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Legal Shifts: Shaping Expectations of Intellectual Property Protection in an Open Innovation Industrial Environment

par Mathieu Bruneau

Département de sciences économiques, Faculté des arts et des sciences

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Résumé

Ce mémoire vise à évaluer les effets de variations des attentes des firmes quant à la protection conférée par les droits de propriété intellectuelle (« PI ») pour les inventions et innovations dans un milieu industriel d'innovation ouverte. D'abord, les régimes de PI aux États-Unis et au Canada sont analysés à travers des cas jurisprudentiels et législatifs et des traités internationaux afin d'illustrer de quelle façon les normes juridiques changent et démontrer les répercussions sur les attentes des firmes. Puis, les attributs du modèle de l'innovation ouverte, où les firmes gèrent à dessein leurs relations d'affaires avec une attitude d'ouverture, sont décrits et sa pertinence est appuyée à l'aide d'un modèle simple. L'accent est mis sur son traitement distinctif des échanges de connaissances et d'intrants à l'intérieur même des firmes et entre elles. Une fois ces notions établies et s'y référant à titre d'hypothèses, un modèle microéconomique des échanges de connaissances entre firmes est élaboré, avec deux variables de choix, la PI et le secret, qui captent les mécanismes de gestion technologique des firmes. Par la tension entre ces variables, les processus de prise de décisions et les interactions entre les firmes sont évalués au moyen d'une analyse statique. Pour étudier plus en détails les choix des firmes, une version à deux joueurs du modèle est examinée au moyen de la théorie des jeux. Dans toutes ces formes du modèle, l'impact des fluctuations des attentes des firmes relativement au droit de la PI est jaugé. Tel que prévu, ces effets pour une firme changent en fonction des choix de gestion de chacune des firmes. Les effets varient également eu égard à la nature des relations à travers lesquelles les échanges de connaissance ont lieu. Dans la variante à deux joueurs, la statique comparative d'un équilibre de Nash en stratégie mixte montre que la relation avec l'autre joueur imprègne les incidences des variations du droit sur les stratégies de gestion technologique. Par exemple, une hausse des attentes de protection juridique de la PI couvrant la technologie d'une firme peut étonnamment mener cette firme à moins y recourir.

Mots-clés: Propriété intellectuelle – Brevets – Secrets commerciaux – Innovation – Innovation ouverte – Gestion de la technologie – Théorie microéconomique – Théorie des jeux – Organisation industrielle – Droit de la propriété intellectuelle

Abstract

The purpose of this thesis is to assess the effects of changes in firms' expectations of intellectual property ("IP") law protection over inventions and innovations in an industrial environment characterized by open innovation practices. To begin, a legal analysis of IP regimes in Canada and the United States is achieved through different cases of court decisions, legal amendments and international treaties in order to show how legal standards vary and to demonstrate the repercussions of legal shifts over firms' expectations. Then, the characteristics of the open innovation management model, in which firms adopt a purposively open mindset in their business relationships, are described, and its relevance is supported using a simple model. Emphasis is laid upon open innovation's distinguishable treatment of intra- and inter-firm flows of knowledge and inputs. Building on these insights and using them as assumptions, a microeconomic model of firms' knowledge flow interactions is constructed, with two choice variables that capture firms' technology management mechanisms in an open innovation industrial environment: IP and secrecy. Through the tension between these two variables, inter-firm interactions and decision-making processes are assessed with a static analysis. To study firms' choices in greater detail, a two-firm version of the model is then examined using game theory. Throughout, the impact of fluctuations in firms' expectations of IP law is assessed. As expected, these effects, for a focal firm, vary depending on that firm's technology management decisions as well as other firms'. Effects also differ with respect to the nature of knowledge flows relationships that each firm undertakes. In the two-firm game theoretic version of the model, comparative statics of a mixed-strategy Nash Equilibrium show that the relationship with the other firm qualifies the consequences of legal shifts on firms' technology management strategies. Notably, increasing expectations of IP protection for a firm's technology might actually result in this firm relying less on IP.

Keywords: Intellectual Property – Patents – Trade Secrets – Innovation – Open Innovation – Technology Management – Microeconomic Theory – Game Theory – Industrial Organization – Intellectual Property Law

Table of Contents

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Foreword

This thesis is the result of a research project submitted to, and supported by, the *Fonds de recherche du Québec – Société et culture*. This project proposed using an interdisciplinary perspective combining economics, law and management to analyze, when they are guided by an open innovation approach, firms' responses to shifts in intellectual property law. In order to abide by this interdisciplinary mandate, this thesis departs from work traditionally published in economics. The first two chapters respectively focus on law and management, while economic modeling begins only in Chapter 3. Readers interested exclusively on this thesis' content in microeconomic theory are invited to read the Introduction, the beginning of Chapter 1 (before Section 1.1), Section 2.1 and then jump to Chapter 3. Where other ideas, concepts and examples from the first two chapters appear in Chapter 3, footnotes refer these readers back.

On a personal note: interdisciplinary work is undervalued. The world, human life and their respective phenomenal manifestations are too complex to be fully understood through the lens of a single discipline. I believe strongly that more truth can be found in ties *between* disciplines than in single disciplinary nodes. Take this thesis: it is guided by a legal context; the subject is technology management; and the analysis is economic. Law sets the pragmatic boundaries. Economic modeling allows generalization and prediction. Management provides empirical bedrock that supports the theoretical assumptions and translates the analysis in concrete action. Each of these disciplines contributes in its own, singular way to this research.

In this thesis, legal sources—legislations and decisions—are indicated using footnotes, as recommended by, and in the manner prescribed in, the *Canadian Guide to Uniform Legal Citation*, 8th ed (Toronto: Carswell, 2014). This method has been chosen because of the difficulty of inserting in-text citations to legal sources that do not impair the text's readability while still being detailed enough for readers unfamiliar with law to understand the reference. Abbreviations are either broken down or explained the first time they appear.

Introduction: What Firms See and What Firms Get

Microeconomic theory is predicated on the idea that firms maximize the net value associated with their products by choosing optimal cost and revenue variables within their purview, while taking into account exogenous elements outside of their control. Several of these elements are generated by the legal environment, which imposes constraints on firms' actions or gives access to a whole array of hitherto impracticable opportunities. Firms whose products are inventive or innovative in nature are particularly concerned as the existence and scope of legal regimes of intellectual property ("IP") greatly affect the range of choices available to them.

Most microeconomic models of intellectual property assume that IP rights will be granted whenever firms apply for them (e.g., Acemoglu, Bimpikis and Ozdaglar 2011; Miceli 2009; Carlton and Perloff 2008; Scotchmer 2004; Landes and Posner 2003; Gilbert and Shapiro 1990; Tirole 1988). This is not a bug but a feature, because modelling requires a context to be reduced to its simplest form in order to better analyze the particular factor(s) under analysis (Nicholson and Snyder 2012; Ostrom 2005). To accurately examine firms' interactions with IP, this simplification must be dispensed with. When firms elect whether to rely on IP protection or not, they typically have no *ex ante* certainty that IP rights will be granted or shall be enforceable against competitors and other third parties—in other words, certainty about these rights' validity and breadth (Lemley and Shapiro 2005; Leffler and Leffler 2003). In these circumstances and under the axioms of Von Neumann-Morgenstern (1944), risk-neutral firms rather maximize their technologies' *expected* net value, or the part thereof they can capture. Firms' *level of expectations* turns into a major parameter in their decision-making processes.

This perspective is not only closer to reality: so long as no specific value for expectations is asserted, it also stands strong when hypotheses of rational and cognizant agents are abated. For firms' technology managers, case law and statutes are one discourse, but only one among many others, that creates "IP law as everyday life" (Murray, Piper and Robertson 2014a). These managers' beliefs regarding the state of IP law, and associated expectations and decisions, are also influenced by the media, discussions with colleagues and friends, corporate policies, industrial practices, social values, community norms, and so on. Each of these discourses is in turn affected by assessments of actual IP law. Some of them, for instance when they are supported by legal advice, are more likely than others to closely reflect the state of IP law. Still, whether or not these beliefs are exact, it remains that firms take decisions based on expectations. These more or less accurate expectations directly or indirectly echo the actual state of IP law, just like a funhouse mirror, despite proportions that may be shrunk or protracted, reflects the same objects that could be observed through an immaculate looking glass.

Analyzing the scenario of expectations becomes particularly significant under conditions of unstable or shifting legal environments in connection with IP. Expectations fluctuate as legislative bodies amend and vote laws, and as courts refine interpretations of legal texts and concepts. Patent law is especially affected by the legal process: by construction, as patent law has to deal with unforeseen and unanticipated technologies,[1] the ground on which its rules are built is bound to remain somewhat unsteady. Firms operating in industrial sectors at the forefront of technological development have to deal regularly with uncertain and shifting legal expectations. As tellingly illustrated below,[2] biotechnologies and information and communication technologies ("ICT"), two industries whose social and economic contributions need no introduction, are sectors that are currently evolving in the aftermath of such legal shifts. The purpose of this paper is to investigate, with a model of microeconomic theory, the impact of shifts in IP law on firms' choices, through the role of expectations in firms'

1 *Harvard College v Canada (Commissioner of Patents)*, [2002] 4 Canada Supreme Court Reports 45 at paras 10, 158.

2 See respectively Sections 1.1 and 1.2.

decision-making processes. To push this examination beyond theoretical underpinnings, legal and management perspectives, concepts and ideas join the economic treatment to provide an interdisciplinary analysis.

Incidentally, there exists a second set of *ex ante* uncertainty and correlated expectations that influence firms' decision-making processes in technology management: uncertainty about the market demand for a firm's technology, and the products it offers that incorporate it (Lemley and Shapiro 2005; O'Connor 2010). Although these factors are constantly taken into consideration herein, notably by preferring not to formalize IP with monopoly models and theory (see, e.g., Bruneau 2013 for a critique of Boldrin and Levine's (2008) use of "monopoly"), they are not the focus of this paper.

To show the repercussions of the legal environment surrounding technological activities on firms' expectations of IP protection, Chapter 1 features actual industry responses to court rulings and legal amendments. It focuses on patent law in biotechnology and ICT industries, but equivalent contexts are described for the exogenous impact of other IP legal regimes—like copyright, trademarks, layout-designs, geographical indications, industrial designs[3] and plant breeders' rights. By using legal decisions as the backbone of this review of legal shifts, Chapter 1 actually *performs* a central aspect of this paper, i.e., to consider expectations of IP protection exogenously. Chapter 2 outlines other core notions of this paper with respect to the industrial ecosystem, focusing on the distinction between inventions and innovations. As this qualification captures the cumulative nature of the innovation process, it is crucial to adequately address the role of IP in firms' behaviour (Frischmann 2012; Scotchmer 2004; Landes and Posner 2003; Gallini 2002). To represent this distinction, this paper's model implies an industrial environment characterized by practices of *open innovation*. Open innovation is a management approach in which decision makers deliberately keep the firm's boundaries open, thus facilitating inward and outward flows of knowledge, technologies and

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[3] In the United States, industrial designs are known as *design patents*, in contradistinction with *utility patents*. To avoid this double usage of *patents*, the Canadian term is preferred herein.

research projects throughout the innovation process (Chesbrough 2003). Although using open innovation as the infrastructure of this paper's model reduces the scope of its conclusions, it provides two noteworthy advantages. First, reminiscent of the previous remark regarding models and simplifications, it renders the model workable. Second, as firms in the biotechnological and ICT sectors have extensively adopted processes typically associated with open innovation (Gassmann, Enkel and Chesbrough 2010), this management model combines well with the legal exposition of Chapter 1 in order to construct a model that can isolate and identify the effects of shifts in firms' expectations of IP protection. Together, these chapters establish this paper's conceptual framework.

These first two chapters having paved the way for this paper's objectives and the foundations of its most important assumptions, it is then possible in Chapter 3 to model firms' behaviour in an industrial setting characterized by practices of open innovation. As is typical in discussions of technology management (Teece 1986; Cohen, Nelson and Walsh 2000; Graham et al 2009), the choice of each firm, which maximizes the value it captures out of its technology, is structured along the trade-off between IP protection and secrecy. Unlike the other chapters, Chapter 3 is written for a readership that is well-versed in the field of microeconomic theory.

Economic analysis takes place in a two-prong manner. First, comparative statics are used to study general multi-firm interactions in the industrial environment. By establishing the different constraints and processes of technology management in this environment, insights for a number of distinctive firms and industrial contexts are found. For instance, non-practicing entities, firms that invent but do not innovate, do not benefit from secretive practices according to the model's results. In the context of tensions between IP protection and secrecy, these firms are thus relatively more likely to be interested in IP protection and to unambiguously benefit from legal shifts that increase expectations of IP protection. Furthermore, in an industrial environment comprised exclusively of computer programming firms, it is observed that copyright protection constitutes a dominant strategy of technology management.

Next, through a game theoretic analysis of a two-firm version of the model, dominant-, pure- and mixed-strategy Nash Equilibria are identified. By examining this game, it is noticed that a unique, dominant-strategy Nash Equilibrium usually arises when the possibility that both firms choose IP protection does not produce judiciary interactions, such as litigation. If a dominant-strategy Nash Equilibrium exists, the intuitive effects of legal shifts on firms' likelihood to choose IP protection are confirmed by the model, as well as corresponding results on their incentive to participate in technological activities. In the event that an interaction of IP litigation would occur, the likelihood of a dominant-strategy Nash Equilibrium is infinitesimal. Then focusing on the model's potential mixed-strategy Nash Equilibrium, it is shown that the impact of legal shifts in this equilibrium vary mostly in relation with the other firm's technology management decisions. Counter-intuitively, legal shifts increasing expectations of IP rights' validity and enforceability for a firm's technology, *ceteris paribus*, do not necessarily increase the likelihood that this firm seeks IP protection, rather the opposite in some circumstances.

Chapter 1: Navigating Through Intellectual Property Law

The patent system is a "statutory creature",[4] a bargain in which inventors obtain a temporary exclusivity over the use of their inventions in exchange for public disclosure, a design whose end-purpose is to encourage research activities (Scotchmer 2004; Gallini 2002). Advocates of the patent system argue that research stimulation emerges from both sides of this *quid pro quo*, in a two-prong impetus: exclusion rights act as a commercial incentive to invent, to exploit inventions, or both (Plant 1934), while public disclosure, restrictions to patentable subject matter and finite terms of protection maintain and enrich the public domain for scientific and technological ideas, a source of building blocks of knowledge on which other inventors and innovators can further stand for their own inventive and innovative endeavours (Frischmann 2012; Machlup 1958; Machlup and Penrose 1950).

This reasoning being laden with conjectural suppositions on the direct and indirect effects of the patent system, it is difficult, if not impossible, to accurately assess its cogency (Moore 2003; Machlup 1958). On the one hand, absent a regime of patents, its benefits would not vanish, since some of the system's alternatives, like trade secrets and rewards associated with academic advancement, provide incentives to invent, while others, including open source licensing, dedication to the public domain and academic publication, disclose technological knowledge freely and readily. On the other hand, patents are not socially free, as they come with the notorious, competition-inhibiting cost of strengthening the patentee's market position and impeding short-term subsequent research (Bruneau 2013; Boldrin and Levine 2008). There are plainly too many alternatives to patents to confidently declare what would occur without this system and pronounce a clear-cut verdict on its effectiveness. Therefore, the patent rationale is not disputed or supported herein, but is instead contemplated objectively: regardless of one's assertions about the desirability of the patent system, one cannot ignore that patent law exists, and that it is propped on this rationale. By the mere existence of this

[4] *Apotex Inc v Wellcome Foundation Ltd*, [2002] 4 Canada Supreme Court Reports 153 at para 37, Justice Binnie.

prop and the structure it supports, inventors have the option of applying for patents and are socially encouraged to do so. Rather than debating whether to take down this structure or not, this paper is mostly concerned by how firms behave with and around it.

In line with this orthodox rationale, patentability of an invention usually requires four conditions: patent-eligible subject matter, novelty, non-obviousness and usefulness.[5] The first condition is satisfied when the patent application does not merely cover "laws of nature, natural phenomena and abstract ideas".[6] Concentrating on the second prong of the patent rationale, it purports to guarantee that the "basic tools of scientific and technological work",[7] the most fundamental building blocks of knowledge, are not pre-empted and hence remain available for everybody to use in their scientific and research inquiries (Frischmann 2012; Landes and Posner 2003).[8] Because nature, pure science and ideas are fundamental, patent law theory supposes that allowing their appropriation, even temporarily, causes too much harm to society through the imposition of undue impediments to others' research projects. The other three conditions are satisfied when legal thresholds of novelty, non-obviousness and (expected) usefulness are met (Gervais and Judge 2011; Pires de Carvalho 2010). The purpose of these three requirements and other limitations unspecified herein is to ensure that the social costs of granting exclusion rights to inventors are outweighed by the social benefits derived from additional new, useful and inventive activities (Landes and Posner 2003; Gervais and Judge 2011).[9] Keeping both prongs of the patent rationale in mind, it is assumed in the

5 In Canada, *Patent Act*, RSC 1985, c P-4, sections 2 "invention", 27(8), 28.2, 28.3 [*Patent Act*]. "RSC" refers to Revised Statutes of Canada. In the United States, 35 USC §101-03. "USC" stands for United States Code. For the 161 members (as of April 26, 2015) of the World Trade Organization ("WTO"), aspects of the last three conditions are mandatory by application of Paragraph 27(1) of the *Agreement on Trade-Related Aspects of Intellectual Property Rights*, better known under the name "TRIPS"; *Agreement Establishing the World Trade Organization, Annex 1C: Agreement on Trade-Related Aspects of Intellectual Property Rights*, 15 April 1994, 1869 UNTS 299, WTO [TRIPS]. For international requirements, reference to the TRIPS is preferred to reference to treaties of the World Intellectual Property Organization ("WIPO") because the TRIPS benefits from enforcement procedures, unlike WIPO treaties. The WTO thus exerts direct pressure on its members to implement the TRIPS' standards (Pires de Carvalho 2010).

6 *Diamond v Diehr*, 450 United States Reports 175 (1981) at 185. United States Reports is the official reporter of the U.S. Supreme Court. Patent-eligibility in Canada follows similar principles; *Patent Act*, *ibid* at 27(8).

7 *Gottschalk v Benson*, 409 United States Reports 63 (1972) at 67.

8 *Mayo Collaborative Services v Prometheus Laboratories, Inc*, 132 Supreme Court Reporter 1289 (2012).

9 *Apotex Inc v Wellcome Foundation Ltd*, *supra* note 4 at para 37, Justice Binnie.

construction of the patent system that exclusion rights conferred to inventions missing any of these three criteria are more likely to produce less social benefits than costs.

Interestingly, these four conditions are guided by utilitarian principles, *a fortiori* in the United States, where the Constitution specifically provides that the legislative power of Congress with respect to patent and copyright law must be exercised "to promote the Progress of Science and useful Arts".[10] In that respect, it should be noted that patent law theory and microeconomic theory both follow utility maximization principles, a convergence that supports this paper's integrative approach.

Depending on the singular characteristics of their inventions, firms contemplating patents in the course of their knowledge and technology management may be more or less confident that they meet the aforementioned four requirements. Besides, the issuance of a patent only creates a presumption of its validity:[11] any alleged infringer is allowed, as a defense in court, to challenge the patent on the ground that one of the four conditions is not complied with.[12]

Patents that have been granted can be rebuffed because of the incomplete and imperfect nature of the examination process. For the sake of concision, only the novelty and non-obviousness criteria of this process are discussed here. When examiners review whether the invention claimed is novel and non-obvious, they look for what is called "prior art", which is composed, roughly, of anything that is publicly known (Gervais and Judge 2011; Lemley and Shapiro 2005; Jaffe and Lerner 2004). If the invention claimed in the patent application already exists in prior art, it cannot be new. Non-obviousness is assessed from the point of view of a person "of ordinary skill in the [prior] art": if that imaginary person finds the

[10] US Constitution, article I, § 8, clause 8. See Justice Stevens' concurrence in *Bilski v Kappos*, 130 Supreme Court Reporter 3218 (2010) for a discussion about how this constitutional proviso frames U.S. patent law in general, the U.S. standard for patent-eligibility in particular.

[11] In Canada, *Patent Act*, *supra* note 5 at sections 42, 43(2). In the United States, 35 USC §282(a).

[12] In Canada, *Patent Act*, *supra* note 5 at section 59. In the United States, 35 USC §282(b)(2).

invention obvious, the patent application fails at the non-obviousness criterion. As patent examiners are indeed human and not omniscient and as the governmental institutions responsible for patent examination face time and budgetary constraints, the screening of prior art is usually confined to the examiner's technical knowledge, elements submitted by the applicant and searches of published patents (Carrier 2009). The prior art reviewed during this examination is thus not exhaustive. It ensues that, in order for the examination process to carry out the patent rationale instead of being a matter of chance, patents issued at the end of this process should be rebuffable.

From the perspective of rational and risk-neutral users, whether other firms or customers, this inevitable uncertainty is borne in mind each time they incur expenses to use or access a patented technology (O'Connor 2010), as they weigh the certain costs of treating the patent as valid against the potentially lower expected costs of betting on the patent being invalid, based on users' expectations of the patent's validity (Lemley and Shapiro 2005). IP law's exhaustion doctrine is a noteworthy aspect to keep in mind to discuss users' bets. When a product containing an IP-protected component is lawfully transferred, the IP right is said to be *exhausted*, meaning that a legitimate transferee can use the *product* free from the restrictions of IP law's exclusionary rights (Correa 2007; Pires de Carvalho 2010). Put simply, as is the case for any other good one possesses, the lawful transferee can use the product, sell it, repair it, include it as an input in one's own innovation or production processes or even destroy it.[13] Nonetheless, exhaustion affects only the product, not the right itself: making a copy of an IP-protected product without sufficient authorization constitutes IP infringement, even for a lawful transferee of the product. This aspect of IP regimes is taken into account when users assess the probabilities associated with their wagers. Licenses and similar contractual arrangements, however, allow IP right-holders to ignore some considerations of IP exhaustion since, in these situations, contract law takes over IP law. In fact, licensing is often relied on

[13] For copyright specifically, some jurisdictions do have special limitations to IP exhaustion under the form of *moral rights*. In Canada and U.S. jurisdictions where some moral rights are granted, they are confined to an author's right to have his or her name associated with the work (or to stay anonymous) and to some rights regarding the work's integrity (Gervais and Judge 2011; Landes and Posner 2003). From this paper's technological viewpoint, the impact of moral rights on the exhaustion doctrine is thus negligible.

with the explicit intention of overriding concerns about exhaustion. It largely explains the prevalence of licensing practices by free and open source software ("F/OSS")[14] proponents, a community of programmers united by their advocacy of wide and "free" access to computer programs and their code. To promote this goal, F/OSS programmers routinely tether licenses to use the IP-protected computer programs and code they developed to heavy restrictions in regard to the methods by which subsequent software applications, incorporating F/OSS code or applications, may be commercially exploited (Phillips 2009).[15]

Now looking from the perspective of inventive firms, uncertainty surrounding the invention's patentability is first reckoned with when deciding to patent or not a technology. For inventive firms, the main alternative to patents—albeit not the only, as has been brought up earlier in this chapter—consists in keeping the technology secret (Landes and Posner 2003). With trade secrets as well, there exists an intrinsic uncertainty regarding the firm's ability to confine the knowledge within its boundaries, and some legal mechanisms can increase firms' expectations to that effect, such as laws that punish trespasses and breaches of contract, or that forbid theft and reverse-engineering (Lemley 2011; Gervais and Judge 2011). For trade secrecy as well, the analysis of firms' choices is accompanied by an assessment of the exogenous legal context and of expectations of protection. For inventive firms, trade secrets' main weakness is that they do not confer exclusion rights: should competitors independently invent or innovate the same technology, they can use it (Landes and Posner

[14] As the saying goes, "free as in free speech, not as in free beer" (Stallman 2002, 43). The distinction between *free* and *open* source software is beyond the scope of this paper. Readers interested in this nuance are directed to Raymond (1999), Stallman (2002) and Phillips (2009).

[15] Because of the complexity of the legal context, the wording of this sentence is very specific and may look odd. The two main licenses used in F/OSS movements are the GNU General Public License and Creative Commons. In general, the *right to use* conferred by these licenses is *annulled* should their conditions not be complied with. Two events ensue. First, contract law leaves (or gives back) the ground to IP law. Second, by definition, an annulment is retroactive. By this *retroactive* termination, it is not only this subsequent application's commercial exploitation (through means disallowed by the license) that violates the IP right, but the use of the computer program altogether. Therefore, all of the license's conditions apply to the use itself, including those terms that do not relate to the use. Should the software be given or sold instead of licensed, as a result of the exhaustion doctrine, the mere use of the software application would never violate the IP right, although, in all likelihood, the subsequent product's commercial exploitation would still be disallowed because of the unauthorized reproduction of IP-protected software. To hearken back to the larger context of this paragraph, this means that users' legal liability, and thus the monetary value of the expected risks in users' bets, can be sizably higher or lower depending on the transfer mechanism.

2003). However, unlike patents, trade secrecy has the benefit of being strictly factual: in addition to its immediacy, it does not require regulatory approval (Lemley 2011).

