \psi^2(4 + 3\delta) - 2\psi(1 + \delta)(3 + \delta) = 0.$$

This expression is decreasing in ψ and strictly negative for $\psi = \frac{1}{2}$. Thus I have $\hat{\psi} < \frac{1}{2}$.

Consider any given $\psi \in [0, 1/2]$, let $\phi = 2\psi$, I have

$$\Pi_2^U(2\psi) = \psi y^U(2\psi) + \frac{\delta}{2} [y^U(2\psi)]^2,$$

with

$$y^U(2\psi) = \frac{1 - \psi}{1 + \delta - 2\psi(1 - \psi)} > y^A(\psi).$$

Given (5.1), I have $\Pi_2^U(2\psi) > \Pi_2^A(\psi)$. Thus I have proved that for any $\psi \in [0, 1/2]$, there exists at least one value for $\phi \in [0, 1]$ such that $\Pi_2^U(\phi) > \Pi_2^A(\psi)$. Since $\widehat{\psi} < \frac{1}{2}$, there exists at least one $\phi \in [0, 1]$ such that $\Pi_2^U(\phi) > \Pi_2^A(\widehat{\psi})$. Since expected profits are all inverse U shaped, it means that there exists $\underline{\phi}^U < 1$, such that $\Pi_2^U(\phi) < \Pi_2^A(\widehat{\psi})$ for all $\phi < \underline{\phi}^U$. Finally $\Pi_2^U(1)$ decreases with δ , as I have

$$\Pi_2^U(1) = \frac{3\delta + 1}{2(2\delta + 1)^2}.$$

Moreover I have:

$$\Pi_2^T(0) = \frac{\delta}{2(1 + \delta)^2} \text{ for } T = U, R, A.$$

For sufficiently large δ , I have $\Pi_2^U(1) < \Pi_2^A(0)$ thus, for sufficiently large δ , there exists $\overline{\phi}^U \in]\underline{\phi}^U, 1]$ such that $\Pi_2^U(\phi) < \Pi_2^A(\widehat{\psi})$ for all $\phi > \overline{\phi}^U$.

Appendix 5.4: Proof of proposition 5.7

Let $W(\gamma)$ denote the total welfare. I have

$$W(\gamma) = 2x(\gamma)(1 - x(\gamma))\frac{1}{2\delta} + (x(\gamma))^2 \left[1 - (1 - y(\gamma))^2 - \delta y(\gamma)^2 \right].$$

After simplifications, I have

$$\frac{dW}{d\gamma} = \frac{dx}{d\gamma} \left[\frac{1}{\delta} + 2x(\gamma) \left[2y(\gamma) - y^2(\gamma)(1 + \delta) - \frac{1 + \delta^2}{\delta} \right] \right] + 2(x(\gamma))^2 \frac{dy}{d\gamma} [1 - y(\gamma)(1 + \delta)].$$

Since

$$\frac{dx}{d\gamma} = 2\delta \frac{d\Pi_2^T}{d\gamma} [x(\gamma)]^2,$$

I can rewrite the derivative of total welfare as

$$\frac{dW}{d\gamma} = 2(x(\gamma))^2 \left\{ \frac{d\Pi_2^T}{d\gamma} (1 + 2\delta x(\gamma) F^T(\gamma)) + \frac{dy^T}{dy} [1 - y^T(\gamma)(1 + \delta)] \right\}.$$

with

$$F^T(\gamma) = 2y^T(\gamma) - (y^T(\gamma))^2(1 + \delta) - \frac{1 + \delta^2}{\delta}.$$

Since $\frac{dy^T}{dy} < 0$ and since $y^T(\gamma) < \frac{1}{1 + \delta}$, the second term in the brackets is always negative.

I know that $\frac{d\Pi_2^T}{d\gamma}$ can be positive or negative. I will consider both cases separately.

- Consider first all γ such that $\frac{d\Pi_2^T}{d\gamma} > 0$.