Had an inventive firm chosen to patent, uncertainty surrounding the invention's patentability then re-spawns every time the firm has to pay renewal fees for maintaining its patent—through the mechanism of renewal fees, a large proportion of patents are forfeited before the end of the statutory term of protection (Bessen and Meurer 2008)—or when it elects to enforce its exclusion right (O'Connor 2010). This last distinctive trait brings Lemley and Shapiro (2005, 75) to describe a patent not as a right to exclude, but as a right to *try* to exclude, by means of enforcement. *Strong* patents, in this line of reasoning, are those for which expectations of validity, concomitant with the associated right to exclude, are high. Conditional to a sturdy demand for products that incorporate the patented invention, strong patents significantly enhance a firm's market position (Gallini 2002) as their strength often suffices to guarantee the success of enforcement. *Weak* patents, unlike their strong counterparts, scarcely support their holders' market positions since invalidation is very probable should they be challenged in court.

Throughout this paper, *enforcement* is understood broadly: it refers to active and direct uses of existing IP rights—a range of practices that includes asking third parties to pay royalties or to obtain a license, using the IP right as leverage in negotiations or transactions with partners, investing in product development associated with a protected invention, setting up spin-offs and assigning them some IP titles, litigating against alleged infringers, and many more. This delineation of *enforcement*, however, does not comprise indirect uses of the IP right, most notably, the determination of prices for market products that contain components protected by IP.

This division is justified by the key consideration in rational and risk-neutral firms' enforcement decisions: in a context of uncertainty, because enforcement exposes inventive knowledge subsumed in the IP right, firms that choose to enforce their IP rights take risks that correspond with the potential wagers of users. In addition to unwanted exposure, enforcement often creates a direct opportunity and motivation for users to challenge the IP right's validity (Lemley and Shapiro 2005). Should the IP right be declared invalid, for whatever reason, costs of using, sharing and reproducing that knowledge decrease sharply for third parties previously exposed to it (Arrow 1959), potentially to zero in the case of digital technologies (Phillips 2009). The risks of knowledge spillovers and legal challenges are contrastively different for market access of *products* that contain the said IP-protected component. In these cases, unless the product carries outward inventive information or the user has technical and legal access to reverse-engineering (Cohen and Lemley 2001; Landes and Posner 2003), market users are not exposed to the protected knowledge (Plotkin 2009). In the same vein, compared to a producer firm's competitors, a single customer has little incentive to bring upon oneself the litigation costs for invalidating a patent (Lemley and Shapiro 2005). These differences explain the choice herein of leaving the outcomes of IP rights in *price determination* of market products out of enforcement issues. Other aspects of IP attached to market products, like litigating against alleged infringers, remain within this paper's definition of enforcement.

It is important to realize that there exists no clear-cut divide between user-firms and inventor-firms; most firms nowadays are both user and inventor. The two following examples, with respect to DNA sequences and computerized business methods, depict this interaction, and how firms are affected by shifts in the legal environment. The overall upshot of the legal rulings discussed in these examples is represented graphically: Figure 1 gauges the impact of these cases on the level of patent protection expected by firms. These two detailed studies are then followed by other situations that explore the role of expectations in broader contexts of IP law. These examples are referred to regularly in this paper, sometimes to explain and support a number of assumptions, other times, to portray different contexts that are examined by the model set out in Chapter 3.

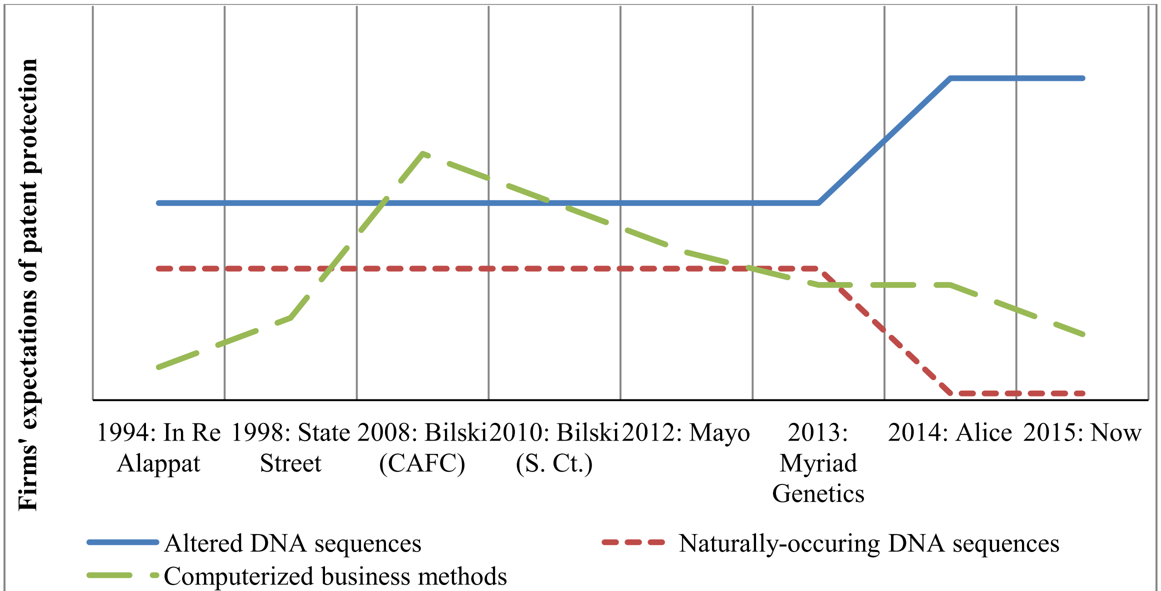

Figure 1 Firms' expectations of patent protection over time, for 3 categories of patents

1.1 The Human Nature, Literally

Starting in the 1970s, the increasing prevalence of biotechnological research awoke many interrogations about patenting modified genes and genetically modified organisms. The questions were promptly dispelled with respect to non-human, modified genes and genetically modified organisms:[16] they are generally patent-eligible. In the meantime, scientists and lawyers continued debating whether human genes and DNA sequences should and could be patented, mostly on the terms of the patent rationale sketched above regarding patent-eligibility: the patent incentive to research activities against the appropriation of fundamental building blocks of scientific research. Some firms had been granted patents related to human genes, but since no courts had specifically ruled on their validity, uncertainty concerning their allowability remained moderately high. Considering the financial value of the patents at stake, firms that had patented human genes preferred to withhold the associated exclusivity by not offering licenses, although they hesitated at enforcing these uncertain patents because of the

[16] *Diamond v Chakrabarty*, 447 United States Reports 303 (1980). In Canada, see *Harvard College v Canada (Commissioner of Patents)*, *supra* note 1.

risks of losing their market position should their patents be nullified. Meanwhile, many laboratories and firms wished to use, in their own research and products, knowledge disclosed in these patents. Nevertheless, they were reluctant to do it because of the high likelihood of facing trial should they press on, with a colossal amount of damage compensation at stake.[17]

In Canada, this issue should eventually be debated in court as a case has been filed by the Children's Hospital of Eastern Ontario, challenging the validity of patents issued for human genes (Payne 2014). In the United States, the legal controversy was dissolved in a 2013 Supreme Court decision, *Association for Molecular Pathology v. Myriad Genetics*,[18] in which a number of parties—research laboratories and advocates for healthcare patients' interests—went to court asking that the human gene patents granted to Myriad Genetics be declared invalid.

After many years of hard work, this biotechnology company had successfully identified genes that were strongly correlated with risks, for women, of developing breast and ovarian cancers. Myriad Genetics applied for and was granted two sets of patent claims for DNA sequences. The firm then implemented its discoveries in diagnostic tests that detect if a woman carries the said genes. Its most famous and vocal client, actor and director Angelina Jolie (Jolie 2013), "came out" right at the moment the Supreme Court was examining the case, a media event that boosted demand and commercial value for products associated with these genes. Backed by its patents, Myriad Genetics was the only active firm in this market, while the patents also hindered firms wishing to enter concomitant markets and offer other health-related services using these genes, hence the lawsuit. The Court rendered a mitigated ruling, in consonance with the aforementioned legal statement that no patents should be granted for mere "laws of nature, natural phenomena and abstract ideas": the first set of claims, on isolated, *naturally*-occurring DNA sequences, was invalidated, even though these sequences

[17] This industrial context comes from *Association for Molecular Pathology v United States Patent and Trademark Office*, 689 F 3d 1303 (Fed Cir 2012). "F 3d" stands for Federal Reporter, Third Series.

[18] *Association for Molecular Pathology v Myriad Genetics, Inc*, 133 Supreme Court Reporter 2107 (2013).

do not exist, in an *isolated* state, in nature; however, patent claims from the second set, on altered, *non-naturally*-occurring DNA sequences, remain in force. Concretely, the decision erased uncertainty regarding the validity of both sets of claims: firms and other parties cognizant of this ruling now have virtually no expectations that patents similar to the first set may be valid in the United States, while they are near-certain that patents similar to the second set are patent-eligible (see Figure 1).

Myriad Genetics reacted positively to this decision since its remaining patents, now ascertained by the top court in the world's biggest market, were enough to secure its exclusive offer of diagnostic services to end-customers (Hurley 2013). Parties involved in the court challenge also rejoiced because the ruling confirmed that they could use freely most of the knowledge they needed for their own research projects, and eventually offer new consumer products banking on these genes (Hurley 2013). These immediate reactions underscore the role of expectations on firms' decisions. On the one hand, Myriad Genetics hinted that it will dedicate more attention to its end-user products in the future. On the other hand, other firms involved, for which prior expected litigation costs prevented new product offerings or scientific endeavours contiguous with these genetic discoveries, are now able to launch their business and research plans. Had the patents from the first set been maintained, further innovation from these other firms and actors would have cost a lot more, continued to be stalled or been canceled. Had the patents from the second set been revoked, an important part of industry research related to human genes would probably have been frozen because of the considerably higher difficulty for firms, in that scenario, to recoup the massive investments required for this research.

1.2 Computerized Business Methods—Tug of War for More Than Twenty Years

The ICT services industry also went through important shifts in patentability expectations. It was confirmed in the 1980s that tangible inventions incorporating computer programs could be patented, for instance, a machine that stops working at definite time intervals based on specific computerized calculations.[19] Nonetheless, the subject of *intangible* inventions incorporating computer programs remains contentious to this day. Inventions at stake here are labeled *business methods*, or, more precisely, *computerized business methods* when they are operated with a computer program. A business method is, as the term implies, a process by which something is achieved within a business context.[20] Patents granted for computerized business methods in the banking services industry are at the heart of this legal controversy. For example, bankers who have contrived a profitable method to manage their clients' accounts in a way no one thought of before probably created a new, non-obvious and useful business method. In order to find out if it could be patented, the only remaining question is whether business methods are "abstract ideas" or, alternatively, to determine under which circumstances some business methods are mere "abstract ideas". In the United States, courts' answers to the patent-eligibility of business methods have fluctuated over time, with rippling effects in firms' decisions regarding patent applications and enforcement. In a way similar to the analysis for human gene patents, the legal environment and firms' choices are linked by variations in firms' expectations of patent protection regarding computerized business methods.

The first noteworthy court decisions affecting computerized business methods came in the 1990s. In three consecutive rulings, the U.S. Court of Appeals for the Federal Circuit ("CAFC"), the highest U.S. court for patent cases after the Supreme Court, assessed patent-eligibility of processes (methods) through the lens of an easy-to-satisfy legal standard that was later coined "useful, concrete and tangible result".[21] Albeit the first of these judgments, *In re Alappat*, was rendered in 1994, the most important of the three proved to be the 1998 *State Street* decision. In that case, the CAFC ruled that a computer program using pre-determined

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19 *Diamond v Diehr*, *supra* note 6.

20 *Bilski v Kappos*, *supra* note 10. The U.S. Supreme Court also tautologically defines *business methods*. There is simply no other way. In Canadian patent law, *process* and *method* are synonymous—see *Refrigerating Equipment Ltd v Drummond & Waltham System Inc*, [1930] 4 Dominion Law Reports 926 at 937—while *process* encompasses *method* in U.S. patent law; 35 USC §100.

21 *In re Alappat*, 33 F 3d 1526 (Fed Cir 1994); *State Street Bank and Trust Company v Signature Financial Group, Inc*, 149 F 3d 1368 (Fed Cir 1998); *AT&T Corp v Excel Communications, Inc*, 172 F 3d 1352 (Fed Cir 1999).

algorithms to execute a transformation of data—in this instance, amounts of money held in clients' bank accounts—constitutes a "useful, concrete and tangible result". The computerized business method was thus declared patent-eligible. By predicating their conclusions on this low standard for processes' patent-eligibility, the CAFC's rulings had the joint effect of setting aside a higher, and older, legal threshold called "machine-or-transformation".[22] Theoretically, levels of legal standards and expectations of patent protection are inversely proportional: the easier a legal standard can be satisfied, the higher expectations of patent protection are.

Following these rulings, the U.S. Patent and Trademark Office ("USPTO"), whose tasks include the examination of patent applications and the subsequent grants or rejections of patents, had no option but to lower its patent-eligibility standard by adapting its guidelines to the low "useful, concrete and tangible result" threshold (Jaffe and Lerner 2004). Moreover, the *State Street* decision received extensive media coverage and attention by firms and patent attorneys around the world (Taketa 2002), thereupon spurring a wave of patent applications for computerized business methods, in services industries (OECD 2004; USPTO 2000) as well as in the software industry (Bessen 2011; Bessen and Hunt 2007; OECD 2004). These observations back the theoretical perspective to the effect that the CAFC's adoption of a very low standard for patent-eligibility of computerized business methods enhanced firms' expectations that these patent applications would be valid (see Figure 1), in turn prompting firms to file more applications for business methods. Firms' behaviour quickly adapted to this shifting legal environment.

To fully understand the controversy over business method patents, one must remember how novelty and non-obviousness are reviewed in the course of patent examination. The number of prior art cited during the examination process was comparable between applications for conventional patent-eligible subject matter and for computerized business methods (Allison and Tiller 2003), but it has been recognized that the quality and relevance of these

[22] *Gottschalk v Benson*, *supra* note 7, drawing on principles set out in *Cochrane v Deener*, 94 United States Reports 780 (1877).

citations were lower for the latter (Cohen and Lemley 2001). Most of the prior art pondered to assess novelty and non-obviousness consists of prior patents, the examiner's technical knowledge and prior art submitted by applicants. Yet, the USPTO had few relevant prior patents to rely on during examination since computerized business methods and computer programs *per se* were relatively new subject matter around the time of *State Street* (Jaffe and Lerner 2004; Graham and Mowery 2003). For the same reason, technical knowledge in computer programming had not been, until then, an asset that the USPTO sought during its hiring process for examiners (USPTO 2000; Graham and Mowery 2003). Finally, for self-evident reasons, applicants avoid submitting prior art that can spoil their applications (Lemley and Shapiro 2005). Consequently, the USPTO was inadequately equipped to satisfyingly examine patent applications for computerized business methods (Bessen and Hunt 2007; Jaffe and Lerner 2004; USPTO 2000), a satisfying examination process being one in which few patents are granted that should not be, and few applications are rejected despite deserving a grant.[23] The main consequence was that, after *State Street*, many *weak* patents were issued for computerized business methods as novelty and non-obviousness were poorly examined.

As mentioned earlier, because weak patents are likely to be defeated should they be challenged in court, they usually provide little benefits in market position for their holders. Furthermore, when trying to enforce them, firms put themselves in a vulnerable spot because they have low expectations of being able to control the knowledge spillovers that occur with enforcement. This reasoning tumbles down when a patent's weakness stems from lack of novelty or non-obviousness, as was the case for many patents for computerized business methods: in these circumstances, the patentee surmises its competitors and other firms already possess the knowledge. Therefore, these patents serve strictly as assets. The risk of their enforcement is limited to losing an asset instead of the more impactful forfeiture of exclusive knowledge or market position. Since these assets concretely offer no other advantages, they are wasted if they are not enforced.

[23] Economists might better know these situations respectively as *false positive* and *false negative*.

As a result, weak patents for computerized business methods encourage rent-seeking practices, where litigation threats are used to compel royalty payments from other parties or to procure other counter-benefits, such as cross-licensing (Bessen 2011; Carrier 2009; Boldrin and Levine 2008). Inasmuch as the royalty asked for is lower than the notoriously enormous costs of patent litigation (even when the defending party is successful in court), rational defendants, in the absence of counter-protection, will choose to pay the "rent" (Lemley and Shapiro 2005), which becomes an entry fee. In addition to some deadweight loss attributable to resources spent for defensive countermeasures, many potentially deleterious effects for competition and for the incentives to innovate emerge from this extra rent cost (Boldrin and Levine 2008; Carrier 2009).

Strong patents are less likely to result in rent-seeking practices because, in most cases, their enforcement is more risky. Though strong patents, by definition, are associated with high expectations of validity that decrease the probabilities of enforcement procedures turning against the patentee's interest, the stakes of a defeat are markedly more impactful for strong patents, whose inventions are usually incorporated in successful market products, than for weak patents. Through their critical role in their holders' market positions, strong patents become more than mere assets. Even when strong patents are used for rent-seeking, the patent rationale suggests that they provide higher social benefits, in incentive to invent and innovate and in public disclosure of new and non-obvious knowledge, than social costs, through rent-seeking and higher market prices attributable to a strengthened market position. Patents for inventions that are obvious or lack novelty, however, are presumed not to offer sufficient compensation for their social costs.

With the debate over the desirability of business method patents raging stronger than ever (National Academies of Science 2004; Federal Trade Commission 2003), three new important cases reached the CAFC a decade later. This time, however, the CAFC rulings were appealed to the Supreme Court. In the first case, *Bilski*, in which a patent application for a hedge fund business method had been refused by the USPTO,[24] the CAFC dismissed the "useful, concrete and tangible result" test and replaced it by going back to the older "machine-or-transformation" test.[25] The CAFC went as far as to assert that the "machine-or-transformation" test is the *sole* legal standard to assess the patent-eligibility of processes (methods). In appeal, the Supreme Court upheld the CAFC's dismissal of the "useful, concrete and tangible result" test, but rejected the CAFC's affirmation that the sole test is "machine-or-transformation".[26] Exemplifying this, the Court denied the patent under analysis without applying the "machine-or-transformation" test, but simply—and vaguely—by affirming that the business method claimed therein was abstract. A majority of the Court also turned down a legal standard by which *no* business methods would have been eligible for patent, an outlook that would have reduced expectations of patent protection for business methods to zero. Compared to the situation prevailing after *State Street*, the end-result after *Bilski* was a higher threshold to obtain patents for computerized business methods—commensurate with lower expectations of patent protection for firms (see Figure 1).

The situation evolved some more two years later, with the *Mayo* decision,[27] in which a process patent to determine optimal drug dosage to healthcare patients was challenged. This business method was not computerized, but the case's reasoning extends to all business method patent applications. The Supreme Court once again raised the threshold for patent-eligibility of business methods, by now asserting that it was possible for a patent application to satisfy the "machine-or-transformation" test and yet not be patent-eligible. In practice, this conclusion made the "machine-or-transformation" test useless (Bruneau 2013). This time as well, the Court rejected the patent by pronouncing the business method to be an "abstract idea". In doing so, it stressed the role of the utilitarian patent rationale for patent-eligibility to judge this kind of cases: courts should make sure that the fundamental building blocks of research and inventive activities remain free of appropriation (Bruneau 2013). In support of judges and patent examiners, the Court set out a two-step framework to determine when patent

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[24] *Bilski v Kappos*, *supra* note 10.
[25] *In re Bilski*, 545 F 3d 943 (Fed Cir 2008).
[26] *Bilski v Kappos*, *supra* note 10.
[27] *Mayo Collaborative Services v Prometheus Laboratories, Inc*, *supra* note 8.

applications claim mere "laws of nature, natural phenomena and abstract ideas". This framework was spelled out more explicitly in the 2014 *Alice* decision.[28] In *Alice*, once again, a patent in the banking services industry was discarded in the pile of invalidated patents, the Court using this time the *Mayo* framework. Consequently, it confirmed if need be that the opinions and conclusions found in *Mayo* extended to computerized business methods.

As a result of this trilogy of Supreme Court rulings, expectations of patent validity for computerized, as well as non-computerized, business methods decreased significantly compared to the same situation in the *State Street* era (see Figure 1). Short-term data show that the number of patent lawsuits filed subsequently to *Alice* (Barry et al 2015; Bessen 2014) and the number of business method patents issued during this same period both notably decreased (Bessen 2014). The upshot in the number of lawsuits is entirely due to changes in firms' behaviour; so far, preliminary analyses trace the cause of this shift back to the *Alice* decision (Barry et al 2015; Bessen 2014). As for the decrease in the number of business method patents being issued, it likely results from a combined reaction of firms' decisions—abandoning or modifying patent applications now expected to be rejected in the light of the *Mayo* framework—and of the USPTO, which responded to the *Alice* decision by tightening its guidelines to assess patent-eligibility in the course of patent examination (USPTO 2015).

1.3 Extending the Scope of this Survey

This chapter has illustrated how expectations of IP rights' validity vary as a consequence of shifts in the legal environment, and how these fluctuations end up affecting firms' decisions. The two contexts that were discussed focused on patents and on two specific industrial settings. In order to widen the spectrum of this paper and its economic model, the final section of this chapter reviews examples of past and potentially future legal shifts that have similar repercussions, albeit (1.3.1) without being confined to patents, and (1.3.2)

[28] *Alice Corp v CLS Bank International*, 134 Supreme Court Reporter 2347 (2014).

without being limited to industry-specific effects. Many of these potential shifts (1.3.3) relate to exceptional uses that do not amount to IP infringement.

1.3.1 Stretching Technologies beyond their Inventive Dimension

IP law offers a dual protection to computer programs, as they are copyrightable in addition to being potentially patentable.[29] Unlike patent protection, which provides exclusion rights over the inventive features of computer programs, copyright protection is tethered to the programs' codes as well as to their interfaces, in other words, to the many ways by which computer programs are *expressed*, either in words or images (Gervais and Judge 2011; Landes and Posner 2003). A computer program executing the exact, same function as another—copyrighted—computer program, but expressed differently, would not infringe the copyright. A patent, on the other hand, would be violated by any computer program that executes the technical function claimed therein, whatever the ways the program is expressed. Even if the breadth of copyright protection is generally thought of as more limited than the protection conferred by patents, copyright still brings about numerous business benefits, particularly with respect to consumers (Phillips 2009; Dam 1995). Software users cannot legally copy it without the firm's approval, typically through license, because copying the application also reproduces the inbred, copyrighted computer programs, an act that requires consent from the copyright-holder.[30].

There existed a period, however, during which it was ambiguous whether computer programs benefited from copyright protection. In the United States, this grey area was clarified in the 1970s and 1980s through successive legal moves, combining court rulings,

[29] In Canada, *Copyright Act*, RSC 1985, c C-42, section 2 "literary work" [*Copyright Act*]. In the United States, 17 USC §101. In application of Article 10(1) of the TRIPS, *supra* note 5, Members of the WTO must provide copyright protection as literary works to computer programs, in both source code (human-readable instructions) and object code (the transformation of source code in a language that the machine can execute, usually binary). User interfaces are also copyrightable as "artistic work" under traditional copyright doctrine.

[30] In Canada, *Copyright Act*, *ibid* at sections 3, 27. In the United States, 17 USC §106, 501.

amendments to copyright law and the establishment by Congress of a commission to study interactions between copyright law and computer programs (Graham and Mowery 2003; Dam 1995).[31] At each of these steps, expectations of copyright protection grew for firms active in the software industry, encouraging them to increasingly exercise these rights, notably through the now ubiquitous license agreement (Phillips 2009). It is on account of bolstered expectations of copyright protection that firms and other participants in the software industry gained enough leverage to request their users and customers to agree to license agreements (Phillips 2009; Murray, Piper and Robertson 2014b). Copyright law was thence instrumental in enabling these participants, whether exclusionary market firms or F/OSS communities, to offer their products differently and exert more control over subsequent uses, hence, to find more ways to capture value for their technologies.

Similar legal shifts happen (i) anytime the scope of an IP regime is extended to a new category of technologies, a situation that could occur should requirements for patent-eligibility be reduced; (ii) when *sui generis* regimes of IP are created for specific technologies, as has been the case in the 20th century for plant varieties, integrated circuits and data required for market approval of pharmaceutical and agricultural products (Correa 2007); or (iii) when new categories of products are granted protection through geographical indications, i.e., designations that certify the origin of a product together with the singular quality or reputation that this origin conveys to consumers (Gervais 2012).

From a Canadian perspective, compared with the country's previous trade commitments and current regulations, the *Comprehensive Economic and Trade Agreement*, with countries of the European Union, and the *Trans-Pacific Partnership*, with Australia, Brunei, Chile, Japan, Malaysia, Mexico, New Zealand, Peru, Singapore, the United States, and Vietnam, contain substantive provisions that, once ratified, shall increase the minimum protection to be

[31] *Apple Computer, Inc v Franklin Computer, Corp*, 714 F 2d 1240 (3d Cir 1983). As the final step in this legal process, this key decision summarizes the legal development that inscribed computer programs in copyright law.

accorded to data submitted for market approval of pharmaceutical and agricultural products, whether patented or not (Lexchin and Gagnon 2014).[32] This increased legal protection should enhance firms' expectations of temporary market exclusivity for these products. As the case of Myriad Genetics illustrates, market exclusivity in these industries can be accompanied by a significant commercial value.

1.3.2 Changing the Terms of Intellectual Property

In Canada, prior to January 1st, 1996, patent protection lasted seventeen years starting from the *issuance* date, subject to the payment of maintenance fees. In 1996, the term of protection switched to twenty years counting from the *filing* date.[33] This change results from Canada accessing the World Trade Organization ("WTO"), because Members of the WTO have to comply with the organization's diverse agreements, including article 33 of the *Agreement on Trade-Related Aspects of Intellectual Property Rights*. This provision enunciates that Members shall make patent protection available for at least twenty years starting from the filing date. Statutory patent law in the United States was similarly revised during the same period (Gallini 2002).

In most cases, where the delay between filing and issuance amounted to less than three years, the term of protection of pending patents was basically extended.[34] For these firms at that time, this statutory modification meant a longer patent term than what was coveted at first. For this additional period of patent protection coverage, expectations of validity prior to this amendment were nil, compared to the continuation of the firm's regular expectations once the

[32] The (particularly convoluted) legal mechanics of these provisions are beyond the scope of this paper, and readers who wish to delve into them are referred to Lexchin and Gagnon (2014).

[33] *Patent Act*, *supra* note 5 at sections 44, 46.

[34] It is worth noting that the way Canada initially amended its legislation was—successfully—disputed at the WTO because applications still under review in 1996 were supposed to receive the old term of protection, which would be less than twenty years from filing for those pending patent applications that would be examined in less than three years. This dispute led to an amendment to section 45 of the *Patent Act*, *supra* note 5. See *Canada—Term of Patent Protection (Complaint by the United States)* (2000) WTO Doc WT/DS170/AB/R (Appellate Body Report), online: WTO <http://docsonline.wto.org>.

amendment was announced. This extension and its associated rise in expectations affected all patent applications in the same manner, indiscriminately of their industrial sectors, thus showing that occurrences of legal shifts can be *de jure* industry-neutral. Of course, this does not preclude the *de facto* industry-specific impacts of these shifts to differ. Should either the term or general scope of protection offered by any IP regime be extended or confined in the future, these changes should likewise affect all right holders. This situation is currently contemplated in Canada, where the government, in negotiations leading to the *Trans-Pacific Partnership*, agreed to a twenty-year extension of the term of copyright protection.[35]

1.3.3 Exceptions Are Everywhere

The term of protection is not the only limitation to the exclusionary right conferred by IP law. Most IP regimes also specify various exceptions, which can by and large be regrouped in two sets: those qualifying the regime's *subject matter* (validity), and those delineating the *application* (enforceability) of conferred titles. As has been examined through the analysis of patent-eligibility, many exceptions germane to subject matter refer to categories that are excluded from eligible protection. Similarly, it can be that an IP regime protects only some aspects of that subject matter while leaving other dimensions untouched. This phenomenon could be observed with respect to the difference between the copyrighted code of computer programs and the non-copyrightable functions executed by this code.[36] For application, IP law regimes often detail a number of dealings that fall within the perimeter of exceptions. These exceptional uses are permitted and do not count as IP infringement. To conclude this chapter, two more examples of limitations in IP law regimes are introduced. Should their ambit be adjusted through court judgments or statutory amendments, they would dampen or boost firms' expectations (i) of IP validity or (ii) of these rights' enforceability.

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[35] "Trans-Pacific Partnership: Text of the Trans-Pacific Partnership", online: New Zealand Foreign Affairs & Trade <http://tpp.mfat.govt.nz/text>. Compare Chapter 18, Article 18.63 with *Copyright Act*, s. 6. Ratification of this trade agreement and amendments to the *Copyright Act* will be necessary for this extension to enter into force.

[36] Jurists usually refer to this as the "idea/expression dichotomy".

(i) Trademark law provides exclusion rights over the commercial use of distinctive marks and other signs that distinguish a firm's goods and services from those of its competitors.[37] From a technological point of view, there exists a conspicuous exception to the subject matter of trademark law: functional features. In most jurisdictions, exclusion rights granted to distinctive marks do not extend to any functional feature the mark may possess.[38] LEGO blocks probably best illustrate this rule. People who grew up in North America or Europe instantly think "LEGO" when they see square construction bricks that can be piled together through circular studs. The legal definition of a trademark is without a doubt satisfied. Yet, these circular studs are functional, and therefore cannot be the object of trademark protection.[39] The intention behind this exclusion is to avoid that trademark registration, with its potentially infinite duration,[40] impairs the rationale behind the temporal limitedness of other IP regimes, namely patents, copyrights and industrial designs (Landes and Posner 2003; Gervais and Judge 2011). These finite terms of protection, as was evoked at the beginning of this chapter regarding patents, ensure that, in the long run, users can build on inventions, ideas and creations that have been disclosed in exchange for appropriate IP protection and that have since joined the public domain. This justification takes even more importance in the case of functions that have no adequate technological substitutes, like the round shape of a tire (Landes and Posner 2003); in these cases, the functional feature literally encompasses the technology's "abstract idea", which is explicitly left out of patent-eligibility in accordance with the patent rationale. Changes to this trademark limitation or to how it is applied may impact the decision-making processes of firms whose technologies come with distinctive, functional designs.

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37 In Canada, *Trade-Marks Act,* RSC 1985, c T-13, sections 2 "distinctive", 2 "Trade-Mark", 19 [*Trade-Marks Act*]. In the United States, 15 USC §1114, 1127 "trademark". At the WTO, Articles 15-16 of the TRIPS, *supra* note 5, require that WTO members provide trademark protection to an extent at least comparable to this description.

38 In Canada, *Trade-Marks Act*, *ibid* at paragraph 13(2). In the United States, 15 USC §1052(e)(5).

39 *Kirkbi AG v Ritvik Holdings Inc*, [2005] 3 Supreme Court Reports 302. LEGO had patented its design in Canada and tried, after the patent's expiration, to enforce common law trademark protection, to no avail.

40 In Canada, *Trade-Marks Act*, *supra* note 37 at sections 19, 46. In the United States, 15 USC §1058-59. For members of the WTO, this indefinite duration is required by the TRIPS, *supra* note 5 at Article 18.

(ii) In addition to numerous user exceptions, copyright regimes also ordinarily exempt from infringement a list of dealings gathered under the fair use doctrine, called "fair dealing" in Canada.[41] This doctrine provides that some specific uses—among others, research, criticism, news reporting, satire and parody—are allowed if they are deemed "fair" according to legal or jurisprudential standards. In legal theory, rights are construed extensively, whereas exceptions are interpreted restrictively (Côté, Beaulac and Devinat 2011; Sullivan 2008), thereby generally confining users' expectations of fair use admissibility. In turn, lower expectations of fair use entitlement are correlated with higher expectations of enforceability for copyright owners. In Canada, however, a major legal shift occurred in the realm of copyright law when the Supreme Court, in the early 2000s, affirmed that fair dealing should not be construed restrictively, as exceptions to copyright, but rather liberally, under a concurrent concept of "users' rights".[42] In words comparable to those that the U.S. Supreme Court recites to discuss patent-eligibility, the impetus was to strike "a balance between promoting the public interest in the encouragement and dissemination of works of the arts and intellect and obtaining a just reward for the creator."[43] Users' rights are thus justified by the imperative of promoting the dissemination of works; under the conditions of the fair dealing doctrine, this diffusion is presumed to produce benefits that dwarf creators' reward losses.

This interpretive distinction may sound arcane to non-jurists, making it difficult to figure out its concrete outcomes. Hopefully a real case will help to discern its implications. Under the fair dealing doctrine, it does not constitute copyright infringement for companies that operate online music services in Canada to provide 30-to-90-second streaming extracts of songs in their catalogues, as these previews help

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41 In Canada, *Copyright Act*, *supra* note 29 at section 29. In the United States, 17 USC §107.

42 *CCH Canadian Ltd v Law Society of Upper Canada*, [2004] 1 Supreme Court Reports 339 at paras 12, 48, 51, Chief Justice McLachlin.

43 *Théberge v Galerie d'Art du Petit Champlain inc*, [2002] 2 Supreme Court Reports 336 at para 30, Justice Binnie, reaffirmed and cited in *CCH Canadian Ltd v Law Society of Upper Canada*, *ibid* at para 23.

consumers "research" the music they desire.[44] The fair dealing doctrine is stretched in two different directions here. First, had "research" been interpreted restrictively, as an exception, it is very unlikely that it could have encompassed activities that are much closer to trade consumption, like grocery store samples given to clients, than to research. Second, the parties invoking this defense (online music providers) were not the actual *users* involved in the fair dealings (consumers "researching" music); legal defenses predicated on the fair dealing doctrine first permitted this possibility only after the concept of "users' rights" was first spelled out.[45] As a consequence of this change in the fair dealing doctrine, Canadian firms partaking in technological sectors where firms regularly resort to copyright protection had to adapt their expectations of enforceability. Similar changes would occur should a jurisdiction bring equivalent modifications to the exceptions permitted by any legal regime of IP. Among others, patent law allows exceptional uses of patented inventions for purposes of research, scientific experiment or non-commercial use.[46] As an exception, this defense is currently applied restrictively (Scotchmer 2004; Landes and Posner 2003; Gallini 2002), but a legal shift that would apply it liberally instead could significantly impact firms' expectations of patent enforceability.

44 *Society of Composers, Authors and Music Publishers of Canada v Bell Canada*, [2012] 2 Supreme Court Reports 326.

45 *CCH Canadian Ltd v Law Society of Upper Canada*, *supra* note 42.

46 In Canada, *Patent Act*, *supra* note 5 at section 55.2(6). See also *Smith, Kline & French Inter-American Corp v Micro-Chemicals Ltd*, [1972] Supreme Court Reports 506. In the United States, this defense is not codified but rather originates from common law principles; see *Madey v Duke University,* 307 F 3d 1351 (Fed Cir 2002). These exceptions are permitted in the WTO superstructure in the TRIPS, *supra* note 5 at Article 30.

Chapter 2: On Distinguishing Inventions and Innovations

Chapter 1 outlined the role of firms' expectations of IP protection in their decision-making processes for technology management and supported the motivation for focusing the analysis of this paper on changes in these expectations. Before setting out a microeconomic model to study the effects of legal shifts in firms' choices, the subject of Chapter 3, it is imperative to first appraise how firms interact with IP rights. The accuracy of this assessment determines the soundness of the model's structure and assumptions.

2.1 Not Reinventing the Wheel, or the Innovation Process

When investigating the role of IP in the technological realm, a common misconception consists in assimilating inventions to innovations. IP rights that apply to technologies cover *inventions*, "creat[ions] or design[s] ([of] something that has not existed before)" (Oxford Dictionaries). Inventing takes a technological idea and *implements* or *applies* it. These implementations or applications are the object of IP protection, while the underlying technological ideas remain in the public domain (Frischmann 2012). Maintaining ideas and other fundamental building blocks in the public domain allows other inventors to access them and build on them. Contrary to the mythological "spark of genius" that is often believed to qualify inventive endeavours, inventors actually use, combine, re-shape, re-configure and build on available and often state-of-the-art knowledge and tools (McGee 1995).[47] With the help of IP law's design, particularly the second prong of the patent rationale,[48] the public domain ensures that a substantial amount and diversity of these building blocks stay at creators' disposal.

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47 Thomas Edison famously put it as "Ten percent inspiration, ninety percent perspiration."

48 See the beginning of Chapter 1.

As a Schumpeterian concept, *innovating* can be defined as "reducing an invention to practice and exploiting it commercially" (Scherer 1965, 165). It brings implementations or applications of technological ideas to market. Understood this way, it is easily apparent that invention is but an initial step *within* the innovation process. The end-result of the innovation process is *an innovation*, a market product, either good or service, that incorporates at least one inventive input.[49] Inventions are necessary, but most of the time insufficient, for innovations to exist; while it can happen that an invention is by itself an innovation, most inventions need further combinations with other inputs in order to become viable and profitable market products, i.e., to be commercially exploited by rational firms. These miscellaneous inputs could include other inventions, designs, branding, data and other forms of information, tangible components ranging from basic tools to high-technology devices, and so forth. In the innovation process, the commercial product's functional requirements are chosen, and the inputs and knowledge components needed to meet these requirements, as well as their appropriate or optimal configuration, are identified. To some extent, the steps required to transform an invention into an innovation are similar to those needed to invent in the first place, albeit at a different, more concrete, level of abstraction (Plotkin 2009).

Microsoft Office Word ("Word") 2007, the text-processing software on which this paper was typed,[50] provides a good example of the innovation process. When initially released, it counted many inventive applications and design components that distinguished it from competing products, including earlier Word editions. Most of these new features could (back in 2007) be defined as inventions, but they likely conveyed little commercial prospects in and of themselves. However, when these multiple inventions were combined together, along with other already-known designs and technical inputs, with the intent of developing a new edition for this multi-purpose text-processing software, this commercially successful (Microsoft News Center 2007) innovative product was obtained.

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[49] The nature of the market depends on the product: not all products are destined for the consumer market. Interestingly, in line with Nordhaus' (1969) seminal formal analysis of patents, economic models of patents tend to analyze *process inventions* (actually process *innovations*) like machineries, not consumer products.

[50] "If it ain't broke, don't fix [or update] it."

For most industries, when in relation with technologies, IP rights do not cover innovations like Word 2007 (although they could), but these individual, new and inventive features integrated in innovations. It is therefore indirectly, though not trivially, that some ramifications of IP law regimes reach the post-invention stages of the innovation process. Models of intra- and extra-organizational interactions between firms' inventive and innovative units differ significantly depending on whether these models approach IP as applying to inventions or to innovations—as conceptually defined herein, not as textually flagged by their authors.

A contemporary to Schumpeter, Plant (1934) similarly distinguished *making* inventions from *exploiting* inventions, the equivalent herein of *innovation*, and he recognized that economic conditions, including IP law, could bring about contrasting stimuli for these two separate undertakings. He argued, for instance, that in harsh economic times firms could prefer exploiting (possibly immature) inventions and reaping their associated benefits now, instead of waiting later for the higher expected benefits of exploiting fully mature versions of the same inventions. This short-term focus, to answer pressing concerns, is likely to implicate a redirection of firms' resources for making inventions to expenditures for exploiting inventions. Meanwhile, these same economic depressions might provide a new impulse for unemployed workers to invent, as tinkering comparatively looks more promising when the job market is sluggish than when it is vigorous. In the same way, in being a constitutive element of the economic conditions, IP regimes stimulate or hinder inventive and innovative endeavours differently. In addition, IP systems pull these activities toward technological directions that offer greater expectations of value capture, based on the structure and breadth of the legal protection (Plant 1934).

The main reason for these varying effects in incentives for invention and innovation is that the innovation process and its integrated invention counterpart have distinctive features despite their similar structures. Plant hinted at one of these particularities, revolving around the second set of uncertainty touched upon *en passant* in this paper's introduction: uncertainty regarding the commercial significance of a technology.[51] This uncertainty is markedly higher during inventive activities than during the subsequent stages of innovation, as the more the firm's innovative product is developed, the clearer is the firm's outlook of market conditions, especially demand. Adding IP management to this discussion and keeping in mind that IP in a technological context applies to inventions, it follows that firms take decisions regarding IP in a relatively more volatile context than would be the case if IP regimes pertained directly to innovations instead of as a side effect. This inversely proportional curb between the innovation's development progression and uncertainty about the commercial prospects of that same innovative product partly explains why so many patented inventions never reach commercial exploitation and, symptomatically, why a significant proportion of renewal fees for maintaining patents are not paid, leading to these patents' automatic forfeit (Bessen and Meurer 2008).

This conceptual distinction between invention and innovation, and its importance, were well-understood by prominent economists of the twentieth century (Plant 1934; Schumpeter 1976; Scherer 1965). Apparently, it became neglected the moment economists studying technological development diverted their analytical lens from conceptual to formal economics. Microeconomic theory tends to (mis)represent the market impact of technological IP rights with monopoly models that incorrectly circumscribe the effects of IP to granting *exclusive* rights on *innovative products* rather than *exclusion* rights on *inventive inputs* (e.g., Miceli 2009; Carlton and Perloff 2008; Lemley and Shapiro 2005; Scotchmer 2004;[52] Landes and

[51] See the Introduction. The phenomenon presented by Plant can be theorized under the idea that firms' level of risk aversion is exacerbated in difficult economic conditions. They feel disutility coming from other sources of risk more acutely, and they will thus seek, *ceteris paribus*, to reduce these risks (tantamount to uncertainty) to a greater level than the one they would find optimal in times of greater prosperity.

[52] The inclusion of Scotchmer (2004) deserves an explanation. Scotchmer's excellent work, like others listed in this paragraph, takes into consideration the potential blocking effects of patents, which incorporate some impacts of the difference between invention and innovation. However, her models leave out key aspects of

Posner 2003; Tirole 1988). This misconception translates to many models of IP that focus on upstream technological research and development (e.g., Acemoglu, Bimpikis and Ozdaglar 2011; Carlton and Perloff 2008; Scotchmer 2004; Tirole 1988). The propensity of this (over)simplification might have been influenced by its prevalence in earlier work assessing formally the optimal structure of the patent system (e.g., Nordhaus 1969; Scherer 1972;[53] Gilbert and Shapiro 1990;[54] Klemperer 1990;[55] Scotchmer 2004; Carlton and Perloff 2009). Inventors and innovators do not research and experiment out of thin air. As just mentioned, they depend on a substantial amount of knowledge components, tools and technological inputs, many of which, depending on their nature and on the norms of the industrial sector, may be covered by IP. These models attempt to identify the effects of IP regimes; yet, they focus entirely on IP's incidental reach on innovations and miss any insight incoming wholly from IP as an incentive or disincentive to inventive activities *per se*. Upstream, by overlooking the innovation process and its interplay with potentially IP-protected inventive inputs, these models understate the consequences of IP on the costs, revenues and overall opportunities specifically associated with the inventions emerging from the research and experimentation stages. Downstream, they limit their analysis to IP's role in the commercial exploitation of innovative market products, as if the inherent inventive inputs were immune to market impetus in firms' decision-making processes.

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this distinction, particularly the one just described with respect to uncertainty in commercial significance. Patents affect these distinctive features differently, and a satisfying model should capture these distinguishing effects: see Chapter 3 for more details.

53 Scherer is well aware of the distinction between invention and innovation, as exemplified by the fact that he scrupulously writes "inventors and innovators" in this (1972) article. Nonetheless, the model therein expands on Nordhaus' (1969) formal work, which assimilates inventors and innovators. Consequently, Scherer's article carries this pitfall.

54 In their conclusive remarks at 112, Gilbert and Shapiro acknowledge their model's shortcomings in that respect.

55 Klemperer's (1990) model differs from the others in that it recognizes that a firm's innovation is but a point in the breadth of exclusivity given by a patent. In this way, his model does take into consideration that patents in themselves do not cover market products. Yet, this work studies patents' market repercussions only, by considering that a firm's patent excludes a number of substitute innovations circumscribed by the patent's breadth, while innovations outside that breadth remain as potentially competing (substitute) market innovations. Unlike most models in this paragraph, Klemperer's substitutability-minded approach accurately addresses IP as exclusion rights instead of exclusive (monopoly) rights. However, by focusing wholly on the *innovation*'s market impact, his model carries the same shortcoming as the other listed here, unable to appropriately distinguish inventions from innovations as it fails to capture important effects of IP, for instance, through licensing.

In the model put forward in Chapter 3, the importance of differentiating inventions from innovations is addressed by exploring a recent approach in technology management, *open innovation*, an organizational structure in which firm boundaries are purposively kept open in a way that facilitates inflows and outflows of knowledge and technologies (Chesbrough 2003). Firms in a growing number of industrial environments routinely adopt and internalize strategies that match this management model (Vanhaverbeke, Chesbrough and West 2014). The initial impression left by these tendencies has been sufficiently striking for governments and international organizations to dedicate special attention to better understand mechanisms of open innovation, their attributes, their effects and their potential (European Commission 2014; Conseil de la science et de la technologie du Québec 2009; OECD 2008).

Open innovation is adopted to represent some assumptions of this paper's model, with respect to the industrial environment, because (i) of its latent theoretical differentiation between inventions and innovations; and (ii) of the relative simplicity by which ideas essential to open innovation can be amalgamated with microeconomic theory to naturally construct a model that distinguishes inventions and innovations. As open innovation theory initially stemmed from actual practices, successes and failures, the phenomena described and predicted by a model of microeconomic theory that is predicated on assumptions of open innovation should translate more easily to real-life explanations and examples. In order to build on these characteristics in the next chapter's model, open innovation is described in the last section of this chapter. But first, to clarify why open innovation turns out to be a pertinent innovation theory, this chapter's next section analyzes and elaborates on Baldwin and Von Hippel's (2010) viability model.

2.2 Why Open Innovation, in One Word: Viability

Baldwin and Von Hippel's (2010) work on the viability of innovation modes underscores the reasons behind open innovation's quick rise in influence and its adoption by many in the early 2000s (Villaroel 2013). These researchers compare the conditions of viability coupled with three modes of innovation:

- Single-user innovation, tautologically, is created by one user for the satisfaction obtained from the innovation process and from one's personal, customized use of the innovation (Von Hippel 1988; 2005; Piller and West 2014);
- Producer innovation is the typical innovation produced by a firm for profit through market release. For its production process, the firm reckons on its internal innovation capabilities, with inventive contributions usually stemming from paid employees; and
- Open-collaborative innovation is conceptualized as a group of people who share their ideas to each other openly and freely, as exemplified in F/OSS projects (Lakhani 2013; Raymond 1999). Besides having access to the innovation achieved as an end-result, participants can benefit in many ways from this cooperation—enjoying the process itself, acquiring new skills, learning from others or signaling their own skills, to name a few (Lakhani 2013; Baldwin and Von Hippel 2010; West and Gallagher 2006). (It is important to note that, despite the resembling terminology, this conception of open-collaborative innovation is *not* synonymous with open innovation (Chesbrough and Bogers 2014).)

In this description, in order to stress once more the importance of distinguishing inventions from innovations, particular attention has been given to the reasons that may incite inventive participants to partake in each of these three innovation modes. These participants may have multiple motivations, so they can choose to engage in more than one of these modes, even for competing innovations. In software development, this reality is eminently recognized as a large number of employed ICT professionals also devote some of their time to F/OSS projects (Lakhani 2013; Phillips 2009).

In Baldwin and Von Hippel's (2010) model, the viability zones of these three modes of innovation are schematized over an x-y axis (Figure 2). The x-axis estimates an innovation project's *design costs*, associated with the costs of identifying an innovation's functional requirements and of finding the knowledge components and inputs needed to satisfyingly solve these functional requirements through a judicious arrangement. The y-axis gauges the project's *communication costs*, which account for the costs of sharing design-related information among participants of the innovation process. The viability of each mode for any given innovation is captured by this graph.

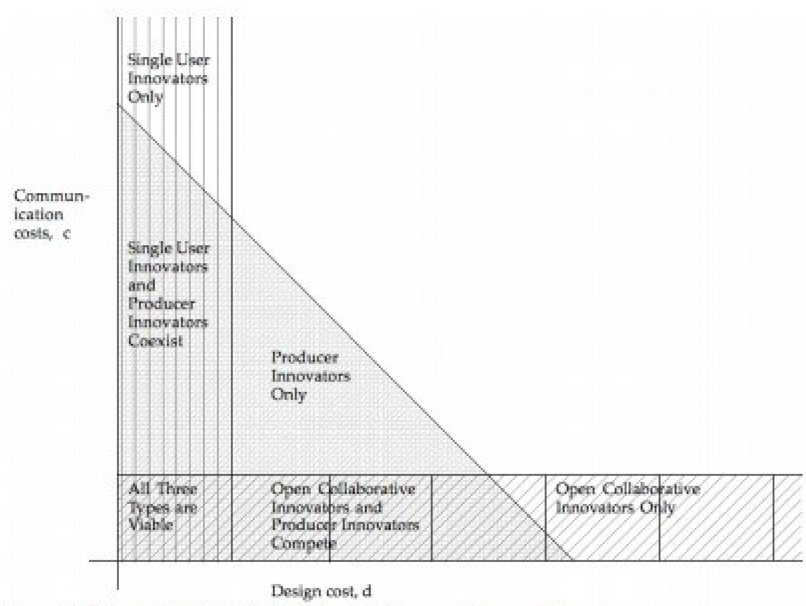

Figure 2 Bounds of viability for all 3 innovation modes
Source: Baldwin and von Hippel 2010

An innovation mode is said to be viable if its value for the innovator as well as for each innovative participant exceeds each of their concomitant individual costs. For the single-user and open-collaborative modes, the value is relatively small, as it sums up to the participants' personal benefits derived from the innovation process, including access to and use of the innovation for oneself. Producer innovators have access to potentially greater value as they seek to make profits by offering the innovative product on the market, but they do so with additional costs—for production and transactions—that the other two modes are not subject to. As the term suggests, *production costs* represent the costs of producing multiples copies of the innovation for market. *Transaction costs* are more intricate, as they account for the costs of securing rights or market power over the innovation and transacting with clients (Baldwin and Von Hippel 2010). Analyzing this graph shows how the deepening presence of ICT in innovation processes profoundly affected these three innovation modes and their viability zones (Baldwin and Von Hippel 2010). To observe these changes, one must first assess how these zones are bounded.

The single-user innovator being, well, alone, no communication costs are incurred during the innovation process. However, its design costs escalate rapidly because of the difficulty for a single user to possess the wherewithal necessary to solve any complex design. Therefore, single-user innovation is algebraically viable when the user's personal value (V_i^U) for the innovation project *i* is higher than the innovation's design costs (d_i), the only category of costs affecting single-user innovators.[56] The viability zone of single-user innovation is thus defined by $d_i \leq V_i^U$, which is graphically represented by a vertical line close to the y-axis (Baldwin and Von Hippel 2010). For any innovation project whose coordinates of design and communication costs fall in this zone, single-user innovation is a viable mode.