It is trivial to show that $\frac{dF^T}{d\gamma} < 0$, and since $F^T(0) < 0$, $F^T(\gamma) < 0$. Thus, since the sign of the derivative of $x(\gamma)$ is same as the sign of the derivative of the second period profit, I have

$$\frac{d}{d\gamma} [1 + 2\delta x(\gamma) F^T(\gamma)] < 0 \text{ for all } \gamma \text{ such that } \frac{d\Pi_2^T}{d\gamma} > 0.$$

Finally since $[1 + 2\delta x(0) F^T(0)] < 0$, I have $[1 + 2\delta x(\gamma) F^T(\gamma)] < 0$ when $\frac{d\Pi_2^T}{d\gamma} > 0$ and

I can conclude that the derivative of welfare is negative.

- Consider now all γ such that $\frac{d\Pi_2^T}{d\gamma} < 0$.

Over that range, it is not clear whether $\frac{d}{d\gamma} [1 + 2\delta x(\gamma) F^T(\gamma)] < 0$. This derivative might be positive for some γ and thus it may be that for large γ , I have $[1 + 2\delta x(\gamma) F^T(\gamma)] > 0$. However if there exists any such γ , then it is obvious that welfare is decreasing for such values. Whether welfare decreases is ambiguous when I have both, $[1 + 2\delta x(\gamma) F^T(\gamma)] < 0$ and $\frac{d\Pi_2^T}{d\gamma} < 0$. Let us then focus at this particular case.

The proof relies on several elements. Let

$$\Sigma = \left\{ \frac{d\Pi_2^T}{d\gamma} [1 - 2\delta x(\gamma) F^T(\gamma)] + \frac{dy^T}{d\gamma} [1 - y^T(\gamma)(1 + \delta)] \right\}. \quad (5.4)$$

I will prove that Σ is bounded above by a negative term and is therefore negative.

First, note that for any T , I may write the second period profit as

$$\Pi_2^T = y^T(\gamma) - (y^T(\gamma))^2 K^T(\gamma),$$

with

$$K^A(\psi) = 1 + \frac{\delta}{2} - \frac{\psi}{2},$$

$$K^U(\phi) = 1 - \phi + \frac{\phi^2}{2} + \frac{\delta}{2},$$

$$K^R(\phi) = 1 - \phi r \left(1 - \frac{\phi}{2}\right) + \frac{\delta}{2}.$$

Notice that in all cases, $K^T > 0$ and $\frac{dK^T}{d\gamma} < 0$. Differentiating the profit function leads to

$$\frac{d\Pi_2^T}{d\gamma} = \frac{dy^T}{d\gamma} [1 - 2K^T(\gamma)y^T(\gamma)] - (y^T(\gamma))^2 \frac{dK^T}{d\gamma}.$$

To have $\frac{d\Pi_2^T}{d\gamma} < 0$, it must be that $[1 - 2K^T(\gamma)y^T(\gamma)] > 0$ and I can conclude that

$$\frac{dy^T}{d\gamma} [1 - y^T(\gamma)(1 + \delta)] < \frac{d\Pi_2^T}{d\gamma} \frac{[1 - y^T(\gamma)(1 + \delta)]}{[1 - 2K^T(\gamma)y^T(\gamma)]}. \quad (5.5)$$

Second, it is trivial to show that for any γ , I have

$$F^T(\gamma) > -\frac{\delta^2 + 1}{\delta}. \quad (5.6)$$

Substituting in (5.4) both (5.5) and (5.6) I have for all γ such that $\frac{d\Pi_2^T}{d\gamma} < 0$,

$$\Sigma < \frac{d\Pi_2^T}{d\gamma} \left[1 - 2x^T(\gamma)(1 + \delta^2) + \frac{1 - y^T(\gamma)(1 + \delta)}{1 - 2K^T(\gamma)y^T(\gamma)} \right].$$

I shall then prove that the expression on brackets is always positive for all γ such that

$\frac{d\Pi_2^T}{d\gamma} < 0$. Since $x(\gamma) < \frac{1}{2\delta^2}$, I have

$$2x^T(\gamma)(1 + \delta^2) - 1 < \frac{1}{\delta^2}.$$

Furthermore one can show that for any T , the function

$$G(\gamma) = \frac{1 - y^T(\gamma)(1 + \delta)}{1 - 2K^T(\gamma)y^T(\gamma)}$$

is decreasing in γ since

$$\text{sign} \frac{dG}{d\gamma} = \text{sign} \left[\frac{dy^T}{d\gamma} (2K^T - (1 + \delta)) + 2y^T(1 - y^T(1 + \delta)) \frac{dK^T}{d\gamma} \right] < 0.$$