Open-collaborative innovation can attract a large number of actors willing to participate freely. This way, they can solve very complex design problems with virtually no design costs.[57] Nevertheless, with any large number of participants from diverse geographical

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[56] The elements of this mathematical notation come from Baldwin and Von Hippel (2010), with some simplification to focus on the aspects pertinent to this section's purpose of underscoring the relevance of open innovation. This notation should not be mixed up with the one used for this paper's model in Chapter 3.

[57] Baldwin and Von Hippel (2010) specify that this simplification is applicable only when tasks in the innovation process are dividable into modules. This way, individual participants are not actually involved in the design work, for which, as was discussed regarding single-user innovators, costs grow fast. Seen from this perspective, *virtually* is the key word. In this layout, the innovator's design costs for a modular innovation can be fixed upfront. Consequently, they can be pre-deducted from the open-collaborative innovator's value, V_i^O,

locations, communication costs, prior to the major advancement in ICT these last decades, would rise exponentially and quickly reach the point where they become unmanageable. Employing a notation equivalent to the one referred to for single-user innovation, open-collaborative innovation is viable anytime the total value (V_i^O) derived by the participants to the innovation project i is higher than the project's costs, here solely constituted of communication costs (c_i). Accordingly, and symmetrically to the single-user innovator, the viability zone of open-collaborative innovation is defined by $c_i \leq V_i^O$, which is traced in Figure 2 as a horizontal line near the x-axis (Baldwin and Von Hippel 2010).

Producer innovators have the opportunity of selling their innovative products to customers, and so, supported by expected market revenues, they are likely to find more value for their innovations. Compared with the other two modes, these revenues provide producer innovators with greater means to counterbalance costs, whether design costs, communication costs or a combination thereof. However, offering the innovation to customers also entails production and transaction costs. Despite these additional expenses, there remains a wide range of innovations for which expected revenues net of production and transaction costs are high enough to incur substantial design and communication costs. For any innovation project i, producer innovation is viable if the expected revenues V_i^P are higher than the sum of all costs—production (p_i), transaction (t_i), design (d_i) and communication (c_i). In Figure 2's layout, producer innovation is viable so long as $d_i + c_i \leq V_i^P - p_i - t_i$. The right-hand side of this inequality represents the producer innovator's budgetary constraint, its expected revenues net of production and transaction costs. In Figure 2, the diagonal line delineates the viability zone of producer innovators, where this budgetary constraint equals the sum of an innovation's intrinsic design and communication costs (Baldwin and Von Hippel 2010).

instead of being assigned a positive amount of costs. V_i^O should thus be defined as the open-collaborative innovator's value net of the costs necessary to set up the modular design.

Achieving a given innovation project entails specific design and communication costs, whose amounts determine the coordinates of this project in Figure 2's graph. This position in turn indicates the mode(s), if any, that is(are) viable to carry out the innovation. As is visible in Figure 2, each of these modes is the only viable process under some circumstances. For instance, projects that require design and communication costs that are both non-trivial are only viable through producer innovation, if viable at all. Also apparent is that, in many cases, two or three modes viably compete or coexist for the same innovation.

Now, what happens to this initial innovative environment when the quality of ICT increases by leaps and bounds, and these technologies become widely available at reasonable costs, a shock that occurred during the 1990s (Foray 2004; Castells 2001) and that has lingered in thereafter? On the one hand, effects of ICT improvements on production and transaction costs are mixed. Whereas digital innovations can be (re)produced cheaply (Baldwin and Von Hippel 2010; Phillips 2009), and producers of tangible innovations have greater access to a global ecosystem to manufacture their innovations at lower costs (Tseng 2013), transaction costs remain mostly unaffected. On the other hand, telecommunications and the internet permit global, large-scale and deep communications and information sharing at very low costs. Likewise, equipped with powerful search engines, web browsers provide free or inexpensive access to a broad range of ideas and designs to help individuals solve various complex problems, for example, with online discussion forums (Piller and West 2014). Thanks to contemporary ICT, innovation processes are subject to considerably less communication and design costs, possibly widening to the same extent the number of innovation modes for which they are viable. Graphically, the location of each individual innovation project in Figure 2 is pulled, to some varying extent, toward the origin (Villaroel 2013). The magnitude of this pull depends on each project's functional requirements. The outcome is that many innovation projects that were previously unviable are now within reach, and a large number of projects that could only be undertaken viably with one mode now fall in zones where more than one mode is viable.

Single-user and open-collaborative innovators are markedly favoured by these changes, as design and communication costs respectively constitute their only constraints. Producer innovators see their costs diminish too, but unlike the other two, they also have to take into account production and transaction costs, thereby nibbling the comparative advantages they derive from contemporary technological improvements. Besides, the pull materialized by the advancements in ICT brings unexpected competition to many producer innovators whose innovation projects were positioned close to the bounds of viability of the other two modes, which are likely now viable for these same innovation projects. For a few given innovation projects, it is even possible that innovators from these emerging viable modes can develop the innovation at lower costs than those of producer innovators.

In this scenario, producer innovators that do not react are likely to suffer unless their innovations are unaffected by ICT or entail hefty design as well as communication costs. Producers can respond to improvements in ICT by learning greater flexibility. Among other means, flexibility can surface when producer innovators become hybrids that integrate processes, participants and inputs from the other two modes of innovation into their own innovation processes, in cases where it is indeed more profitable to do so (Baldwin and Von Hippel 2010). For instance, crowdsourcing (Villaroel 2013; Füller, Hutter and Hautz 2013) is a hybrid innovation process in which a producer innovator relies on collaborative practices to harness ideas and knowledge components from community participants traditionally alien to the producer innovator (Baldwin and Von Hippel 2010). As flexibility allows them to reorient their activities better and faster, hybrids are more likely to have a higher hand in current industrial ecosystems, where the penetration and performance of ICT are ever intensifying. Even the most hegemonic company of the 1990s, Microsoft, chose to adapt its processes to this reality, and it did so expressly by embracing practices and norms of open innovation to reach out to innovators from other modes (Phelps and Kline 2009).

Henry Chesbrough's seminal book on open innovation, written in 2003, was not meant exclusively for an academic public, but also for firm managers (Chesbrough and Bogers 2014). It was a sensible move on his part: the evidence collected to set up the concept of open innovation was deeply grounded in the empirical examination of technology management practices, from important firms (Xerox, IBM, Intel, Procter & Gamble, Lucent) evolving in various industrial ecosystems (software, hardware, semiconductors, consumer goods). It thus made sense to engage from the start with people positioned on the first line to actively respond to a publication structured in a way that amalgamates management and business practices and views into a theory that would then be coined "open innovation". The open innovation approach is undergirded by practice. If truth is to be found in the value-maximizing assumption of microeconomic theory, then it must follow that the pre-2003 adoption of these practices and views resulted from an adaptation to transformed conditions in the industrial setting, which made these practices comparatively more profitable than before. Retrospectively, with Baldwin and Von Hippel's work in mind, open innovation constitutes one way by which producer firms can hybridize their innovation processes and integrate new processes, participants and knowledge components in a technological environment that warrants it for firms to keep vying for market success and value.

2.3 How Open Innovation Innovates

Open innovation is defined as "a distributed innovation process based on purposively managed knowledge flows across organizational boundaries, using pecuniary and non-pecuniary mechanisms in line with each organization's business model" (Chesbrough and Bogers 2014, 27). To go over and contextualize each of the components of this definition, the open innovation funnel (Figure 3, taken from Chesbrough and Bogers 2014, 18), which is profusely referred to in open innovation literature, shall be relied on.

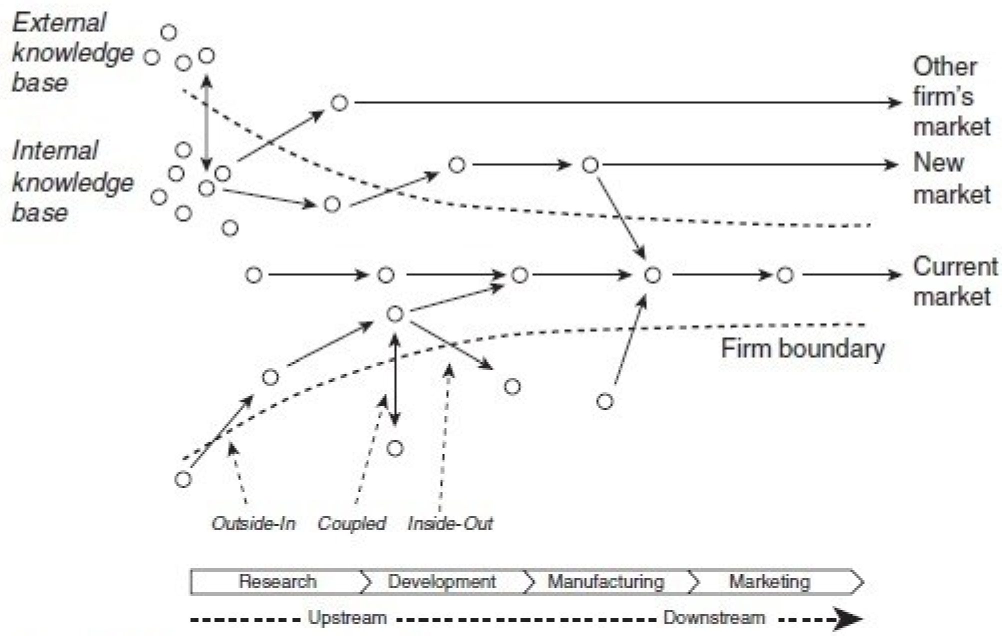

Figure 3 The open innovation funnel
Source: Chesbrough and Bogers 2014

Open innovation is predicated on the idea that knowledge in industrial environments is widely dispersed (Hayek 1945; Chesbrough 2003), a starting point that is particularly relevant in today's globalized markets. Not coincidentally, this starting point converges with the foregoing analysis, which emphasized the role of ICT in the rise of open innovation as a pertinent and viable management model. Market globalization has itself been sparked by the increasing performance and adoption of ICT since they facilitated and accentuated movements of workers, technologies and capital (Barney 2004; Chesbrough 2003; Castells 2001), each of which encompasses and carries knowledge components. In Figure 3's funnel, this distribution of knowledge is principally portrayed by the division of knowledge bases on the left-hand side: the firm (the dotted funnel) is aware of, and internalizes, some of that basic knowledge, but an important part of it lies outside the firm.

Should a firm be *closed*—meant as the opposite of *open*—it would be represented by a hard-line funnel. Unlike firms practicing open innovation, closed firms are not permeable to external knowledge. Accordingly, they cannot benefit from the inclusion of external knowledge in their own innovation processes and innovative market products. Firms that find more and better ways to absorb external knowledge (Cohen and Levinthal 1990) and that recognize this knowledge's potential are more likely to offer superior technological products, and to achieve equivalent results faster and less expensively than closed competitors can do (Bessant and von Stamm 2013; Christensen 2006). To refer to the terminology used in the previous section, this potential upshot represents the advantages for a producer firm to hybridize its innovation process, by allowing it to access innovations that are unviable through strictly "closed" producer innovator mechanisms,[58] and to achieve already-viable innovations in potentially more efficient ways, for instance, by outsourcing some parts of the innovation process. The significance of opening the innovation process is enhanced in industries where competition takes place for a large part on the advance and quality of technological offerings, such as the computing and software industries (Saxenian 1994).

Contrary to the impressions the term may evoke, open innovation does not boil down to entirely opening the innovation process. If the closed innovation paradigm amounts to erecting walls around the innovation process, open innovation simply installs doors in these walls. Once these doors are operational, it is up to the firm to decide which doors to open and which doors to keep locked. For every door, these two options ought to vary over time, based on the firm's strategies and business model (Vanhaverbeke and Chesbrough 2014; Möslein 2013). The scenario of a firm razing the walls is but one way for a firm to practice open innovation. Taking up open innovation does not work as a management panacea, and neither should it be seen that way: it offers extra and different opportunities, and it fosters fresh strategic responses in industrial environments where some elements of open innovation are espoused, but it does not guarantee that these new opportunities and strategies are better or more efficient than those that previously existed and that remain applicable. Furthermore, the firm still has to manage

[58] In Figure 3, the zones where only single-user or open-collaborative innovators are viable.

this openness efficiently, failing which, open innovation might end up hurting the firm (Vanhaverbeke, Chesbrough and West 2014).

Fully coherent with the way innovation is conceptualized in this paper, and in line with the previous section's discussion, inputs in the innovation process (the individual circles in Figure 3) are the elements that help solving the functional and market requirements needed to *design* the end-innovation. They are inherently *knowledge components*. The production and marketing processes, which bring innovative products to customers, often involve non-knowledge inputs, but knowledge components are sufficient for the innovation process. However, as Figure 3 shows, the production (manufacturing) and marketing processes overlap with the innovation process and, through dynamic interactions, may add new knowledge components to the innovation process. There is an aspect particularly interesting for this paper's distinction between inventions and innovations that has received only scattered attention so far in open innovation literature: through the open innovation process, *knowledge* as a whole—represented by the sum of all the knowledge components (circles) in Figure 3—is a shapeshifter. It takes different forms depending on the stage of the innovation process (the timeline arrows at the bottom of Figure 3). As a consequence, a "one-size-fits-all" efficient solution in managing all of the firm's *knowledge components* is unlikely.

Early in the innovation process, most of the knowledge involved is composed of *pure* or *basic knowledge*. As mentioned above, by excluding "laws of nature, natural phenomena and abstract ideas", legal standards of patent-eligibility and other features of IP regimes usually ensure that these pools of basic knowledge cannot be appropriated (Frischmann 2012). The distinction between internal and external knowledge bases (on the left-hand side of Figure 3) is therefore mainly determined by a firm's capabilities at absorbing knowledge (Cohen and Levinthal 1990), while appropriation considerations are mostly ignored. Then, as research and experimentation activities are being conducted in the firm, either more basic knowledge is begotten, or some basic knowledge is *applied* for various implementations (Frischmann 2012; Fabrizio 2006). At some level of abstraction, activities that yield either basic or applied knowledge can be conceptually integrated under the umbrella of *research*. Referring to econometric measurements, Frischmann (2012) distinguishes basic from applied research through the variances in commercial uses that are expected of the firm's research agendas—a higher variance in the case of basic research, as it can lead to a myriad of unforeseen implementations. Frischmann's approach thence distinguishes both types of research not through the conventional but inaccurate binary dichotomy, but with a continuum. The implicit uncertainty behind variance assessments is closer to how research is achieved in reality,[59] especially once it is acknowledged that firms are usually uncertain about the commercial prospects of their inventions and innovations.

When research activities bring forth applied knowledge, the firm is updated about ways by which basic knowledge can be implemented, potentially in commercial applications (Landes and Posner 2003). This applied knowledge typically consists of inventions, protected by IP rights or not depending on the firm's strategies and business model (Chesbrough and Ghafele 2014). In turn, these factors depend on the effectiveness and availability of appropriation instruments, and on the mechanisms by which the firm can best use its assets to tap into the value of these inventions (Teece 1986).

Next, in the development stage, knowledge components exist under the form of innovations. By combining inventive implementations with other components, innovations convey *technical knowledge* on how their inbred elements of basic and applied knowledge interact with a number of technical settings. For instance, Word 2007 works differently depending on the operating system of the device it is installed on. As a result, its technical interactions with other software applications and with the device's overall design are more or less convenient and efficient. This knowledge matters to many people involved: Microsoft itself as the firm that markets Word 2007, customers, firms that offer competing products,

[59] See Chesbrough (2003) for numerous examples of innovations developed by corporate research units whose missions were actually to invent.

firms like computer manufacturers that incorporate Word 2007 in their innovations or products, firms that use Word 2007 as a tool in their own activities, and the list goes on.

New layers of knowledge, *assembly knowledge*, are created similarly at the manufacturing stage. There, the previous forms of knowledge interact with various production settings, which include, depending on the technical backdrop, designs, materials, digital formats, and logistics processes such as platforms (Tseng 2013). Finally, the whole length of Figure 3 represents the innovation process up to market, the result of which is an innovative market product. At this point, *commercial knowledge* is generated as at least three separate streams of information simultaneously travel back to the firm. First, customer reactions to the innovation's market presence carry information about its commercial value, a critical factor in firms' decision-making processes about the innovation and its inventive input(s). Second, the firm receives information about the nature of the actual use(s) made of the product; technological history abounds with cases of innovative products that have not been adopted for the purposes they were intended for (Barney 2004). This second stream of information may have a tremendous impact, positive or negative, on knowledge informed by the first stream. Third, the market response, particularly from lead users, indicates future technological needs, desires and upcoming trends in relation with the innovative product (Von Hippel 2005). This stream sends important signals for firms' subsequent or affiliated innovation processes.

Of course, the order of this sequence is simplistic (empirically, see Shah and Mody (2014) for entrepreneurial cases), and this description of a straight innovation process is increasingly disrupted by strategies of open innovation. As an example, through openness, it is easier and thus more common for firms to offer beta or incomplete versions of their innovations to users, particularly key clients, in order to receive partial commercial knowledge at the development stage (Möslein 2013; Bessant and von Stamm 2013).

Each time an open firm learns about the formation of new knowledge, either from the inside or from the outside of its boundaries, it can strategically adjust its innovation process. Most of these adjustment decisions happen through *knowledge flows*, which allow knowledge components to cross the firm's walls, through one of their doors (Chesbrough 2003; Chesbrough and Bogers 2014). These flows can take place at any stage of the innovation process and hence can carry any of the aforementioned forms of knowledge. Flows can move knowledge outside-in (inbound), inside-out (outbound), or they can be coupled (Enkel, Gassmann and Chesbrough 2009; Chesbrough and Bogers 2014). In Figure 3, they are represented by the arrows. In practice many of them are manifested by contracts. Each type of flows can be managed through a variety of different relationships and means, depending on the firm's business model (Vanhaverbeke and Chesbrough 2014; Chesbrough 2006a). Inbound flows can be incarnated by licensing-in external knowledge components; buying IP assets; actively searching for knowledge; investing in start-ups; spin-ins, mergers and acquisitions; collaboration with partners like customers, universities and suppliers; crowdsourcing and contests; and so forth. Conversely, out-licensing, spin-offs, funding start-ups, donations, assignments of IP assets and joint ventures typically characterize outbound flows (Chesbrough and Bogers 2014). Coupled flows involve a mutual transfer of knowledge components, such as can be found in joint ventures, strategic alliances or platform launches (Gassmann and Enkel 2004; Piller and West 2014). In this paper's model, coupled flows are not explicitly examined. Instead, they are simplified as a combination of inbound and outbound flows, which are both formally analyzed in the model.

Through knowledge flows, a firm may be able (1) to enhance the value of its innovative products, (2) to capture some value in other firms' innovative products or (3) to launch innovative and valuable products that would not have existed otherwise.[60] At first sight, it may look like these three sources of value respectively capture the advantages arising from inbound, outbound and coupled flows of knowledge (see, e.g., O'Connor's (2010) description

[60] An account of the ways by which each of the practices mentioned in the previous paragraph may increase the value captured by a firm for its inventions and innovations is beyond the scope of this paper. Readers interested in such a description are directed to this section's references for open innovation, especially to Chesbrough (2003 and 2006a).

of in- and out-licensing), but this perception misses the complex ramifications of firms' strategies. The case of IBM illustrates this point.

Following major losses in the early 1990s, IBM re-oriented its business model from hardware, PC and computer mainframe manufacturing toward high-level information technology services (Chesbrough 2003). Unlike its main competitors in this new market, which relied on proprietary and exclusionary solutions, IBM focused on F/OSS solutions around the Linux operating system and the Java programming language, which were—and still are—used as preeminent software platforms (Phillips 2009). Had IBM subscribed to a narrow outlook of the role of knowledge flows, it would have supported value creation in its new business model with inbound flows, like obtaining licences to inputs that improve IBM's offerings, hiring talented F/OSS developers, acquiring prominent firms involved in F/OSS and so forth. Instead, these inbound mechanisms ended up being incidental among IBM's massive expenditures in the *external* development of free and open source standards through IP donations, direct investments in the Linux Foundation, out-licensing and spin-out research projects (West and Gallagher 2006; Phillips 2009). In short, for value creation in its information technology services, IBM mainly relied on outbound flows. With this strategy, IBM ensured that F/OSS applications would remain at the leading edge of information technology product offerings. Combining this advantage with F/OSS being technically free,[61] many organizations worldwide adopted F/OSS solutions. In turn, the more organizations opted for them, the more IBM enjoyed positive network externalities and profitably entrenched its business model for expert information technology services oriented toward F/OSS applications (Phillips 2009).

[61] That F/OSS software itself is free does not mean that the adoption of F/OSS solutions is costless. Software must be installed and updated, some programs require customization, and employees need to be trained, among other costly services.

As the case of IBM hints, providing one's firm with *learning* capabilities is crucial within the open innovation mindset, since the firm cannot make any strategic adjustment if it does not know about these new opportunities (O'Connor 2006). IBM could not have converted its business model toward information technology services if it had not previously perceived the ascending importance of F/OSS and foreseen the concomitant organizational demand for high-quality information technology services. For inbound knowledge flows, an open firm ought to be mindful of the existence of external knowledge components and of their latent blooming value should these components be integrated in the firm's internal innovation processes. For outbound knowledge flows, the firm should stay aware of partners that could be interested in its knowledge components or, alternatively, spread information to the industrial environment that signals the internal knowledge components that the firm possesses, and for which it considers outbound knowledge flows.[62] Internally, when firms are sufficiently large and decentralized, this need for learning capabilities encourages the creation of channels of communications between a firm's units, and kindling team spirit and cooperation within and between these units (Doz 2013; Phelps and Kline 2009). Externally, it stresses the importance of creating and maintaining networks through a myriad of individually-tailored ties in the business ecosystem, which includes industry associations, universities, investors, governmental institutions, start-ups, suppliers, customers, firms from complementary markets, competitors and any other relevant partner (Simard and West 2006; Saxenian 1994).

The type of relationship associated with these external links should differ based on the level of articulation of the knowledge components at stake. In absolute terms, a knowledge component is either *tacit* or *articulate* (Polanyi 1958). Whereas articulate knowledge is limpid, somewhat easy to understand and can be transmitted effortlessly, tacit knowledge is difficult to convey, even with verbal or written-down explanations (Polanyi 1958). Skills, know-how and technical expertise are typically listed as tacit knowledge (Bruneau 2013). Concretely, however, knowledge articulation is not absolute, but relative, as it depends on the other

[62] This alternative comes at the risk of short-sightedness: the focal firm may incorrectly evaluate the industrial sectors that could be interested in the knowledge component it signals. Basic knowledge components, for which commercial prospects and possibilities are more uncertain and variable, are particularly prone to this myopia.

person's familiarity with the field. For example, when an economist wishes to convey *all* the insights gathered from an economic model to someone who has never learned calculus, meticulous work of popularization must be slogged through, while these same results can be grasped by other economists simply by showing them the maths. In the former case, the knowledge component is tacit for the economist's *vis-à-vis*, while the same knowledge component is generally articulate for experienced economists. This relativist standard also occurs for a large portion of knowledge components in the innovation process.[63] For instance, computer programmers articulate most of their applied and technical knowledge through coding languages, easily readable by other computer programmers who mastered these languages, but hardly understandable for the lay public (Bruneau 2013; Plotkin 2009). Tacit knowledge can yet be handed over, but this sharing either requires more efforts to aptly convey the knowledge component, typically in a master-apprentice relationship (Polanyi 1958), or necessitates pre-steps of articulation—e.g., learning calculus or code languages. In both ways, transferring (relatively) tacit knowledge involves additional costs, often through supplementary efforts, that hinder tacit knowledge's potential diffusion and make it more "sticky" (Von Hippel 1994).

The extra costs necessary for the transmission of tacit knowledge are more likely to be committed under some relational circumstances. First, when both the transferor and the transferee partake in the same technological sector, geographical area, or both, it is probable that commonalities in their cultural and technological environments partially or fully pre-articulate tacit knowledge components. Furthermore, when two partners are strongly connected, the strength of a tie being characterized by the frequency and regularity of its activations (Simard and West 2006), the *vis-à-vis* is more consciously cognizant of the benefits it gets from this bond. This awareness raises the firm's willingness to undertake a burdensome transfer or articulation that participates in sustaining the good relationship. In the

[63] An astonishing instantiation of this phenomenon took place in the Myriad Genetics case discussed in Section 1.1. Despite being presented expert evidence and having access to all the necessary documents expounding the scientific and technical background of the patents challenged therein, one Supreme Court judge declared in his concurring opinion that he was "unable to affirm those details on [his] own knowledge or even [his] own belief." See *Association for Molecular Pathology v Myriad Genetics, Inc*, *supra* note 18 at 2120, Justice Scalia.

same vein, strong ties foster trust (Simard and West 2006), a characteristic also found in business relations maintained by repeated formal contracts (Brousseau, Lyarskaya and Muniz 2010). In a network tie, trust increases a firm's confidence that it will be satisfyingly compensated when it consents to (articulation) efforts that inure to the other party's benefits.

This relational context brings attention to the only part of the open innovation definition that has not been scrutinized yet: open innovation is a *purposive* mode of management. When firms' decision-makers follow an innovation process characteristic of open innovation, they do so because they believe it will produce positive outcomes for the firm; in the jargon of microeconomic theory, because they expect these practices to maximize the value that the firm can capture from its technologies. For the model herein, this purposive management of knowledge flows allows it to replicate value-optimizing principles of microeconomic theory. Some industries, such as ICT and biotechnologies, have extensively—and often consciously (Chesbrough and Bogers 2014)—adopted mechanisms of open innovation (Gassmann, Enkel and Chesbrough 2010). An assumption of openness, where every firm's value-optimizing procedure takes into account the benefits and costs of knowledge flows otherwise left in abeyance, appears reasonable for modeling these industrial settings. The model is now ready to be laid bare, a task with which the next chapter has been entrusted.

Chapter 3: Modeling IP Legal Shifts

This chapter begins by configuring the model (3.1), namely, the variables and parameters that define firms' cost and revenue structures. At the core of the model lies a tension between two technology management mechanisms: IP protection and secrecy. Because of interactions between firms' technology management decisions and their expected values, the model includes a game theoretic component.

Once the model's terms are set, general multi-firm applications are achieved (3.2), mainly by assessing firms' development, participation and mechanism constraints (3.2.1). These constraints are relevant in order to determine when the model's calculus relations between its different components stand without discrete leaps. As these constraints are analyzed, observations about some industrial contexts and the effects of legal shifts in expectations of IP protection are made particularly in the case of non-practicing entities—firms that invent or own an invention, but prefer not to innovate. Then, the model describes the process by which firms choose their technology management mechanism (3.2.2), and some industrial contexts in which some firms might have dominant strategies are discussed. Outcomes of legal shifts of IP protection are part of this examination. This survey is briefly extended in terms of the simple or complex nature of firms' innovations (3.2.3): simple innovations require few inputs and are relatively of little use in other firms' innovation processes, while complex innovations necessitate an important number of inputs and can themselves be integrated as input into numerous other innovation processes.

In the last section, a two-firm game theoretic process of this model is developed (3.3). After first describing the game itself (3.3.1), dominant-strategy, pure-strategy and mixed-strategy Nash Equilibria are described and analyzed (3.3.2). Finally, for this two-firm variant, the goal of this paper is achieved: the effects of legal shifts of expectations of IP protection over firms' internal inventions are examined in the context of a focal firm's strategy in the mixed-strategy Nash Equilibrium of this game. One particularly interesting insight from the model's formal analysis is that, contrary to common reasoning, an increase in a firm's expectations of IP protection over its invention does not necessarily boost that firm's likelihood or willingness to choose IP protection as its technology management mechanism.

To make the model more concrete, and because it is designed for inventions and innovations, it is presumed, unless specified otherwise, that patents are the IP mechanism at stake. Other forms of IP or of legal regimes that impact on technology managers' expectations can similarly be analyzed using this model, with a few adaptations.

3.1 The Structure

In the model's basic form, the industrial environment is composed of n playing firms under the set N, where $N = \{1, 2, ..., i, ..., j, ..., n\}$. Here, j refers to any firm or technology not i, while $-i$ designates the whole set with the exclusion of i. To reduce technology management to its simplest applications, each firm playing in this technology game exploits only one potential innovation, which in turn contains one and only one internal invention. Unlike how it may appear at first glance, this simplification is by and large consistent with the industrial environment envisioned in Chapter 2. For this model to somewhat reproduce the technology management processes of firm organizations that would actually make more than one invention or think of developing more than one innovation, one needs only to consider that each of these organizations' individual inventive units or teams represents one player. Since large organizations tend to decentralize their activities to a level that gives ample autonomy to their units (Phelps and Kline 2009; Chesbrough 2003; Saxenian 1994), these firms' inter-unit relationships, communications and tensions approximate this model's inter-player interactions. It is also on the basis of decentralized units that the previous chapter's discussion about learning mechanisms and capabilities applied to inter- as much as to intra-organizational learning.[64]

Ensuing from this reduction to singularity, a player's *technology* is defined dually, encompassing one internally-invented input and one potential innovative product. Sometimes, the inventive activities are consciously driven towards specific objectives; other times, the invention emerges incidentally or without its originator even being aware that an invention is unfolding. In the software sector, for example, it happens regularly that computer programmers code new, non-obvious and useful functionalities without taking notice (Stallman 2002). To cover all those patterns of invention, the shape of the internally-invented input is predetermined exogenously by the model, yet unspecified. Although the basic model does not count out the possibility that two firms made the same invention, the majority, if not the totality, of firms' internal inventions differ. Had it happened that two firms brought out the same invention, the model does not constrain these two firms to contemplate the same innovation. In fact, the innovative product consists merely of a *potentiality* in a firm's technology because the decision to develop the firm's innovation up to market is endogenous to this model. It is therefore generally the case that firms have different technology offerings; in other terms, it is assumed in this model, particularly in its two-firm version, that technology $i \neq$ technology j, albeit the model could allow the possibility for some technologies to be identical in the case where n is high. So long as most of the industrial environment's technologies contrast with one another, ensuring that many players do not directly compete for the same market(s), the model's assumption of openness stands.[65] These differing technologies generate individualized variables and parameters for each player. Hence, even if the model presents identical decision-making processes and dilemmas to all players, firms usually play differently, in all likelihood ending in asymmetric results.

[64] See Section 2.3 above.

[65] By this assumption, firms adopt open innovation strategies; for more information, see Section 2.3 above.

For reference through the next pages, the objective function to be optimized by each player in this paper's model follows as Equation 1.1. The rest of this section defines and outlines each and every element involved in this objective function and describes interactions that occur between players.

$$V_i(\lambda_i\, \pi_i\,,\; q_i\,, \boldsymbol{\lambda_{-i}}\, \boldsymbol{\pi_{-i}}\,,\, \boldsymbol{q_{-i}}) := -\, \bar{c}_i \,-\, c_i^D(q_i\,, \boldsymbol{\lambda_{-i}}\, \boldsymbol{\pi_{-i}}\,,\, \boldsymbol{q_{-i}}) + z_i\,(\lambda_i\, \pi_i\,,\; q_i\,, \boldsymbol{q_{-i}})$$
$$-\,\lambda_i\, C_i^{IP} - C_i^S(q_i) + [\lambda_i\, \pi_i + q_i]\; R_i^M + [1 - \lambda_i\, \pi_i - q_i]\; R_i^* \qquad \textbf{(1.1)}$$

3.1.1 Choice Variables and their Cost Functions

In compliance with principles of microeconomic theory, each firm chooses cost and revenue determinants within its control to maximize the technological value, V_i , that it expects to capture from its technology.[66] By the assumption that firms in this model embrace openness, opportunities offered by knowledge flows, for the internal invention as well as for the potential innovative product and knowledge derived thereof, must be reckoned with in value-optimizing decisions.[67] This paper's model reduces firms' decisions to two variables chosen simultaneously: IP protection and secrecy. Each of these variables represents a mechanism that enables firms to exert some control over access and use of their internally-developed invention, and the applied knowledge stemming therefrom. Downstream in the innovation process, these mechanisms increase firms' expected revenue accruing from the market exploitation of their potential innovative product. As a result, both of these technology management mechanisms influence significantly how firms handle knowledge flows (Chesbrough and Ghafele 2014). As the other side of a coin, technology management costs, which comprise the *direct* costs of choosing a positive value for any of these two variables, accompany this decision.

[66] For readability purposes, the fact that some variables and parameters are based on expectations, as is the case with *expected value* here, is not marked.

[67] For more context about knowledge flows and the assumption of openness, see Section 2.3 above.

The first variable, λ_i, represents a firm's discrete choice of filing for patent protection or not. As a binary variable, $\lambda_i^c \in \{0, 1\}$.[68] Closely related to this decision is π_i, the industry's level of expectations that firm i's patent is valid and enforceable. $\pi_i \in [0, 1]$ and is exogenous, given by the state of the legal environment and taking into account the technical specifications of invention i, predetermined by nature.[69] Shocks affecting π_i sometimes apply to expectations of protection for all patents within an industry, as was generally the case in Chapter 1's legal exposition of patents in the banking services industry. Other times, the consequences of these shifts focus on expectations for only a subset of patents within a wider industry, as could be observed with Myriad Genetics. These cases also exemplify that, because there are few inventions for which $\pi_i = 0$ or $\pi_i = 1$, firms are usually uncertain whether the patent protection they envisage is valid and enforceable.

The decision to patent the firm's internal invention requires a thorough examination of the accompanying costs of applying for and securing a patent grant. Embodied in C_i^{IP}, these costs include examination, registration and maintenance fees; costs of legal services for patent prosecution;[70] expected losses of market revenue due to unavoidable delays before the patent is granted; and any other unavoidable expense or abandoned value opportunity attached to the decision to patent the invention. As they are incurred upfront, none of these expenditures or value losses depend on expectations of patent protection, π_i. This cost parameter does not include patent enforcement costs, which are subsumed elsewhere in the objective function, namely, within benefits derived of knowledge transfers.[71] Constructed this way, C_i^{IP} can be

[68] Variables with a c superscript refer to the optimized value chosen by a firm, with reference to said firm's objective function. This choice is the focus of this chapter's next sections.
[69] See Chapter 1 for a conceptual and empirical exposition of the role of the legal environment on expectations of IP protection, π_i.
[70] To avoid possible confusion, a moment of legal jargon is in order. *Patent prosecution* refers to the application and review process with a national patent office. It should be distinguished from *patent litigation*, where a patent is challenged or enforced in court.
[71] See z_i below, in Subsection 3.1.2. As a reminder, *enforcement* has been defined at the beginning of Chapter 1.

assessed in advance by firm *i* and is thus fixed *ex ante* in this model. When $\lambda_i^c = 0$, it goes without explaining that these costs are null. In the model, this result is obtained simply by multiplying λ_i with the parameter C_i^{IP}.

The second choice variable, q_i, is the expected level of trade secrecy that a firm chooses for that same invention. Trade secrecy is a continuous variable—$q_i^c \in [0, 1]$—because a firm has access to numerous means to endogenously reach a desired level of expectations that its internal invention shall stay secret. To enumerate a few: inserting non-competition, confidentiality and loyalty clauses in its employees' contracts—in exchange of which employees are likely to request monetary compensations—(Gilson 1999; Gervais and Judge 2011); providing limited and guarded entry to the firm's premises (Landes and Posner 2003); and incorporating digital restrictions management ("DRM") components in the firm's technology (Phillips 2009).[72] Moreover, there exist means that, despite not *enhancing* a given level of secrecy like those just listed, contribute to *maintain* it through the firm's activities, such as having the firm's partners agree to non-disclosure agreements (O'Connor 2010); relying on intermediaries to find potential partners without disclosing technically- or commercially-sensitive knowledge about the firm's technology (Möslein 2013);[73] and taking extra precautions in daily operations (Kitch 1977), like refusing to deal with some potential customers or partners because of their capabilities at reverse-engineering or otherwise breaking the secret.

[72] DRM means are used to digitally block some uses of, and access over, some technologies. Drawing on digitally prehistoric examples, access to the content of a CD may require a password. Likewise, in the film industry, DVDs and Blu-Ray discs have components that make it impossible to extract their content without first circumventing or breaking a DRM mechanism. These discs can thus only be *played*, and their content cannot be accessed by regular means. In computer-related industries, DRM can be highly sophisticated, and it is used to keep some knowledge, including some inventions, secret.

[73] A combination of intermediaries and contracts can be particularly attractive if knowledge around the internal invention is articulated. Once articulated knowledge is transmitted to potential partners, the ease with which the latter can appropriate and reproduce that knowledge, when it is not legally protected by contract or IP, has been well documented, starting with theoretical work by Arrow (1959).

Like its IP counterpart, a reliance on secrecy is only possible through costly management decisions since measures carried out by a firm to reinforce the secrecy surrounding its internal invention implicate efforts or expenditures. This paper's model distinguishes between the *costs of enhancing secrecy*, which determine the level of secrecy expectations chosen by the focal firm, and the *costs of maintaining secrecy*. The latter is examined within the cost function of the firm's technology, when discussing the impact of firms' chosen levels of secrecy on knowledge flow opportunities.[74] The costs of *enhancing secrecy*, however, are not covered therein, mostly because they differ in two ways. First, specific means of secrecy are mutually independent; hence costs ascribed to each secrecy-enhancing measure chosen by a firm do not expand or diminish depending on the firm's adoption or rejection of other means available. Second, the direct and opportunity costs of secrecy-enhancing means are unaffected by technology management decisions made by other firms in the industrial environment. As an example of these two traits, security services cost the same amount whether their potential hiring firms combine these services with other means of secrecy or not; the same can be said with respect to the technology management decisions carried out by other firms in the industrial environment. This independence can be logically evaluated for most secrecy-enhancing measures one can think of. For these reasons, when a firm chooses a positive level of trade secrecy, it can *ex ante* determine its optimal secrecy-enhancing means for any expected level that the firm envisages. These costs, C_i^S, are strictly increasing as the level of secrecy expectations chosen by a firm, q_i^c, escalates.

Designed this way, C_i^S must be at its maximum when $q_i^c = 1$.[75] At this point, the firm elects to implement sufficient and necessary measures to guarantee full secrecy over its internal invention and to maintain this secret. Exogenously, law significantly shapes secrecy measures at a firm's disposal, by enabling or confining them and affecting their costs. For instance, legal protection of trade secrets results in lower costs for firms to protect their trade

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[74] See c_i^D and z_i below, in Subsection 3.1.2.

[75] Keeping in mind value-optimizing principles on which firms' decisions are predicated, firms in these conditions choose the least costly path that leads to full secrecy for their internal inventions. The endogenous method by which firms choose their level of secrecy expectations is described in Subsection 3.2.2.

information (Lemley 2011). Conversely, operating in a legal environment that does not punish actions that breach secrecy, for instance reverse-engineering, relatively increases the costs of secrecy expectations. Therefore, this model also analyzes some effects of secrecy-related legal factors through C_i^S or the bounds of q_i^c.

Building on basic value-optimizing principles, it is assumed that the firm adopts secrecy-enhancing means in a decreasing order of efficiency, with the theoretical result that the higher is a firm's contemplated level of secrecy, the more costly is a marginal increment to this level. When the firm decides not to take any measure to secure the secret around its internal invention, $C_i^S = 0$. At this level, it is assumed that $q_i^c = 0$ because the firm then has minimal expectations that secrecy shall linger on.[76] Therefore, the cost structure for secrecy-enhancing means can be written:

$$C_i^S := C_i^S(q_i) \qquad \textbf{(2)}$$

where $C_i^S(0) = 0$, and $C_i^S(q_i^c)$ is increasing and convex, i.e., $\frac{dC_i^S}{dq_i} > 0$, $\frac{d^2C_i^S}{dq_i^2} \geq 0$.

For any level of secrecy expectations other than the absence thereof and full secrecy, the firm is strictly uncertain whether secrecy surrounding its internal invention shall be kept.

[76] To be accurate, choosing not to make any effort to protect the firm's secret may actually entail $q_i > 0$ since secrecy expectations here are *minimal*, not null. For instance, if the internal invention is believed by other players to be of trivial value, or applied knowledge associated therewith is tacit enough for its transfer to require substantial costs or efforts (see Section 2.3 above), it might well happen that most actors in the industrial environment do not expect any net gain by exposing the invention or being exposed to it. In turn, this scenario indicates the possibility for secrecy expectations to be positive despite the absence of efforts allocated to this purpose. Relying on assumptions of strict monotonicity based on the shape of C_i^S, the model herein bypasses this situation without loss of generality by assessing q_i to be at its absolute minimum in these situations, i.e., $q_i^c = 0$ when the firm makes no effort to secure secrecy around its internal invention.

Since patents involve public registration and disclosure (Scotchmer 2004; Landes and Posner 2003), it is assumed in the model that when the firm applies for patent protection, it cannot expect a positive level of secrecy.[77] This assumption, coupled with value-maximizing principles under which firms will not choose to waste resources or efforts, imposes the constraint $\lambda_i^c + q_i^c \in [0, 1]$ and thus introduces a tension between both variables. Hinted at the beginning of Chapter 1, this trade-off between patent protection and secrecy is well-documented, both conceptually (Teece 1986; Gallini 2002; Landes and Posner 2003) and empirically (Cohen, Nelson and Walsh 2000; Graham et al 2009).

A positive value for either λ_i^c or q_i^c, whichever it is, installs the firm in comparable circumstances: it wields a mechanism to control access to its internal invention and its uses, it faces direct costs for its technology management mechanism, it likely has to plod through a field of uncertainty, and, as shall now be examined, it encounters indirect ramifications arising from improving or worsening value opportunities in firms' innovation processes.

3.1.2 Technology Costs and Knowledge Flows

Each firm expects costs and value opportunities in association with its technology, C_i^T, composed of three steps that respectively cover (i) the inception of the firm's internal invention; (ii) the *development* of the innovative product, including inbound knowledge flows; and (iii) potential outbound knowledge flows and patent litigation during the innovation process.[78]

[77] See the beginning of Chapter 1. Once symmetry of information, an admittedly strong assumption, is pre-supposed, public registration or public disclosure are each sufficient to carry this result, and all forms of IP protection involve either one or the other, or both as is the case of patents (Scotchmer 2004).

[78] For the characteristics of, and differences between, inbound and outbound knowledge flows, see Section 2.3 above.

The firm's technological endeavours begin with the contriving of its internal invention. As mentioned above, the shape of this invention is unspecified in this model, an abstraction that must also extend to the process by which the internal invention is obtained. It follows that the costs associated with the invention's inception, $\overline{c}_i$, are a fixed parameter out of the firm's control and unaffected by its technology management decisions. With this internal invention in hand, the firm gets two opportunities: first, integrating it into an innovation project, alongside other inputs or design components that are either developed internally or acquired through inbound knowledge flows; second, sharing this internally-invented input with other firms through outbound knowledge flows. The bi-directionality of knowledge flows replicates real-life industrial networks in which firms are both potential inventors and users (of others' inventions). Whether a transferor or a transferee, a firm enters into a knowledge flow transaction with another if the associated *net value* that it expects to capture out of it is positive (Zajac and Olsen 1993).

Through inbound knowledge flows, a firm can obtain applied (inventive) or technical (innovative) knowledge or inputs from other firms in order to increase its technology's net value. This result generally occurs by reducing the costs of the focal firm's development process, c_i^D, in comparison with the *costs of independent innovation*—namely, the *ex ante* minimal costs of the development activities that the firm would have undertaken internally, absent transactions, to attain the same innovative result.[79]

[79] Being limited to development, the costs of independent innovation exclude the costs of making the internal inventive input, $\overline{c}_i$. The costs of independent innovation are *ex ante* minimal: the firm assesses in advance its optimal internal development process, which is not specified by the model, nor does it need to be. Obviously, if the firm's expected costs of independent innovation are lower than the development costs envisaged instead with the inclusion of a particular inbound knowledge flow, a rational firm would elect not to carry out the deal, unless the transaction provides additional and compensating value through other channels, for instance, because the external input increases the firm's expected market revenue for the innovative product by attracting additional customers. By focusing on the *net value* created by a transaction instead of the formal exchange covered by it, the model takes into account these subsidiary sources, or losses, of value.

When positioned on the other side of a prospective transaction, a firm can transfer its own invention, its innovation, or knowledge stemming thereof to gain supplementary net value, z_i , typically as a monetary compensation.[80] Even in the absence of patent protection or of secrecy-maintaining measures, transferring knowledge components to another firm does not necessarily entail a loss of control over that knowledge. Inputs or designs produced by know-how or ensuing from tacit knowledge,[81] for instance, can be very costly to replicate for the transferee. The business model of consultant firms often adheres to this pattern. When disassembling C_i^T into its three terms, z_i contrasts with $\bar{c}_i$ and c_i^D because, by construction, it represents a value gain in the objective function.

How do these three terms integrate potential knowledge flows? Suppose that firm *i* *invents* a new microchip and *innovates* a novel computer that runs on this chip. Another firm, *j*, develops a software application, and the faster the computers used to program its software work, the cheaper are its development costs. If firm *j* has capabilities in computer manufacturing and wishes to add firm *i*'s chip in the computers that it customizes for its own innovation process, it can potentially do so through a transaction with firm *i*. A similar opportunity presents itself if firm *j* does not intend to build its own computers from scratch and instead wishes to buy several of firm *i*'s computers. A third possibility is that firm *j* does not actually benefit from better computers, but it does from learning about the performance level of the next generation of chips, in order to determine how complex its software application can be while still running smoothly on its customers' devices. This technical knowledge can be treated as an input in firm *j*'s innovation process, and acquiring this knowledge through a transaction with an important chip and computer producer like firm *i* may be simpler and less costly and provide more accurate data for firm *j* than estimating it by

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80 As the previous note implies, monetary compensation directly ensuing from the transaction is not the only way outbound knowledge flows can increase a firm's net technological value. The case of IBM and its purposive reliance on network externalities, described in Section 2.3, constitutes a good example.

81 See the end of Section 2.3.

its own means.[82] By virtue of principles of microeconomic theory, in these three scenarios, the knowledge flow would only take place if the net value of the transaction is positive for both parties involved (Zajac and Olsen 1993). If the transaction's net value is positive for both parties, it is computed in this model via an increase in z_i and a decline in c_j^D. For any firm for which the knowledge flow is outbound, even when the input transmitted is the innovation itself, this additional value is separate from the revenues expected to accrue from the customer market for the innovative product. In this paragraph's example, it means that the sale of firm *i*'s computers to the general consumer market is accounted for elsewhere in the model, as market revenue.[84]

The calculation of a transaction's net value reckons with *transaction costs*—defined as the combination of (i) the *direct* costs of implementing the transaction and (ii) the *indirect* costs of identifying it in the first place.[85] Partly because of transaction costs, the net value acquired through knowledge flows is affected by technology management decisions, whether those of the focal firm or those of its prospective partners. A firm's choice of positive secrecy expectations, if no extra care is applied, is susceptible to decrease as the firm interacts with other actors in the industrial environment. In order to maintain its chosen level of secrecy expectations, the firm can rely on non-disclosure agreements, intermediaries and a diversity of precautionary measures, which, in turn, inflate the transaction's costs. These additional transaction costs can be direct, for instance when a party adopts special procedures and safeguards to deal with knowledge disclosed under a non-disclosure agreement, or indirect, as is the case when a secretive party hires an intermediary, or when a firm has to scrutinize the industry more closely to spot a secretive firm with which it can have a valuable transaction. On a case by case basis, secrecy thence entails that either one or both of the parties involved in a knowledge flow could benefit less than it or they would in the absence of secrecy,

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[82] It is worth noting that this third instance embodies a situation where a firm's decision to keep its invention entirely secret does not prove much of an obstacle for a knowledge flow transaction to be beneficial, given that at least one of the two firms involved can spot the transaction opportunity.

[84] This model's treatment of market revenue is exposed in Subsection 3.1.3 below.

[85] To be clear, *transaction costs* in this model are conceptually different from transaction costs in Baldwin and Von Hippel's model discussed in Section 2.2.

sometimes to the point that aborting the transaction altogether becomes the most rational decision. Logically, the magnitude of secrecy-maintaining measures to be implemented, and their associated costs, can only go up or stay even as the firm's chosen level of secrecy expectations expands. Consequently, q_i and the vector $\boldsymbol{q}_{\boldsymbol{-i}}$ must be included as arguments in both c_i^D and z_i : conditional on each firm's technology management choices not triggering discrete reactions in the industrial environment, a condition that applies to all calculus assumptions described in the present subsection,[86] development costs are non-decreasing as the level of secrecy expectations chosen by any firm augments, while revenue from outbound knowledge flows are non-increasing in the same circumstances.

Costs of secrecy-maintaining measures vary. Whereas firms that need to preserve relatively low secrecy expectations could be satisfied by high- as well as low-performing means, firms that need to sustain relatively high expectations should be more apprehensive of measures that could perform poorly. It follows that when the level of secrecy expectations to maintain is low, the array of secrecy-maintaining means at the firm's disposal is wider. Some of these additional means are likely to be more cost-efficient. Based on the assumption that firms' managers are guided by value-optimizing principles, it is thus surmised in this model that the secrecy-maintaining measures that can suitably sustain increments of secrecy expectations are most costly the higher a firm's initially-chosen level of secrecy expectations is—for all parties involved in the knowledge flow transaction. This presumption dictates the shape of the second derivative of both c_i^D (convex) and z_i (concave) with respect to q_i and to any component of the vector $\boldsymbol{q}_{\boldsymbol{-i}}$.

A firm's management decision to patent its internal invention has more ambiguous effects on the industrial ecosystem, mostly because, here, the consequences vary greatly between both sides of a knowledge flow transaction. In their inbound knowledge flows, patentees' development costs remain unchanged by their own decision. In their outbound knowledge

[86] These discrete leaps are discussed endogenously in Subsections 3.2.1, 3.2.2 and 3.2.3.

flows, however, patentees can enforce their patents, resulting in three additional segments of expected value benefits and costs. First, patentees can find beneficial transactions into which they would not have entered absent this legal protection, typically because they would not have enjoyed sufficient negotiating leverage or control over knowledge spillovers for them to find positive net value in these flows. Second, in cases where patentees would have agreed to some transactions even absent their patents, they might expect to be able to capture more value from these transactions than they would have obtained otherwise. Third, patentees can launch litigation procedures against firms to which they have not contractually permitted the use of their patented inventions.[87] Litigation is the equivalent of trying to convince or force, respectively through a negotiated settlement or trial, another firm to enter into a valuable transaction with the patentee.[88] (Sometimes, based on the terms of the settlement or the judgment, there might not even be a *knowledge* flow associated with the "transaction" —only a cash flow.)