For any T , I have $G^T(1) > \frac{1}{\delta^2}$. Thus I can conclude that for all γ I have

$$G^T(\gamma) > \frac{1}{\delta^2} > 2x^T(\gamma)(1 + \delta^2) - 1,$$

thus the term in brackets is positive and welfare decreases for all γ .

Conclusion

This thesis stems from the insight that patents do not only function as an incentive mechanism that creates monopolies on stand alone innovations, but that in many sectors they have become strategic instruments that change the way firms compete and innovate. In sectors such as biotechnology, semi-conductors, telecommunication equipment or software, the industrial property of marketable technologies is indeed often fragmented into several patents, and the need to secure an access to key patents has led the firms to accumulate patent portfolios which they use strategically. The purpose of the thesis is to enter the "patent thicket" in order to shed light on this strategic role of patents. Thus the three parts of the thesis are not meant to form a complete answer to a single question. They nevertheless allow to draw consistent results about industrial organization within the "patent thicket".

Throughout the thesis I have applied the theoretical concepts of innovation cumulativity (Scotchmer, 1991) and complementarity (Shapiro, 2000) in order to capture the fragmentation of patents. I have then developed three theoretical models to study how firms can use their patents strategically. These models have allowed me to evaluate how the firms' behaviour affects the social efficiency of R&D investments. In conclusion of the thesis, I summarize my contributions by following these general guidelines.

From technological to legal cumulativity and complementarity

Throughout the thesis, I used the concepts of complementarity and cumulativity alternatively to feature the conditions of competition based on innovation within a "patent thicket". The three models that I developed shed light on the duality of these two concepts. Cumulativity and complementarity can indeed be interpreted either in terms of technology or in legal terms.

In the first two parts, I started from a purely technological interpretation of complementarity and cumulativeness. Both basically feature innovations independently of any legal aspect. Patents intervene only at a second step of the analysis, by creating exclusivity on innovations that, by definition, result from each other or can be combined with each other. I developed in Part 1 a model that builds upon the concept of complementary innovations. More precisely, I measured the stringency of the non-obviousness requirement by the number of complementary innovations embodied in a patentable technology. In Part 2, I essentially focused on cumulative innovations. I demonstrated that forward patent protection facilitates the persistence of dominant firms when innovations are cumulative.

In Part 3, I departed from the usual definitions of complementary and cumulative innovations by ruling out their technological dimension in order to focus only on the legal one. Indeed it happens in some cases that innovations infringe a patent although they have not been developed thanks to the knowledge protected by this patent, so that there is no real cumulativeness nor complementarity. Such situations may especially occur where there is a deficiency of the patent system, if examiners at the Patent Office grant patents with claims that largely exceed the underlying invention, or if Courts uphold unjustified infringement claims. By considering such forms of purely legal cumulativeness and complementarity, I shed light on patenting strategies that are independent from R&D strategies, but can influence them.

A theoretical approach of patent strategies when innovations are cumulative and complementary

The aim of this thesis was to capture and explain theoretically the patent strategies that may take place in a framework of complementary and cumulative innovations. The three Parts of the thesis go beyond the framework of the "tragedy of anticommons". This static framework emphasizes the impediments to innovation created by the fragmentation and scattering of patents between different holders. By contrast my goal was to explain why patents come to be fragmented and scattered, and how firms can adapt to such an environment. For that purpose I asked why firms sought to acquire patents. I also explored how they can use their own patents to protect themselves against their competitors' ones. I was able as a result to shed the light of economic theory on some of the patent strategies that have been revealed by empirical studies.

In the first Part, I developed a model that explained how a weak enforcement of the non-obviousness patentability requirement can result in scattered patents on complementary innovations. This model highlights the "tragedy of anticommons" as a consequence of the firms' R&D strategies in a context of leniency of the patent office examiners. It however also reveals a mechanism that limits the cost of patent fragmentation when the non-obviousness test is too weak. Indeed the firms tend to drop out of the patent race once a first essential innovation has been patented by a competitor, which suppresses the risk of patent scattering.