For a situation to lead to litigation or settlement instead of a negotiated transaction, it suffices that the patentee expects higher positive net value this way, or that it expects positive net value through litigation while the defending firm expects to be subjected to negative net value through either litigation or any transaction. If the patentee wins in court, the consequence for the losing party is the equivalent of a substantial value loss, not counting also

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[87] These three segments of value are consistent with how *enforcement* is defined at the beginning of Chapter 1.

[88] Algebraic examples might help to better discern the three segments. Suppose firm *i* has a patented input, and firm *j* could potentially be interested in it for its own innovation process. Firm *j* cannot substitute firm *i*'s input with any third-party alternative. The two firms negotiate as best as they can for their own benefits.

With the first segment, absent the patent, firm *i* gets net value x_1, $x_1 < 0$. No matter what positive net value firm *j* would get from the deal, firm *i* should reject it. By enforcing a patent in the transaction's negotiations, firm *i* now captures r_1, $r_1 \geq 0$, while firm *j* potentially ends up with w_1, $w_1 \geq 0$. Both parties accept this transaction.

With the second segment, absent the patent, firm *i* gets net value x_2, $x_2 \geq 0$, while firm *j* receives y_2, $y_2 \geq 0$. No patent is necessary for both parties to accept this transaction. By enforcing a patent, though, firm *i* now captures r_2, $r_2 \geq x_2$, while firm *j* ends up with w_2, where $y_2 \geq w_2 \geq 0$. Both parties continue to find this transaction valuable, although firm *j* might be dissatisfied by the outcome because firm *i*'s patent enforcement generally triggers a greater transfer from firm *j* to firm *i*.

With the third segment, absent the patent, no matter what is the value obtained by firm *i*, firm *j* receives y_3, $y_3 < 0$. Therefore, firm *j* would refuse any transaction. By launching litigation procedures, firm *i* now captures r_3, $r_3 \geq 0$, while firm *j* could accept a settlement deal with net value loss w_3, where $0 > w_3 \geq s_3$. s_3 typically represents the sum of the costs of firm *j*'s legal defense and its expected loss in the case that the court rules in its disadvantage.

the costs of legal defense. If the defending firm wins in court, it still has to pay its legal fees. If the settlement loss of value for the defendant is lower than the expected loss of value of patent trial,[89] the defendant should settle, a rational decision even if the defendant actually believes the patent to be invalid or unenforceable against its firm (Lemley and Shapiro 2005). This calculated behaviour is reminiscent of the heavily disparaged post-*State-Street* legal environment described in Section 1.2, where many firms invoked weak patents to collect rent from other firms.

Litigating, however, is less tempting when the defending party also patented its internal invention. As mentioned in Chapter 1, patents that have been granted are presumed to be valid, so the active litigant's expectations of winning in court against that other firm relatively decrease as that other firm acquired a patent of its own, bringing down the active litigant's expected benefits from the third segment. Actually, firms that possess substantial patent portfolios tend to rarely clash in court, or at least to quickly reach a settlement agreement that includes cross-licensing;[90] patents are often acquired with a defensive intent in order to chill potential active litigants (Cohen, Nelson and Walsh 2000; Shapiro 2000; Mann 2005).

Since the model is designed in a way that leaves patent enforcement costs out of C_i^{IP}, they must be included in z_i. These costs mainly consist of attorney and negotiation fees. Owing to the patentee's dormant option not to enforce its patent, $z_i\ (\lambda_i\ \pi_i = \pi_i)$[91] must be bounded minimally at $z_i\ (\lambda_i\ \pi_i = 0)$. This floor is applicable to each prospective enforcement decision because, for each of them, a value-optimizing firm would not elect to enforce its patent unless its expected additional benefits arising from a particular enforcement exceed its corresponding expected costs. This account of enforcement and litigation imposes that the firm's revenues accruing from outbound knowledge flows, z_i, are non-decreasing in $\lambda_i\ \pi_i$.

89 Expectations are based on π_i.
90 With the notable exception of Apple and Samsung! (Although strictly against each other.) See Bruneau (2013) for a fuller account of this behaviour.
91 When firm *i* chooses to patent its internal invention, $\lambda_i = 1$. z_i's other arguments are held constant.

However, when they increase, this augmentation can be relatively lower when $\lambda_j \pi_j > 0$ or when $\lambda_j \pi_j$ rises simultaneously. Due to the foregoing analysis of enforcement, $[\lambda_i \pi_i]$ is herein inserted as an argument within the function z_i .

The development costs, c_i^D , of firms on the inbound side of these enforcement decisions are obviously affected.[92] Through the first segment, these firms can benefit from patent enforcement as they participate in extra transactions that provide them with positive net value. When firms participate to a second-segment transaction from an inbound point of view, however, the net value accruing to them is non-increasing with respect to the transaction that would take place absent their partners' patents. In most cases, this net value is actually diminishing since the said partners, thanks to their patents, stand in a stronger position in their negotiations. Finally, as explained above, the third segment is always detrimental to defending firms, although less so when the defending firm patented its own internal invention. Strictly for this third segment, expected development costs escalate for each other firm that patents its internal invention, as these IP titles increase the risks that firms—accidentally, willfully, or not at all—infringe some enforceable patents and face litigation procedures. As described before, these expected costs can be mitigated, although not nullified, when $\lambda_i \pi_i > 0$. To deal with the bi-directionality of observations related to these three segments, it is assumed in the model that firms on the inbound side of transactions expect potential losses from the second and third segments to exceed potential benefits from the first, even when $\lambda_i \pi_i > 0$. By taking into account the negotiating leverage that a patent provides in first-segment transactions, this assumption usually provides a reasonable outlook. Thus the vector $[\boldsymbol{\lambda}_{-i}\, \boldsymbol{\pi}_{-i}]$ is integrated as an argument to c_i^D .

92 This paragraph is algebraically expounded in note 89, firm *j*.

The question arises though: are there cross-effects between this vector and firm *i*'s technology management option of choosing secrecy? Theoretically, yes. For instance, risks of additional development costs associated with the third segment could be reduced by choosing secrecy, or additional secrecy, as a patentee cannot litigate against firms it is not aware of. Conversely, to counterbalance the expected loss of transactional value ensuing from the second segment, or to increase net value accruing from first-segment transactions that were not contemplated in the absence of the other party's patent, firm *i* could anticipatively or reactively choose to reduce its level of secrecy expectations. Because these cross-effects occur on a case-by-case basis and are potentially bi-directional, assessing these interactions within the model is particularly difficult and significantly reduces the intuition that the model may provide. Accordingly, it is assumed herein that these cross-interactions do not occur in the choice of firms' optimal level of secrecy expectations; q_i^c is independent from both the vectors $[\boldsymbol{\lambda}_{-i}\ \boldsymbol{\pi}_{-i}]$ and $\boldsymbol{q}_{-i}$.

This design verily leads to a loss of generality for the model by leaving out some substantial cross-interactions between firms' technology management decisions. Yet it is not so (i) when these cross-effects would actually not occur, on a case-by-case basis; (ii) when these effects would mutually cancel themselves because of their potential bi-directionality; or (iii) when they would be of too little significance to counterbalance any other effect captured by the model as it is. By multiplying knowledge flow interactions, the model's assumption of openness supports the second and third scenarios, particularly in industrial landscapes that comprise a high number of firms. To summarize this crucial subsection:

$$C_i^T\,(\lambda_i\,\pi_i\,,\,q_i\,,\boldsymbol{\lambda_{-i}}\,\boldsymbol{\pi_{-i}}\,,\,\boldsymbol{q_{-i}}) := \bar{c}_i\,+\,c_i^D\,(q_i\,,\boldsymbol{\lambda_{-i}}\,\boldsymbol{\pi_{-i}}\,,\,\boldsymbol{q_{-i}}) - z_i\,(\lambda_i\,\pi_i\,,\,q_i\,,\,\boldsymbol{q_{-i}}) \qquad \textbf{(3)}$$

where $\dfrac{\partial z_i}{\partial \lambda_i \pi_i} \geq 0$, $\dfrac{\partial^2 z_i}{\partial \lambda_i \pi_i\, \partial \lambda_j \pi_j} \leq 0$, $\dfrac{\partial c_i^D}{\partial \lambda_j \pi_j} \geq 0$ and $\dfrac{\partial^2 c_i^D}{\partial \lambda_j \pi_j \partial \lambda_i \pi_i} \leq 0$;

$$\frac{\partial c_i^D}{\partial q_i} \geq 0,\ \frac{\partial z_i}{\partial q_i} \leq 0, \text{ and thus } \frac{\partial C_i^T}{\partial q_i} \geq 0, \qquad \frac{\partial^2 c_i^D}{\partial q_i^2} \geq 0,\ \frac{\partial^2 z_i}{\partial q_i^2} \leq 0, \text{ and thus } \frac{\partial^2 C_i^T}{\partial q_i^2} \geq 0;$$

$$\frac{\partial c_i^D}{\partial q_j} \geq 0,\ \frac{\partial z_i}{\partial q_j} \leq 0, \text{ and thus } \frac{\partial C_i^T}{\partial q_j} \geq 0, \qquad \frac{\partial^2 c_i^D}{\partial q_j^2} \geq 0,\ \frac{\partial^2 z_i}{\partial q_j^2} \leq 0, \text{ and thus } \frac{\partial^2 C_i^T}{\partial q_j^2} \geq 0;$$

$$\frac{\partial^2 z_i}{\partial q_i\, \partial q_j} = 0, \quad \frac{\partial^2 c_i^D}{\partial q_i\, \partial \lambda_j \pi_j} = 0, \text{ and } \quad \frac{\partial^2 c_i^D}{\partial q_i\, \partial q_j} = 0.$$

3.1.3 Market Revenue

As could be observed in previous subsections, it is assumed in the model that many determinants in which firms usually have a say and that impact value-maximizing decisions, such as the costs of securing patent protection or of secrecy-enhancing measures, are elected *ex ante* with value-maximizing principles. This method is adopted in order to better redirect the interactive effects of the two technology management variables toward the knowledge flow components, while still giving due consideration to other industrial factors. It is again relied on with respect to the model's market revenue structure, where most of the determinants within firms' purview, such as their levels of production, are determined *ex ante*, regardless of firms' actual decisions with respect to λ_i and q_i. In this paper's theoretical model, these market revenue components are simplified as parameters, although they are not so in reality. This treatment is enabled by the model because *ex post* interactive effects on market revenue of firms' choices for their two technology management variables are already incorporated within C_i^T, in the analysis of knowledge flows' net value. For each firm, there are thus only two market scenarios that warrant examination. Both are based on the strength of firms' market position.

On the one hand, if the firm succeeds in maintaining secrecy over its internal inventive input or in being granted a valid and enforceable patent that covers this internal invention, the firm can exert some control over its use and access. Since this input is incorporated in the firm's innovation, the firm benefits from a relatively strong market position for its innovative product. Drawing on conventional microeconomic theory, it follows that the firm takes into account this stronger market position when it selects its business model of *competitive advantage*. By assessing potential business models, the firm determines *ex ante* the market revenue structure by which its expected value is maximized with this competitive advantage.[93] Various elements would need to be mulled over, or minute hypotheses to be laid down, for this paper's model to express any definitive statement on the form of the firm's business model, whether a standard monopoly model that restrains output to artificially induce scarcity and thus raise market price; price discrimination structures like tariffs or market separation; tie-in sales; or any other mechanism. Although interesting, these decisions are outside the scope of this paper. Hence, this paper's model does not presume of the business model opted for by the firm under a scenario of competitive advantage, nor does it need to so long as market revenue expectations generated by this business model are deemed to maximize the firm's expected value for its innovative product. *Ex ante* expected market revenue determined this way, and thence associated with a business model of competitive advantage, is denoted R_i^M .

On the other hand, if the secret surrounding the internal inventive input has been revealed—to be noted, choosing to dispense with secrecy[94] automatically discloses the invention—and the firm has not secured a valid and enforceable patent over it, then other

[93] To be clear, firms do *not* maximize expected market revenue. Value optimization requires firms to take into account their cost structures. In these *ex ante* operations, since no decisions have yet been made with respect to technology management, the costs of independent innovation are the development costs under consideration. If the cost structure of secrecy or of patent protection then necessitates a downward adjustment to the market revenue structure, it is accounted for as an indirect cost of secrecy-enhancing measures within C_i^S or of applying and securing a patent within C_i^{IP} . (See how these two cost structures are defined in Subsection 3.1.1.) Other *ex post* adjustments in the value optimization of development costs and market revenue are captured in the analysis of knowledge flows. "Adjustments" can be substantial.

[94] $q_i = 0$. See note 76 above and accompanying text for specific assumptions about this situation.

firms can access and use the focal firm's internal invention and applied knowledge emanating thereof.[95] In this situation, market competition between the focal firm and market suppliers of substitutable products is more on par. This context of *even competition*, like its counterpart of competitive advantage, is acknowledged in the firm's *ex ante* determination of its optimal business model. Here as well, this paper's model does not specify the nature of this business model in any way expect that it establishes *ex ante* the firm's market revenue structure that maximizes the firm's expected market value in circumstances of even competition. The firm can achieve this result using a typical model of perfect competition, a first-mover advantage, product differentiation, branding, and so forth. Using equivalent notation as for the business model of competitive advantage, the firm's market revenue structure, when relying on a business model of even competition, is marked R_i^*.

Because business models of even competition remain available to firms that reap the benefits of a competitive advantage, it must be the case that, for a given innovative product, $R_i^M \geq R_i^*$.[96] In delineating *enforcement*, price determination of innovative market products had been set aside.[97] In line with this qualification and consequent with how the market revenue parameters have been defined, the business models singled out by the firm—and which constitute R_i^M and R_i^*—are determined independently of the firm's choices for its two technology management variables. Regarding the calculation of expected market revenue, these variables only determine the probabilities with which the firm expects each of these two business models, and concomitant market revenue structures, to emerge. Under the axioms of Von Neumann-Morgenstern (1944) and the assumption of risk-neutrality, the overall

95 That other firms *can* access and use the invention and related applied knowledge does not mean that the focal firm retains no advantage from being their originator. For instance, if applied knowledge attached to this invention is tacit, other firms may have to incur substantial costs and delays to access and use it without the originator's support. Similar issues were discussed in the analysis of C_i^T in Subsection 3.1.2.

96 An obvious scenario in which the *ex ante* value-maximizing revenues are equal for both types of business models is $R_i^M = R_i^* = 0$, in other words, when it is always optimal*, ex ante*, for a firm not to develop its innovation.

97 See the beginning of Chapter 1.

expectations of market revenue by the firm, based on these probabilities stemming from technology management decisions, is summed up as:

$$R_i(\lambda_i\ \pi_i,\ q_i) := [\lambda_i\ \pi_i + q_i]\ R_i^M + [1 - \lambda_i\ \pi_i - q_i]\ R_i^*$$

$$= [\lambda_i\ \pi_i + q_i]\,[R_i^M - R_i^*] + R_i^* \quad \textbf{(4)}$$

where $\dfrac{\partial R_i}{\partial \lambda_i \pi_i} = R_i^M - R_i^* \geq 0$ and $\dfrac{\partial R_i}{\partial q_i} = R_i^M - R_i^* \geq 0.$

By adding all of the cost and revenue structures described in this section and defined in Equations 2, 3 and 4, the value-maximizing function expounded in Equation 1.1 can be rewritten at a more abstract level, focusing on the choice variables:

$$V_i(\lambda_i\ \pi_i,\ q_i, \boldsymbol{\lambda_{-i}}\ \boldsymbol{\pi_{-i}}, \boldsymbol{q_{-i}}) = -C_i^T(\lambda_i\ \pi_i,\ q_i, \boldsymbol{\lambda_{-i}}\ \boldsymbol{\pi_{-i}}, \boldsymbol{q_{-i}}) - \lambda_i\ C_i^{IP} - C_i^S(q_i)$$

$$+\ R_i(\lambda_i\ \pi_i,\ q_i) \quad \textbf{(1.2)}$$

3.2 The Basic Model—Multi-Firm Interactions

While it is assumed herein that most of the firm's value determinants can be optimized *ex ante* regardless of the firm's technology management decisions, this approach cannot be extended to factors that are affected by other firms' choices for their own technology management variables. This is the lot of an industrial environment characterized by open innovation, in which firms consider transactions with one another during the innovation process. Firm *i* tries to guess firm *j*'s technology management decisions in its own value-optimizing choices, and vice-versa. Firms' reciprocal attempts at assessing their respective behaviour imply that a focal firm ought to anticipate as accurately as it can the rippling effects that its choices will have on its own innovation process through other firms' expected responses to, and prescience of, these decisions. Without this appraisal, the focal firm would fail to internalize other firms' adjustments in its management processes, leading to sub-optimal decision-making. This game theoretic technique is at the center stage of each firm's technology costs, C_i^T, in which knowledge flow interactions and decisions are encompassed. This section explores general interactive and endogenous effects that can be observed in the model, while Section 3.3 reduces the problem to a two-firm context, for an in-depth game theoretic analysis.

3.2.1 Constraints and Discrete Leaps

It was specified in Subsection 3.1.2 that most of the model's calculus assumptions are conditional to the absence of discrete reactions. Circumstances by which a value-optimizing firm would make a discrete choice can be identified endogenously in the model. Three possible leaping scenarios emerge, each corresponding to a constraint: the development, participation and mechanism constraints. These constraints and the effects of leaps on the model guide the structure of this section.

Development Constraint

The net sum of expected costs and revenues associated with the innovative dimension of a firm's technology must be positive for the firm to choose to develop this innovation. Otherwise, the firm would rationally prefer not to innovate, with a resulting development value of zero. Define z_i^D as the part of z_i that represents technical (innovative) knowledge and inputs, and z_i^0 as the equivalent part of z_i with respect to applied (inventive) knowledge and inputs. By the definition of z_i, $z_i^0 + z_i^D = z_i$, and both subdivisions have the same shape and arguments as z_i. Having specified that, the development constraint can thence be expressed as

$$- c_i^D(q_i, \boldsymbol{\lambda_{-i}} \boldsymbol{\pi_{-i}}, \boldsymbol{q_{-i}}) + z_i^D(\lambda_i \pi_i, q_i, \boldsymbol{q_{-i}}) + R_i(\lambda_i \pi_i, q_i) \geq 0.$$

If the development constraint is not satisfied, the firm's decision not to develop implies that

$$R_i^M = R_i^* = R_i(\lambda_i \pi_i, q_i) = c_i^D(q_i, \boldsymbol{\lambda_{-i}} \boldsymbol{\pi_{-i}}, \boldsymbol{q_{-i}}) = z_i^D(\lambda_i \pi_i, q_i, \boldsymbol{q_{-i}}) = 0,$$ [98]

and the model's objective function set out as Equation 1.1, for this firm, becomes

$$V_i(\lambda_i \pi_i, q_i, \boldsymbol{\lambda_{-i}} \boldsymbol{\pi_{-i}}, \boldsymbol{q_{-i}}) = - \bar{c}_i + z_i^0(\lambda_i \pi_i, q_i, \boldsymbol{q_{-i}}) - \lambda_i C_i^{IP} - C_i^S(q_i).$$

In this formulation, and based on Equations 2 and 3's calculus assumptions,

$$\frac{\partial V_i}{\partial q_i} = \frac{\partial z_i^0}{\partial q_i} - \frac{dC_i^S}{dq_i} < 0.$$

Therefore, when a firm does not innovate, secrecy fails to deliver any benefit to the focal firm. It follows that $q_i^c = 0$ when the development constraint is not met. Equation 2 requires that $C_i^S(0) = 0$. The objective function of firms that do not develop an innovation, including other firms' actual choices of technology management as shall be explored in Subsection 3.2.2 , is trimmed to

$$V_i^0(\lambda_i \pi_i, 0, \boldsymbol{\lambda^c_{-i}} \boldsymbol{\pi_{-i}}, \boldsymbol{q^c_{-i}}) := - \bar{c}_i + z_i^0(\lambda_i \pi_i, 0, \boldsymbol{q^c_{-i}}) - \lambda_i C_i^{IP} \qquad \textbf{(5)}$$

With this function, the technology management decision becomes a simple one, reduced to the dilemma of patenting the internal invention or not. With a straight decomposition of

98 Sometimes, the development constraint cannot be met because of exogenous factors, for instance, jurisdictions that forbid that university departments engage in business activities. In their case, these equalities are obtained exogenously, but the following analysis of their behaviour applies as well as if these firms had reached these results endogenously.

Equation 5, it surfaces that the firm seeks patent protection for its invention, with $\lambda_i^c = 1$, when

$$z_i^0(\pi_i, 0, \boldsymbol{q^c}_{\boldsymbol{-i}}) - z_i^0(0, 0, \boldsymbol{q^c}_{\boldsymbol{-i}}) \geq C_i^{IP}.$$

In words, this firm plays patent protection when the net revenue extracted by patent enforcement, taking costs of enforcement into account, is high enough to compensate for the costs of obtaining a patent grant. All of these observations are conditional, of course, on the firm's expected value to be positive, the object of the second constraint.

Non-Practicing Entities

In this model, firms for which the development constraint is not satisfied correspond to *non-practicing entities*, a group as varied as universities, research institutions and laboratories, IP aggregators and some start-ups (O'Connor 2010).

IP aggregators are firms that offer patent-holders enforcement of their patents on their behalf—*enforcement* as defined herein. Specifically, they do not innovate. They have been getting a bad press since the turn of the century, earning the moniker "patent trolls" by those who criticize this industrial practice, a term that received some authoritative credence when President Obama used it in his 2014 State of Union address (Lamarque 2014). This disparaging treatment is directly related to the post-*State-Street* controversy described in Chapter 1: IP aggregators are more likely than other non-practicing entities to enforce weak patents, using them to collect rent.[99] Since inventions protected by weak patents are, by their nature, obvious or already known, they provide little or no assistance to inventive and innovative endeavours of firms that pay royalties for them, willingly or grudgingly. To be fair, not all patents enforced by IP aggregators are weak. Furthermore, IP aggregators can contribute positively in the innovation landscape by supporting inventors with additional

[99] See Section 1.2 for a summary of the *State Street* controversy and a description of *weak* patents.

revenue,[100] and by helping users by acting as a one-stop shop for inventive inputs and knowledge (O'Connor 2010).

The model's ramifications with respect to the development constraint invite three comments applicable to non-practicing entities in general, IP aggregators in particular for some of them.

(i) Whether they patent their inventions or not, non-practicing entities tend to be transparent about the inventive material they possess. For IP aggregators, it is self-evident since the business model consists in patent enforcement. In the academic context, this phenomenon is often attributed to cultural practices unique to scientific research (Merton 1973) or to the assertion that researchers' rewards, like reputation, endowments, tenure, pride or personal satisfaction, necessitate (quick) publication (Fabrizio 2006). For aggregators as well as researchers, the model hints at a concurrent explanation: secrecy simply offers no benefits in the absence of innovation projects, making transparent mindsets unequivocally rational once the decision not to innovate has been taken.

(ii) Should governments wish to address problems raised by the weak patents enforced by IP aggregators, as was the case of the Obama administration, the model indicates that policies and legal shifts that target and increase the costs of patent enforcement or acquisition—in the case of IP aggregators, patents are often assigned to them by patent-holders—should reduce aggregators' net revenue. The economic incentive to adopt this business model would thus decline.

[100] In this model, this case is reflected if firm *j* assigns part or all of its outbound knowledge flow activities, z_i, to firm *i*, an IP aggregator. For firm *i*, the cost of being granted exclusive or sole enforcement rights to firm *j*'s invention would conceptually be equivalent to the exogenous cost of inventing, $\overline{c}_i$. If, thanks to its expertise in IP enforcement and economies of scale, the IP aggregator collects more income for firm *j* (and itself, to compensate for its services) than firm *j* would have obtained on its own, this decision is rationally sound for the inventive firm. In practice, firm *j* would also benefit by being able to focus its attention and resources in its other endeavours, for instance, developing an innovation.

(iii) In the absence of discrete leaps in other firms' technology management choices, $\frac{\partial V_i^0}{\partial \lambda_i \pi_i} = \frac{\partial z_i^0}{\partial \lambda_i \pi_i} \geq 0$ and $\frac{\partial V_i^0}{\partial \lambda_j \pi_j} = 0$. Legal shifts that increase the focal firm's expectations of patent protection in particular, or all firms' expectations of patent protection in general, have a non-decreasing effect on a non-practicing entity's expected value.

Participation Constraint

In a similar way as the development constraint, when the maximal value expected to be captured by a firm, V_i, is negative, that firm aborts its technological activities and chooses neither to invent nor innovate. Whether the development constraint is satisfied or not determines whichever of Equations 1.2 or 5 is relevant as a starting point: the participation constraint, once inserting in other firms' technology management choices, takes either of these two forms:

$$V_i(\lambda_i \pi_i, q_i, \boldsymbol{\lambda^c}_{\boldsymbol{-i}} \boldsymbol{\pi}_{\boldsymbol{-i}}, \boldsymbol{q^c}_{\boldsymbol{-i}}) = -C_i^T(\lambda_i \pi_i, q_i, \boldsymbol{\lambda^c}_{\boldsymbol{-i}} \boldsymbol{\pi}_{\boldsymbol{-i}}, \boldsymbol{q^c}_{\boldsymbol{-i}}) - \lambda_i C_i^{IP} - C_i^S(q_i)$$
$$+ R_i(\lambda_i \pi_i, q_i) \geq 0$$

$$V_i^0(\lambda_i \pi_i, 0, \boldsymbol{\lambda^c}_{\boldsymbol{-i}} \boldsymbol{\pi}_{\boldsymbol{-i}}, \boldsymbol{q^c}_{\boldsymbol{-i}}) = -\bar{c}_i + z_i^0(\lambda_i \pi_i, 0, \boldsymbol{q^c}_{\boldsymbol{-i}}) - \lambda_i C_i^{IP} \geq 0.$$

Deconstructed in the traditional "Revenue ≥ Costs" formulation, the two possible participation constraints can respectively be rewritten as:

$$z_i(\lambda_i \pi_i, q_i, \boldsymbol{q^c}_{\boldsymbol{-i}}) + R_i(\lambda_i \pi_i, q_i) \geq \bar{c}_i + c_i^D(q_i, \boldsymbol{\lambda^c}_{\boldsymbol{-i}} \boldsymbol{\pi}_{\boldsymbol{-i}}, \boldsymbol{q^c}_{\boldsymbol{-i}}) + \lambda_i C_i^{IP} + C_i^S(q_i)$$

$$z_i^0(\lambda_i \pi_i, 0, \boldsymbol{q^c}_{\boldsymbol{-i}}) \geq \bar{c}_i + \lambda_i C_i^{IP}.$$

Theoretically, if a firm expects positive value, it has an economic incentive to participate to technological activities. As mentioned in Chapter 1, the role of the patent system as an incentive to technological endeavours is more ambiguous. It is obvious from the revenue sides of these constraints that when the general strength of *all* patents increases,[101] patentees' market positions for innovations are solidified, as well as their access to more valuable outbound knowledge flows. These effects corroborate the conventional wisdom of patents. Nonetheless, as value accruing from knowledge flows suggests, overall patent strength does not necessarily make patentees better off. Specifically, this observation is made when the positive value extracted from a firm's strengthened patent protection is lower than the sum of increased costs of patent enforcement; of potential transactional value losses in inbound knowledge flows; and of costs of facing more and stronger patent infringement claims from other firms—firms are encouraged to litigate more because of a higher likelihood of success—albeit the focal firm's defensive litigation costs are mitigated if it also patents its invention. Put simply, the overall assessment of patent strength must also consider the concomitant costs, and this evaluation does not yet reckon with patents' main technology management alternative: secrecy.

Mechanism Constraint

The tension in technology management resides in the fact that it is not possible for firms to rationally choose both secrecy and IP protection: the firm has to choose only one of them—or none, captured by the model as playing secrecy with $q_i^c = 0$. Theoretically, any anticipated parametric change affecting a firm's decision-making dilemma has the potential to trigger discrete responses by the focal firm, through which it would jump from one technology management mechanism to the other. The mechanism constraint thus articulates the conditions under which discrete responses are not activated. In order to express it mathematically, it is necessary to examine technology management decisions more closely, the focus of the next subsection.

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[101] Each of the components in the vector $\boldsymbol{\pi}$, without underscript.

For the model, the importance of discussing these constraints, in addition to the observations they have allowed so far, stems from calculus. Because the model's calculus generalizations require continuous functions, they do not necessarily stand when firms make discrete leaps germane to any of the constraints. For instance, it is assumed in the model that $\frac{\partial z_i}{\partial q_i} \leq 0$. If firm *i* reduces its initially-chosen level of secrecy expectations, its expectations of net value accruing from outbound knowledge flows should be non-decreasing—due to lower transaction costs. This statement is false if firm *i*'s diminished secrecy is attributable to either its development or participation constraints not being met. In these cases, firm *i* steps out of development or the industrial environment altogether, thereby making impossible many or all valuable outbound knowledge flows. As a result, z_i is most likely diminished, whereas the model's calculus assumptions assert that it should be non-decreasing. For these reasons, all of the model's calculus generalizations are conditional on all three constraints being satisfied.

3.2.2 Tension between Technology Management Mechanisms

Internally, a firm's technology management decision is a two-stage game. In the first stage, the firm chooses between secrecy and patent protection. In the second stage, if it initially chose patent protection, it is ready to reap its expected value. If the firm opted for secrecy instead, it then has to choose a level of secrecy expectations. The microeconomic analysis of rational technology managers' decision-making process then consists, through backward induction, of first assessing the firm's optimal level of secrecy expectations given that it chooses secrecy in the first stage, and, second, of comparing the firm's expected value associated with this optimal level of secrecy expectations against the equivalent when it chooses patent protection. Rational technology managers pick the mechanism that yields the most expected value.

Step One: Optimal Level of Secrecy Expectations

If the development constraint is not satisfied, it has already been observed and commented that the optimal choice of secrecy expectations must be zero. Hence, by construction, when technology managers *select* an optimal level of secrecy, the development constraint is necessarily satisfied. Likewise, $\lambda_i^c = 0$ once it is implied that a firm's technology managers choose secrecy. Taking account of other firms' simultaneous decision-making processes, the objective function becomes:

$$V_i^S(0,\ q_i, \boldsymbol{\lambda^c_{-i}}\, \boldsymbol{\pi_{-i}}, \boldsymbol{q^c_{-i}}) := -\ \bar{c}_i\ -\ c_i^D(q_i, \boldsymbol{\lambda^c_{-i}}\, \boldsymbol{\pi_{-i}}, \boldsymbol{q^c_{-i}}) +\ z_i\ (0,\ q_i, \boldsymbol{q^c_{-i}}) - C_i^S(q_i)$$
$$+\ q_i\ [R_i^M\ -\ R_i^*] +\ R_i^* \qquad \textbf{(6)}$$

Assuming that all three constraints are satisfied for other players no matter the level of secrecy expectations firm *i* chooses, V_i^S is continuous with respect to q_i. In that case, the calculus assumptions applying to q_i in Equations 2, 3 and 4 are sufficient to know that V_i^S is concave with respect to q_i. Since $q_i \in [0, 1]$, this concavity combines with the extreme value theorem to ascertain that if the derivative $\frac{\partial V_i^S}{\partial q_i} = 0$ contains an interior solution, this solution maximizes the firm's expected value given that it chooses secrecy. Otherwise, the optimal level of secrecy must be located at one of the bounds, meaning that, in those cases, $q_i^c \in \{0, 1\}$, whichever bound is coupled with the highest expected value.

In most situations, i.e., those in which an interior solution exists, the firm's chosen level of secrecy expectations is determined by

$$\frac{\partial V_i^S}{\partial q_i} = -\ \frac{\partial c_i^D}{\partial q_i} +\ \frac{\partial z_i}{\partial q_i} -\ \frac{dC_i^S}{dq_i} +\ R_i^M\ -\ R_i^* = 0$$

$$R_i^M = R_i^* + \frac{\partial c_i^D}{\partial q_i} + \frac{dC_i^S}{dq_i} - \frac{\partial z_i}{\partial q_i}$$

(Marginal revenue of secrecy expectations = Marginal cost of secrecy expectations)

q_i^c is defined indirectly as the level of secrecy expectations, if any, that solves this equality. In this model, because $\frac{\partial^2 z_i}{\partial q_i \partial q_j} = 0$, $\frac{\partial^2 c_i^D}{\partial q_i \partial \lambda_j \pi_j} = 0$, and $\frac{\partial^2 c_i^D}{\partial q_i \partial q_j} = 0$, q_i^c is independent of the other arguments contained in V_i^S. Should these assumptions be relaxed, these vectors would be arguments in the indirect function of q_i^c.

Social Sub-Optimality of Secrecy Choice

Interestingly, when a firm rationally chooses its level of secrecy expectations in this way, social optimality, appraised from a producer-focused perspective, is generally not reached. This result stems from externalities in the industrial landscape that emerge when a firm plays secrecy. These social costs are not accounted for in the focal firm's rational choice. For notational convenience, the proof is computed with respect to the rational choice and social optimality of q_j, but the results aptly apply to q_i by virtue of firms' symmetric decision-making processes.

From a producer-focused social perspective, expected social value is given by

$$\sum_{i=1}^{n} V_i(\lambda_i \pi_i, q_i, \boldsymbol{\lambda_{-i}} \boldsymbol{\pi_{-i}}, \boldsymbol{q_{-i}}).$$

Keep in mind all observations made previously regarding the concave shape of V_j with respect to q_j. Since Equation 3's calculus assumptions indicate that the shape of V_i with respect to q_j is also concave, it must be the case that these observations apply to the summation of all firms' expected value functions. A firm's choice of secrecy expectations is socially optimal when marginal social benefits of that firm's choice equal its marginal social costs. Social costs and benefits expected from a marginal increase in q_j are given by

$$\frac{\partial \sum_{i=1}^{n} V_i}{\partial q_j} = -\frac{\partial c_j^D}{\partial q_j} + \frac{\partial z_j}{\partial q_j} - \frac{dC_j^S}{dq_j} + R_j^M - R_j^* - \sum_{i \neq j}^{n} \frac{\partial c_i^D}{\partial q_j} + \sum_{i \neq j}^{n} \frac{\partial z_i}{\partial q_j}$$

$$= \frac{\partial V_j^S}{\partial q_j} - \sum_{i \neq j}^{n} \frac{\partial c_i^D}{\partial q_j} + \sum_{i \neq j}^{n} \frac{\partial z_i}{\partial q_j}.$$

If an interior solution exists for firm *j*'s socially optimal choice of secrecy expectations, q_j^*, it is given by the amount of secrecy expectations by which this equation equals zero.

It has been demonstrated that an interior solution for q_j^c is obtained when $\frac{\partial V_j^S}{\partial q_j} = 0$. Knowing, thanks to Equation 3's calculus assumptions, that

$$-\sum_{i \neq j}^{n} \frac{\partial c_i^D}{\partial q_j} + \sum_{i \neq j}^{n} \frac{\partial z_i}{\partial q_j} \leq 0,$$

marginal social costs of firm *j*'s choice of secrecy expectations are generally[102] higher than firm *j*'s individual costs, while marginal social benefits are the same socially and individually. To counterbalance for these additional social costs, it must generally be the case that $q_j^* \leq q_j^c$, thence sub-optimality.

[102] "Generally" because the possibility that $-\sum_{i \neq j}^{n} \frac{\partial c_i^D}{\partial q_j} + \sum_{i \neq j}^{n} \frac{\partial z_i}{\partial q_j} = 0$ mathematically exists as the concavity is not strict.

Step Two: Choosing between Secrecy and Patent

When firm *i* chooses to seek a patent, $q_i^c = 0$ and $\lambda_i^c = 1$, which simplifies that firm's objective function to

$$V_i^{IP}(\pi_i, 0, \boldsymbol{\lambda^c}_{\boldsymbol{-i}} \boldsymbol{\pi}_{\boldsymbol{-i}}, \boldsymbol{q^c}_{\boldsymbol{-i}}) := -\bar{c}_i - c_i^D(0, \boldsymbol{\lambda^c}_{\boldsymbol{-i}} \boldsymbol{\pi}_{\boldsymbol{-i}}, \boldsymbol{q^c}_{\boldsymbol{-i}}) + z_i(\pi_i, 0, \boldsymbol{q^c}_{\boldsymbol{-i}}) - C_i^{IP} + \pi_i [R_i^M - R_i^*] + R_i^* \qquad \textbf{(7)}$$

Replacing q_i by q_i^c in Equation 6 and comparing it with Equation 7, firm *i* strictly prefers patent protection when

$$V_i^{IP}(\pi_i, 0, \boldsymbol{\lambda^c}_{\boldsymbol{-i}} \boldsymbol{\pi}_{\boldsymbol{-i}}, \boldsymbol{q^c}_{\boldsymbol{-i}}) > V_i^S(0, q_i^c, \boldsymbol{\lambda^c}_{\boldsymbol{-i}} \boldsymbol{\pi}_{\boldsymbol{-i}}, \boldsymbol{q^c}_{\boldsymbol{-i}})$$

i.e., if

$$-c_i^D(0, \boldsymbol{\lambda^c}_{\boldsymbol{-i}} \boldsymbol{\pi}_{\boldsymbol{-i}}, \boldsymbol{q^c}_{\boldsymbol{-i}}) + z_i(\pi_i, 0, \boldsymbol{q^c}_{\boldsymbol{-i}}) - C_i^{IP} + \pi_i [R_i^M - R_i^*] >$$
$$- c_i^D(q_i^c, \boldsymbol{\lambda^c}_{\boldsymbol{-i}} \boldsymbol{\pi}_{\boldsymbol{-i}}, \boldsymbol{q^c}_{\boldsymbol{-i}}) + z_i(0, q_i^c, \boldsymbol{q^c}_{\boldsymbol{-i}}) - C_i^S(q_i^c) + q_i^c [R_i^M - R_i^*]. \qquad \textbf{(8)}$$

Should the inequality sign point in the opposite direction, firm *i* strictly prefers secrecy to patent protection. [103]

In absolute terms, Inequality 8 cannot be reduced further. Nonetheless, some observations can be made to identify some conditions under which Inequality 8 always stands. Based on the assumption of independence between firms' choices of secrecy expectations and other firms' technology management decisions, namely $\frac{\partial^2 z_i}{\partial q_i \partial q_j} = 0$, $\frac{\partial^2 c_i^D}{\partial q_i \partial \lambda_j \pi_j} = 0$, and $\frac{\partial^2 c_i^D}{\partial q_i \partial q_j} = 0$, it must be the case that

[103] Should the two sides be equal, firm *i* would be indifferent between patent protection and secrecy.

$$z_i\ (\pi_i\ , 0, \boldsymbol{q^c}_{-i}) \geq z_i\ (0,\ q_i^c\ , \boldsymbol{q^c}_{-i})$$

because $\frac{\partial z_i}{\partial q_i} \leq 0$ and $\frac{\partial z_i}{\partial \lambda_i \pi_i} \geq 0$ (see Equation 3's calculus assumptions). Similarly,

$$-\ c_i^D\,(0, \boldsymbol{\lambda^c}_{-i}\ \boldsymbol{\pi}_{-i}\ , \boldsymbol{q^c}_{-i}) \geq -\ c_i^D\,(\ q_i^c\ , \boldsymbol{\lambda^c}_{-i}\ \boldsymbol{\pi}_{-i}\ , \boldsymbol{q^c}_{-i})$$

since $\frac{\partial c_i^D}{\partial q_i} \geq 0$ (see also Equation 3's calculus assumptions).

Therefore, to find that Inequality 8 holds unequivocally for a firm, it is sufficient to show that

$$\pi_i\,[\,R_i^M\ -\ R_i^*\,] - C_i^{IP} > q_i^c\ [\,R_i^M\ -\ R_i^*\,] - C_i^S\,(\,q_i^c\,) \qquad \textbf{(9)}$$

Before examining two industrial contexts in which this inequality always stands, a few comments need to be expressed about Inequality 8 in order to better understand its role.

Mechanism Constraint, Revisited

Inequality 8 now allows the mechanism constraint to be described in mathematical form. The mechanism constraint is satisfied when Inequality 8 holds true whatever technology management decisions other firms make, taking full account of these decisions' effects on firm *i* through potential knowledge flow interactions in the industrial environment. The mechanism constraint is also met *mutatis mutandis* if the inequality sign in Inequality 8 points in the other direction.[104] In that event, the focal firm prefers to play secrecy instead of patent protection as is the case in Inequality 8's standard formulation. In game theoretic language, for Inequality 8 to always apply, patent protection—or its secrecy adaptation—must be firm *i*'s

[104] To be clear, Inequality 8's reversible property does not translate to Inequality 9, which confines the latter's applicability.

best response to each of the other firms' sets of contemplated strategies, in other words, one of the two technology management mechanisms is a dominant strategy for firm *i*. Since all firms face the same constraints and decision-making processes, if Inequality 8—with the inequality sign pointing in any of the two directions for each of them—applies to all the firms active in an industrial environment, this strategy set constitutes a dominant-strategy, thus pure-strategy, Nash Equilibrium ("NE") for the industrial environment. Nevertheless, it is not necessary that all firms satisfy the mechanism constraint for a dominant- or pure-strategy NE to exist: for instance, if it is a dominant strategy for firm *i* to seek patent protection for its invention, a pure-strategy NE does not require that firm *j*'s decision be a best response to firm *i* choosing positive expectations of secrecy. From there and through cascading dominant strategies, a unique dominant- or pure-strategy NE can be obtained in the industrial environment without the mechanism constraint being satisfied for some of the players involved. Nash Equilibria of this model in a two-player game are further analyzed in Section 3.3, in which the mechanism constraint is fully relaxed as it is endogenously integrated into that two-player variant.

Copyright Protection of Computer Programs

It has been mentioned several times that the model applies to all regimes of IP, sometimes with a few adjustments. For inventions that are protectable with more than one IP regime, it is possible to analyze them through the lens of overlapping applications of the model, each taking into account distinct dimensions of secrecy. This is the case of computer programs, discussed in Subsection 1.3.1, for which patent and copyright protections coexist. In the copyright perspective of this model, computer programs are singularly relevant as they are the most inventive of copyrightable works.

For decades now, doubts about the validity of copyright protection granted to computer programs have been dispelled. In addition, this protection is free[105] and is granted automatically to any original source code or interface, without particular costs or efforts.[106] For a firm whose invention is a computer program and on which this model's analytical framework and assumptions are applied, expectations of copyright protection are very high, while concomitant costs are trivial, meaning that:

$$\pi_i \rightarrow 1 \text{ and } C_i^{IP} \rightarrow 0.$$

Transposed in Inequality 9, these parametric values are sufficient to guarantee that the inequality holds true, and thus that Inequality 8 stands as well. For a computer programming firm, copyright protection is a dominant strategy.

By aggregating these parametric values in an industrial environment composed entirely of computer programming firms adopting open innovation practices, it can be surmised that a dominant-strategy NE exists, with all firms playing copyright protection. In fact, this reality has been skimmed over *en passant* in Chapter 1. Whereas two ideologies in this industry feud regarding patent protection of computer programs, opposing F/OSS communities to other actors more willing to use exclusionary means, it is interesting to observe that both currents support copyright protection and actively rely on it in their industrial and business activities (Phillips 2009; Murray, Piper and Robertson 2014b). The model suggests that, at least in relation to copyright protection, decisions that are often considered ideological are actually predicated on rational grounds. In contrast, for patents over computer programs, it is generally not the case that $\pi_i \rightarrow 1$ or that $C_i^{IP} \rightarrow 0$. Unsurprisingly, an equilibrium by which all computer programming firms would choose to patent their inventions and actively use these patents, as is the case with copyright, does not exist.

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105 Free as in "free beer", this time. See *supra* note 14.

106 Jurisdictional standards of originality vary (Gervais and Judge 2011), but suffice it to say that originality is not a standard as demanding as patent law's novelty criterion. Originality is closer to "the work originates from the author." Unless a computer programmer copies a previously-existing code or makes only minor variations, the copyright protection of that programmer's work is *ipso facto* nearly certain.

Tacit Secrets

Tacit knowledge, like skills, know-how and unarticulated business methods,[107] can be tricky to secure since it exists mostly in the cognitive memory of people who are in contact with it. Should a firm wish to keep this knowledge under its exclusive purview, few secrecy-enhancing measures are suitable. They mostly rely on covenants not to compete and similar clauses in employees' work contracts. Yet, in some jurisdictions, notably California, covenants not to compete in labour contracts are void (Gilson 1999). Besides, a variety of exogenous legal shifts or industrial contexts could impair firms' access to reliable secrecy-enhancing means (Lemley 2011). When a firm's invention consists in tacit knowledge such as consulting or banking services, and the firm inhabits an industrial environment peculiarly obstructive for secrecy, these circumstances can be fitted in the model by assuming that there are no reliable secrecy-enhancing measures at the firm's disposal. A context like this, unusual indeed but still plausible around tacit inventive knowledge, entails that $q_i^c = 0$.[108] Since Equation 2 dictates that $C_i^S(0) = 0$, Inequality 9 is simplified to

$$\pi_i [R_i^M - R_i^*] - C_i^{IP} > 0.$$

In this industrial environment, building on the steps that transformed Inequality 8 into Inequality 9, any combination of parameters by which

$$\pi_i [R_i^M - R_i^*] > C_i^{IP}$$

is sufficient to ascertain IP protection as a dominant strategy for firm *i*. Furthermore, this inequality suggests that legal shifts that boost firm *i*'s expectations of IP protection increase its likelihood that IP protection constitutes a dominant strategy. Unlike in the case of copyright

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[107] See Section 2.3.

[108] See note 76 and accompanying text. The caveat contained therein is particularly important as the *minimal* level of secrecy in the absence of secrecy-enhancing measures is likely to be higher for tacit knowledge—because of its sticky nature—than for articulate knowledge.

protection of computer programs, though, because these parameters are individualized for each firm, the presence of this industrial environment's special conditions is hardly sufficient to envision a pan-industrial dominant-strategy NE, even by supposing the unlikely scenario by which all firms face the exogenous constraint $q_i^c = 0$.

3.2.3 Complex and Simple Innovations

Conceptually, innovations can be divided in two categories: complex and simple (Merges and Nelson 1990). On the one hand, complex—or cumulative—innovations require a variety of different input components, and these innovations, in turn, can themselves be integrated as input in plenty of other innovation processes. Complexity is a feature of most innovations in the software and electronics industries, among others, as well as in industries producing pieces for transportation vehicles such as automobiles, trains and aircraft. On the other hand, simple, or discrete, innovations need only a small number of components and similarly have a limited usability in other firms' innovation processes. Pharmaceuticals and innovative alterations of everyday objects like razors and forks share these characteristics.

It is generally recognized that firms rely on different innovation processes and business plans depending on whether the innovation is complex or simple (Scotchmer 2004; Merges and Nelson 1990). In an industrial environment where firms generally adopt practices of open innovation, the distinctive attributes of simple innovations support a presumption that firms that produce them participate in only a few knowledge flows, but the relative importance of these partnerships is relatively high. Conversely, when firms develop complex innovations with a mindset of open innovation, it is likely that they maintain many knowledge flows, even though most of them, individually, have a relatively minor impact. If a firm's partner, participating in either an inbound or an outbound knowledge flow, drops out of the industry, the focal firm is more likely to find a substitute partner to replace that knowledge flow and thus compensate for its value loss if its innovation is complex rather than simple, particularly if *n* is high.

In this model, this dichotomy helps in assessing the industrial contexts in which the direct effects of legal shifts on *other* firms' technology management decisions are more or less likely to bear significant repercussions in the *focal* firm's technology management dilemma. These cascading ramifications are presumed to be relatively more significant when the focal firm develops a simple innovation. Although a focal firm that develops a complex innovation can expect a greater number of ripple effects that surface because of legal shifts imposing themselves on other firms' technology management decisions, individually, each of these indirect effects should be relatively minor or null thanks to the focal firm's fast and easy access to equivalent alternatives. Based on this logic, firms that develop simple innovations are more susceptible to actual leaps in the model's three constraints. Consequently, it is relatively more reasonable to assume that the model's calculus generalizations stand in the case of a focal firm that develops a complex innovation.

3.3 The Variant Model—Two-Firm Interactions

Without adding many additional layers of assumptions and thereby losing interpretive generality, it is difficult to examine the interactions in an industrial landscape composed of a high number of firms because of the multiplicity of scenarios. A two-firm industrial environment allows a comprehensive breakdown of firms' technology management choices, of interactions between these choices, and of the effects of legal shifts on the focal firm's strategies. Because of players' interactions, the analysis must proceed with a game theoretic approach. The game represents step two of Subsection 3.2.2's study of technology management decisions, although in greater details. First, the game is solved by determining under what conditions, for parameters, a unique, dominant-strategy NE exists. A dominant strategy NE usually arises when the two players do not potentially litigate in the event that both seek patent protection. Regarding the focal firm's expected value and its propensity to choose patent protection, the analysis of legal shifts over dominant strategies are on par with intuitive incentive theory. Then, supposing that the emergence of a dominant-strategy NE is hampered by parameters' values, the game explores the possibility of multiple pure-strategy NE. Next, by supposing again the absence of a firm's dominant strategy, the game's mixed-strategy NE is identified in terms of the model's parameters and initial variables. Last, potential effects on the focal firm's strategy of legal shifts modifying the expectations of patent protection over that firm's invention are analyzed in the case of a mixed-strategy NE. There, the results are more ambiguous, thereby colliding with the intuition of a non-decreasing propensity to rely on patent protection when associated expectations increase.

Unless specified otherwise, *firm i* should be read as the focal firm in this section's analysis. In the same vein, π_i and π_j should respectively be interpreted as expectations that the *focal* firm's patent is valid and enforceable and as corresponding expectations applying to the *other* firm's prospective patent. Since firms face symmetric technology management problems despite their individualized parameters and variables, the analysis applies *mutatis mutandis* to firm *j* as a focal firm.

3.3.1 Let the Game Begin

The two players simultaneously choose among two strategies: patent protection or secrecy. Prior to the start of the game, each firm assesses its optimal choice of secrecy expectations in the way described in step one of Subsection 3.2.2. For firm *i*, the probability of choosing patent protection is denoted u, $u \in [0, 1]$. Firm *j*'s concomitant probability of patenting its internal invention is given by l, $l \in [0, 1]$.[109] As shown in the normal form of the game outlined as Figure 4, four potential outcomes of firms' expected value sets arise depending on the strategies played by each player.