In the second Part, I presented a set of strategies, all of which are based on the trading of patented innovations, that help dominant firms persist against new entrants. Dominant firms, be they incumbent monopolists or firms with a superior cost structure

in a duopoly, can in many cases use patents to reach contractual arrangements with new entrants. Indeed such arrangements can be profit improving for the industry if they allow a reduction in R&D costs or prevent price competition. When innovation is cumulative, forward patent protection still facilitates the persistence of dominant firms. In particular, patents may be a means of blocking new entrants that have developed drastic innovations. I developed a model of cumulative innovation that upholds this result. It shows that when an upstream patent enables the development of a patentable, drastic innovation, an incumbent monopoly is more likely to preempt it than a new entrant. This stems from the firms' asymmetric abilities to derive a profit from the upstream patent in case the competitor has patented the drastic innovation. In that case, the patents are mutually blocking, and the incumbent has a superior bargaining power because it already enjoys a monopoly rent.

In Part 3, I developed a model in which two symmetric competitors can use their patents to block each other. I showed that the firms have an incentive to accumulate blocking patents because it is a way to reduce their competitor's incentive to invest in R&D. This is especially profitable in sectors where R&D is relative cheap and easy so that all competitors are likely to innovate. I also used the model to study the firms' incentives to sign early cross-licensing agreements. I showed that they do so in two different cases. When R&D costs are high and hold ups likely, the firms sign early cross-licensing agreements in order to facilitate downstream investments. But when R&D costs are low and hold ups are unlikely, the firms use such agreements to reduce the intensity of R&D competition, which is anti-competitive.

Patent races when innovations are cumulative and complementary

The three models that I developed in the thesis transpose different patterns of patent race between two firms in a framework of cumulative and complementary innovations. Each of them allows to derive results as regards the impact of patents and patent strategies on the efficiency of R&D.

The theoretical model that I developed in the first Part of the thesis focuses on the non-obviousness patentability requirement as a policy lever. I adapted the model developed by Green and Scotchmer (1990) to study whether protecting two complementary innovations with the same patent improves the efficiency of R&D investments. Thereby I introduced complementary innovations in a patent race model that initially described cumulative innovations. Excepted Kamien and Schwartz (1991)'s paper on the cross-licensing of complementary patents, such models of patent race with complementary innovations are quite seldom in the literature. Indeed most papers on complementary innovations (Shapiro, 2001; Lerner & Tirole, 2004) discuss pricing issues in a static framework, and neglect R&D investments and their welfare effects.

In Part 2, Chapter 3 showed that patents, by facilitating the persistence of dominant firms, tend to create an innovation regime featured by incremental innovation. This regime contrasts with the Schumpeterian "creative destruction" model, in which new entrants regularly eliminate former monopolies because they have higher incentive to develop breakthrough innovations. The model developed in Chapter 4 is in line with this general conclusion. I showed that when an upstream patent enables a drastic innovation, it is more difficult for the entrant to benefit from a "business stealing" effect, so that its investments

are more proportionate to the social value of the innovation.

In the Part 3, I departed from the literature on patent races by ruling out the assumption that the winner takes all thanks to its patent. I assumed that two competitors can develop different innovations, each of which is protected by a different patent. In this setting, R&D investments are socially efficient when these patents simply confer a protection against imitation. When the protection conferred by patents goes beyond the underlying innovation, I showed that firms have an incentive to acquire blocking patents, which results in lower R&D investments. Hence broad patents always trigger inefficient R&D investments. The lower R&D investments induced by the risk of hold up may however be profit increasing if the risk of hold up is not too important. This is why upstream cross-licensing agreements can be either welfare improving or welfare decreasing. When blocking patents have a negative effect on the firms' profits, ex ante agreements facilitate the development of new products, which is welfare improving. But when the risk of hold up is initially low, firms can also use ex ante agreements to jointly reduce R&D competition, which is welfare decreasing.

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