[109] *u* for *up*, *l* for *left*.

$(V_i(\lambda_i^c\,\pi_i, q_i^c, \lambda_j^c\,\pi_j, q_j^c)$; $V_j(\lambda_j^c\,\pi_j, q_j^c, \lambda_i^c\,\pi_i,\ q_i^c))$		Firm j's strategy sets: $(\lambda_j^c\,\pi_j, q_j^c)$	
		$(\pi_j, 0)$ with Pr. $[\,l\,]$	$(0,\ q_j^c)$ with Pr. $[\,1-l\,]$
Firm i's strategy sets: $(\lambda_i^c\,\pi_i, q_i^c)$	$(\pi_i, 0)$ with Pr. $[\,u\,]$	$(-C_i^T(\pi_i, 0,\ \pi_j, 0) - C_i^{IP} + R_i(\pi_i, 0)$; $-C_j^T(\pi_j, 0,\ \pi_i, 0) - C_j^{IP} + R_j(\pi_j, 0))$	$(-C_i^T(\pi_i, 0, 0,\ q_j^c) - C_i^{IP} + R_i(\pi_i, 0)$; $-C_j^T(0,\ q_j^c,\ \pi_i, 0) - C_j^S(q_j^c) + R_j(0,\ q_j^c))$
	$(0,\ q_i^c)$ with Pr. $[\,1-u\,]$	$(-C_i^T(0,\ q_i^c,\ \pi_j, 0) - C_i^S(q_i^c) + R_i(0,\ q_i^c)$; $-C_j^T(\pi_j, 0, 0,\ q_i^c) - C_j^{IP} + R_j(\pi_j, 0))$	$(-C_i^T(0,\ q_i^c, 0,\ q_j^c) - C_i^S(q_i^c) + R_i(0,\ q_i^c)$; $-C_j^T(0,\ q_j^c, 0,\ q_i^c) - C_j^S(q_j^c) + R_j(0,\ q_j^c))$

Figure 4: Two-player game in normal form

The focal firm's expected value, based on each of these outcomes' probabilities, is given by

$$
\begin{aligned}
&ul\,[\,-C_i^T(\pi_i, 0,\ \pi_j, 0) - C_i^{IP} + R_i(\pi_i, 0)\,] \\
&\quad + [\,u - ul\,]\,[\,-C_i^T(\pi_i, 0, 0,\ q_j^c) - C_i^{IP} + R_i(\pi_i, 0)\,] \\
&\quad + [\,l - ul\,]\,[\,-C_i^T(0,\ q_i^c,\ \pi_j, 0) - C_i^S(q_i^c) + R_i(0,\ q_i^c)\,] \\
&\quad + [\,1 - u - l + ul\,]\,[\,-C_i^T(0,\ q_i^c, 0,\ q_j^c) - C_i^S(q_i^c) + R_i(0,\ q_i^c)\,].
\end{aligned}
$$

After cleaning terms that cancel themselves and ascribing each term to the probability variable(s) that apply(ies) to it, the focal firm's expected value, in terms of variables u and l, is linearly given by the game theoretic objective function

$$V_i^G(u, l) = A_i + u\,B_i + l\,G_i + ul\,H_i \qquad \textbf{(10)}$$

where A_i is a constant regrouping terms that are unaffected by the players' strategies; B_i is the constant of terms directly proportional with the focal firm's probability of seeking patent protection for its invention; G_i is the equivalent of B_i regarding the other firm's probability of itself choosing patent protection; and H_i is a constant of terms directly proportional with the firms' mixed probabilities of playing patent protection.

To facilitate the computation and analysis of the game, each of these four sets of parameters are disaggregated in Table 1, including some of their derivatives with respect to π_j. Originating from Equation 3's calculus assumptions, these derivatives are helpful to discuss the potential effects of legal shifts on the focal firm's strategy. The notation is slightly altered though, in order to take into consideration cross-interactions in third-segment revenues and costs of patent enforcement in this model's version, where C_i^T and its components have been parameterized. When the focal firm's development costs, c_i^D, are differentiated, they are marked $c_i^D(0)$ if one of the two firms plays secrecy. In that case, "0" portrays the absence of interaction. Conversely, if both firms play patent protection, c_i^D's and z_i's functions to be differentiated are marked as $c_i^D(\pi_i)$ and $z_i(\pi_j)$. This notation reflects the idea that, usually, π_i and π_j are independent from c_i^D and z_i respectively, but not in these cases, owing to cross-interactions.[110]

[110] $\frac{\partial^2 z_i}{\partial \lambda_i \pi_i \, \partial \lambda_j \pi_j} \leq 0$, and $\frac{\partial^2 c_i^D}{\partial \lambda_j \pi_j \partial \lambda_i \pi_i} \leq 0$; see Equation 3's calculus assumptions.

Table 1: Constants of firm *i*'s expected payoff in a two-player game and their derivatives	
$A_i =$	$-C_i^T(0,\ q_i^c, 0,\ q_j^c) - C_i^S(q_i^c) + R_i(0,\ q_i^c) = V_i(0,\ q_i^c, 0, q_j^c)$
$B_i =$	$-C_i^T(\pi_i, 0, 0,\ q_j^c) - C_i^{IP} + R_i(\pi_i, 0)$ $+ C_i^T(0,\ q_i^c, 0,\ q_j^c) + C_i^S(q_i^c) - R_i(0,\ q_i^c)$ $= V_i(\pi_i, 0, 0, q_j^c) - V_i(0,\ q_i^c, 0, q_j^c)$
$\dfrac{\partial B_i}{\partial \pi_j} =$	0
$G_i =$	$-C_i^T(0,\ q_i^c,\ \pi_j, 0) + C_i^T(0,\ q_i^c, 0,\ q_j^c)$ $= V_i(0,\ q_i^c,\ \lambda_j^c \pi_j, 0) - V_i(0,\ q_i^c, 0, q_j^c)$
$H_i =$	$-C_i^T(\pi_i, 0,\ \pi_j, 0) + C_i^T(\pi_i, 0, 0,\ q_j^c)$ $+ C_i^T(0,\ q_i^c,\ \pi_j, 0) - C_i^T(0,\ q_i^c, 0,\ q_j^c)$
$\dfrac{\partial H_i}{\partial \pi_j} =$	$-\dfrac{\partial c_i^D(\pi_i)}{\partial \lambda_j \pi_j} + \dfrac{\partial z_i(\pi_j)}{\partial \lambda_j \pi_j} + \dfrac{\partial c_i^D(0)}{\partial \lambda_j \pi_j} = ?$

In this two-player industrial environment, Equation 10 allows the reformulation of the participation constraint in more precise terms:

$$V_i^G(u, l) = A_i + u\, B_i + l\, G_i + ul\, H_i \geq 0.$$

Regarding the development constraint, terms and derivatives in V_i^G are sufficiently general to accommodate a firm's adapted objective function should its development constraint not be satisfied. Finally, the mechanism constraint is fully relaxed by virtue of this variant's simplification to a two-player environment, which enables the game to endogenously internalize firms' technology management decisions.

3.3.2 Nash Equilibria

When acting rationally, the focal firm chooses u in a way that maximizes Equation 10. At first glance, the focal firm has no control over the components A_i and $[\, l\, G_i\,]$. Because of Equation 10's linear shape with respect to u, and taking into account that l is not a constant but a variable fully within the control of the other firm, this maximization process implies the result

$$u^* \in \begin{cases} 1 & \text{if} \quad B_i + l\, H_i > 0 \\ 0 & \text{if} \quad B_i + l\, H_i < 0 \\ [0\,,1] & \text{if} \quad B_i + l\, H_i = 0 \end{cases} \qquad \textbf{(11)}$$

Dominant-Strategy NE

Since the focal firm's optimal decision rests on the other firm's choice of l, interactions between both firms' strategies must be discussed in order to assess NE. There is an exception though: if $H_i = 0$, the focal firm's optimal choice of u does not interact with the other firm's choice, letting the focal firm choose $u^* = 0$ or $u^* = 1$ depending on whether B_i is positive or negative. Table 1 indicates that

$$B_i = V_i(\pi_i, 0, 0, q_j^c) - V_i(0,\ q_i^c, 0, q_j^c).$$

In a logical way, B_i is positive, and playing patent protection is a dominant strategy for the focal firm, when choosing patent protection is the focal firm's best response to the other firm choosing secrecy, given, of course, that $H_i = 0$. Otherwise, playing secrecy is a dominant strategy for the focal firm. In the absence of third-segment interactions captured in H_i, the focal firm's best response when the other firm plays secrecy necessarily translates as the focal firm's best response when the other firm chooses patent protection instead. Since the players' decision-making processes are symmetric, and interactions are by definition reciprocal, the absence thereof likely leads to the other firm also having a dominant strategy in this game. If both $H_i = 0$ and $B_i = 0$, the focal firm is strictly indifferent between patent protection and secrecy, and both constitute a best response to the other firm's strategy, whichever it is.

In sum, $H_i = 0$, $B_i \neq 0$ and $B_j \neq 0$ are the conditions by which both firms have a dominant strategy in this game, which would lead to a dominant- (and pure-) strategy NE. $H_i = 0$ when

$$-C_i^T(\pi_i, 0, \pi_j, 0) + C_i^T(\pi_i, 0, 0, q_j^c) + C_i^T(0, q_i^c, \pi_j, 0) - C_i^T(0, q_i^c, 0, q_j^c) = 0.$$

Because Equation 3's calculus assumptions imply that $\frac{\partial^2 C_i^T}{\partial q_i \, \partial \lambda_j \pi_j} = 0$, $\frac{\partial^2 C_i^T}{\partial q_i \, \partial q_j} = 0$, the most important of these conditions, $H_i = 0$, happens when the two firms do not interact regarding third-segment revenues of patent enforcement, on a case-by-case basis. More precisely, this situation occurs when neither of the two firms litigates against the other in the event that both patent their inventions. Absent these court interactions, the positive and negative signs in front of these four C_i^T terms necessitate that each of the arguments' increasing and decreasing effects cancel themselves as they do not vary between terms. In turn, $H_i = 0$.[111]

With a dominant-strategy NE, the focal firm's expected value equals

$$V_i^D(u^*, l^*) = A_i + u^* B_i + l^* G_i\,,$$

where the choice of u^* depends on whether patent protection is a best response to the other firm playing secrecy. Analysis of the other firm's ensuing strategy and each firm's respective expected value, including effects of legal shifts, follows straightforwardly with the help of

[111] Theoretically, the terms also cancel themselves in the very unlikely event that both firms initiate patent litigation procedures, and the bi-directional net value results of the firms' technology management interactions are equal. Plainly, when "what one earns by [its own] patent, one loses by [the other's] patent". Since each of the model's parameters is individualized, the probability of this occurrence is extremely small. In order to lighten the text, this slim possibility is not analyzed any further in this paper, nor is it referred to.

Table 1 and Equation 3's calculus assumptions. Conditional on each of the two firms' participation constraints being satisfied with this unique, dominant-strategy set:

(i) Legal shifts enhancing the focal firm's expectations of patent protection increase the likelihood that patent protection constitutes a dominant strategy for that firm, and thus that it seeks patent protection for its invention.

(ii) If the focal firm plays patent protection, a legal shift boosting its expectations of patent protection affects its expected value positively, thereby incentivizing its participation in the technological game.

(iii) Conversely, legal shifts increasing the other firm's expectations of patent protection, in the event that its dominant strategy is to play patent protection or that the increment is significant enough to elicit the other firm to switch to patent protection as its technology management choice, likely erode the focal firm's expected value, thus bringing down its incentive to invent and innovate as well.

Other Pure-Strategy NE

The analysis of H_i has indicated that the main condition for the absence of dominant strategy is an interaction between both firms in the event that they both play patent protection. In the model's construction, this situation only arises if one or both of the firms seek(s) revenue through patent litigation. In order to continue the game's analysis, the rest of this section, and of this chapter, posits that these court interactions qualify the two firms' relationship in the game.

In that context, there is (are) either zero or two pure-strategy NE. In line with Set 11, there is no pure-strategy NE when:

1) If the focal firm plays $u = 1$, the other firm's best response is to play l such that $B_i + l\, H_i < 0$; and

2) If the focal firm plays $u = 0$, the other firm's best response is to play l such that $B_i + l\,H_i > 0$.

By reversing the signs, the game contains two pure-strategy NE when:

1) If the focal firm plays $u = 1$, the other firm's best response is to play l such that $B_i + l\,H_i > 0$; and
2) If the focal firm plays $u = 0$, the other firm's best response is to play l such that $B_i + l\,H_i < 0$.

In the case where there are two pure-strategy NE, which depends entirely on the firms' parameters, there might be coordination problems between both firms' simultaneous decisions, as is typically the case in Bach-Stravinsky games. Coordination issues can be market-based, for instance a rivalry for the same customer base. Other times, they are regulatory, typically stemming from antitrust law and authorities. Identifying a NE that is not plagued by coordination problems is particularly relevant in these settings.

Mixed-Strategy NE

So long as there is no dominant-strategy NE, there is a mixed-strategy NE. In Set 11, it is specified that the focal firm chooses patent protection with any probability when $[B_i + l\,H_i = 0]$. The focal firm's indifference in its chosen probability of playing patent protection results from the computation that, when $[B_i + l\,H_i = 0]$, the focal firm's expected payoff becomes, by converting Equation 10,

$$V_i\ (u, l) = A_i + l^c\,G_i \qquad \textbf{(12)}$$

where u, the focal firm's only variable within its control at this stage of the game, has no effect on the focal firm's expectations of technological value. This result is achieved when the other firm plays patent protection with a probability of

$$l^{MS} = -\frac{B_i}{H_i} \qquad \text{conditional on } H_i \neq 0.^{112}$$

This equality is obtained by isolating l in $[B_i + l\,H_i = 0]$.

If the focal firm simultaneously plays a strategy that also renders the other firm indifferent with respect to its own probability of choosing patent protection, by their mutual indifference, each of the firms' strategies would be a best response to the *vis-à-vis*' strategy—the definition of a NE. With this strategy set, the game would find a mixed-strategy NE. By symmetry of both firms' strategies, parameters and variables, the focal firm's strategy that makes the other firm indifferent is

$$u^{MS} = -\frac{B_j}{H_j} \qquad \text{conditional on } H_j \neq 0.$$

The mixed-strategy NE is thus the strategy set $(u^{MS}, l^{MS}) = (-\frac{B_j}{H_j}, -\frac{B_i}{H_i})$. Equation 12 represents the focal firm's expected value when the game is in a mixed-strategy NE, conditional to this expected value to be positive—the participation constraint. By inserting in it the other firm's mixed-strategy choice in a NE, the focal firm's expected value in a mixed-strategy NE can be defined in terms of the game's parameters:

$$V_i^{MS} = A_i - \frac{B_i G_i}{H_i} \qquad \textbf{(13)}$$

In the absence of a dominant-strategy NE, the mixed-strategy NE offers notable interpretive advantages over its counterpart pure-strategy NE. If there are pure-strategy NE, which is uncertain, they come as a pair, and their associated strategies and expected technological values vary depending on the parameters, on a case-by-case basis. The mixed-

[112] Not coincidentally, the prior analysis of H_i shows that this condition is satisfied by positing that the game does not contain any dominant-strategy NE.

strategy NE, however, is unique; it defines each firm's equilibrium strategy and expected value in terms of the game's general parameters; and its existence is ascertained so long as there is no dominant-strategy NE. When fierce rivalry or exogenous conditions do not allow or support the coordination of decisions by firms, for instance because of antitrust regulations, a focal firm can find it desirable to select a strategy that fully anticipates the other firm's strategy. By symmetry, the other firm is likely to also plan this way. Rendering the counterpart indifferent by playing the mixed-strategy set is one way by which they can obtain this advantage. For these reasons, this model's last step—the analysis of the impact on the focal firm's strategy of legal shifts affecting expectations of patent protection related to its invention—takes the two-firm mixed-strategy NE as the industrial environment subjected to an exogenous shock.

3.3.3 Analysis of the Mixed-Strategy Nash Equilibrium

The analysis of exogenous legal shifts that marginally decrease or increase expectations of patent protection associated with the focal firm's invention focuses on the effects on that firm's strategy. The circumstances under which these legal shifts increase or decrease the focal firm's probability to apply for patent protection are computed and discussed. As seen with the analysis of the dominant strategy NE, the basic intuition is that when expectations of patent protection for the focal firm's invention increase, that firm's likelihood of seeking patent protection should likewise increase. Because of the peculiar context of a mixed-strategy NE defined by this model's assumptions, this initial impression is contradicted in some situations.[113] It is shown that, in a mixed-strategy NE, the nature of legal shifts' effects depends mostly on the other firm's behaviour and parameters, as the focal firm adapts its own strategy to maintain the other firm in an indifferent state.

[113] Unlike the legal shift dissected in this subsection, the effects of legal shifts on both firms' expected values are non-conclusive. Too many determinants interact in a way that a great deal of additional assumptions would need to be joined to the computation in order to merely obtain a very limited and case-specific prediction of legal shifts' effects. Interested readers are invited to use Table 1 and Equation 3's calculus assumptions if they wish to delve into these results.

In this computation, the symmetric arrangement of the game is put to contribution. Since Table 1 focuses on constants related to firm *i* and these terms determine l^{MS}, firm *j*'s strategy, firm *j* is referred to as the focal firm here, while firm *i* is the *other* firm. This way, the outcomes on the focal firm's strategy of a legal shift marginally increasing π_j are examined.

Effects of Legal Shifts—Expectations on the Focal Firm's Invention

Conditional on the absence of dominant strategies, the focal firm's mixed-strategy in a NE is defined as $[l^{MS} = -\frac{B_i}{H_i}]$. The effect on the focal firm's strategy of a legal shift on expectations of patent protection for its invention can be computed by differentiating its equilibrium strategy with respect to π_j:

$$\frac{\partial l^{MS}}{\partial \pi_j} = -\frac{\frac{\partial B_i}{\partial \pi_j} * H_i - B_i * \frac{\partial H_i}{\partial \pi_j}}{H_i^2}$$

$$= \frac{[V_i(\pi_i,0,0,q_j^c) - V_i(0,q_i^c,0,q_j^c)] * [-\frac{\partial c_i^D(\pi_i)}{\partial \lambda_j \pi_j} + \frac{\partial z_i(\pi_j)}{\partial \lambda_j \pi_j} + \frac{\partial c_i^D(0)}{\partial \lambda_j \pi_j}]}{H_i^2}.$$

The last equality sign is obtained by replacing the constants and their derivatives by their corresponding computations in Table 1.

Knowing that $H_i \neq 0$, it must be the case that the denominator is positive. Hence, an exogenous marginal augmentation of patent protection expectations for the focal firm's invention increases this firm's likelihood to patent if:

$$[V_i(\pi_i, 0, 0, q_j^c) - V_i(0, q_i^c, 0, q_j^c)] * [-\frac{\partial c_i^D(\pi_i)}{\partial \lambda_j \pi_j} + \frac{\partial z_i(\pi_j)}{\partial \lambda_j \pi_j} + \frac{\partial c_i^D(0)}{\partial \lambda_j \pi_j}] > 0 \quad \textbf{(14)}$$

Consider that each set of brackets represents a term. The first bracket term is positive when the other firm's best response to the focal firm choosing secrecy is patent protection, while it is negative when it is not the case.

In the second bracket term, since the absence of dominant strategy implies litigation in the event that both firms seek patent protection, and $\frac{\partial^2 c_i^D}{\partial \lambda_j \pi_j \partial \lambda_i \pi_i} \leq 0$,

$$\frac{\partial c_i^D(0)}{\partial \lambda_j \pi_j} - \frac{\partial c_i^D(\pi_i)}{\partial \lambda_j \pi_j} > 0.$$

This difference captures the marginal hike in the other firm's development costs that does not occur when its decision to patent relatively reduces patent litigation risks and expected costs. $\frac{\partial z_i(\pi_j)}{\partial \lambda_j \pi_j}$ represents the other firm's loss of potential patent litigation revenue due to the relative defense that the focal firm's marginally-increased expectations of patent protection provide itself. This component is negative because $\frac{\partial^2 z_i}{\partial \lambda_i \pi_i \partial \lambda_j \pi_j} \leq 0$. All three components of the second term put together, they represent the other firm's net value gain or loss emanating from marginally-increasing patent litigation interactions—a gain if that second bracket term is positive, otherwise, a loss.

Combining the two terms together, a legal shift increasing expectations of patent protection for the focal firm's invention likewise increases this firm's equilibrium probability to seek patent protection in two scenarios:

i) Inequality 14's two bracket terms are positive. Here, in any case, the other firm relatively benefits from itself choosing patent protection—enhanced patent litigation interactions yield marginally increasing positive net value for the other firm, and patent protection is the other firm's best response to the focal firm choosing secrecy. The other firm's parameters determine, in a mixed-strategy equilibrium, the focal firm's likelihood of patenting its invention. As seen with the analysis of the dominant-strategy NE, an exogenous increase in the focal firm's expectations of patent protection reduces the other firm's expected value. Since the focal firm plays a strategy that maintains the other firm in indifference, the focal firm wishes to counterbalance the exogenous shock's direct effects on the other firm by enhancing its probability to patent, since the other firm possesses an unequivocal best response to this move. By this response, the focal firm keeps the other firm indifferent.

ii) Inequality 14's two terms are negative. The analysis when the two terms are positive applies similarly. In this case, secrecy is the other firm's best response when the focal firm plays secrecy. In the event that both firms play patent protection, the other firm's net value is eroded with marginally-increasing patent litigation interactions. Here as well, in order to keep the other firm indifferent, the focal firm wants to counterbalance the expected loss of value for the other firm that results from the legal shift. The focal firm reacts by enhancing its own probability to seek patent protection since the other firm's parameters indicate that it benefits unequivocally from this move.

If parameters' values do not lead to one of these two situations, the focal firm's likelihood to patent in a two-firm mixed-strategy NE actually declines as expectations of patent protection for its invention increase. The foregoing analysis applies *mutatis mutandis* in the event that Inequality 14 is negative. Presumably, since higher expectations of patent protection reduce the other firm's expected value, the only means at the focal firm's disposal to repair the other firm's state of indifference is to in turn reduce its likelihood to apply for patent protection. In sum, in a mixed-strategy NE, it is mostly the other firm's parameters that dictate the focal firm's response to legal shifts. This adjustment does not necessarily go in the direction that would appear rational and intuitive in a basic microeconomic analysis.

Conclusion

The purpose of this paper was to analyze the effects of legal shifts in relation with IP in an industrial environment characterized by open innovation in general, more particularly with respect to firms' technology management decisions.

In Chapter 1, the nature and actual effects of these potential legal changes have been delved into, most notably through patent law cases in the banking services industry and in the biotechnological sector. It has also been discussed that legal shifts may occur in other regimes of IP like copyright and trademarks. In some circumstances, these shifts affect an entire industry while, other times, their impact is confined to a single firm. The cases and legal theory generally indicate that legal shifts affect firms through their expectations of IP protection over their inventions and innovative products. Legal shifts can boost these expectations, as is evidently the case with trade agreements, while other times they erode them, as recent U.S. Supreme Court decisions did with respect to computerized business methods. In whichever directions, it appears that results on firms' responses and incentive to partake in inventive and innovate activities are ambiguous. Better understanding this ambiguity and determining particular circumstances under which this ambiguity is dissolved constitute some of the goals of this paper's economic treatment.

Then, in Chapter 2, the importance of the distinction between inventions and innovations has been stressed. On the one hand, inventions are new yet inchoate. They are applications or implementations of technological ideas. On the other hand, innovations combine a number of input and design components, at least one of which is an invention or an inventive design, in order to bring them to market and, eventually, customers. This distinction is particularly significant because economic models tend to amalgamate the two and ascribe to inventions effects and assumptions that only apply to innovations, or vice-versa. The distinction between inventions and innovations was the main driver behind the decision to assume that industrial landscapes analyzed in this paper are characterized by open innovation. As a management model that focuses on knowledge flows between firms and actors inhabiting the industrial environment, open innovation not only captures the distinction between inventions and innovations, but it also procures an empirical analysis of inter-firm relationships. The relevance of open innovation in this paper has been highlighted with an adaptation of Baldwin and von Hippel's 2010 model of viability for innovation modes: there are many reasons to believe that open innovation is a particularly viable model in the current technological context, where ICT act as a wave that raises the entire field of technology development. The pace, quality and cost-efficiency of technological activities have been significantly improving in this context.

Next, a microeconomic model has been set up in Chapter 3, representing firms' inter-relationships in an industrial environment where it was assumed that firms adopt an open innovation approach. Because of this assumption, knowledge flows by which firms interact at the inventive and innovative stages while yet competing on the market stage bring a distinctive flavour to the model. By having firms choose between two technology management mechanisms—patents and secrecy—it was then possible to ascribe the effects of these decisions on firms' cost and revenue determinants. In turn, multi-firm analyses of this model were developed, particularly with the goal of determining firms' development and participation constraints in this environment, as well as to assess the processes by which firms choose their optimal technology management mechanism. Along this track, comments and findings were made about the nature of some industries or business models, such as non-practicing entities and the widespread use of licenses and copyright law by computer-programming firms. At different moments, the effects of legal shifts have been evaluated.

The main assessment, however, took place at the end of the model's exploration, in a two-firm game theoretic version of the model. Having identified circumstances where there are dominant-, pure- and mixed-strategy Nash Equilibria, it has then been possible to assess the impact of legal shifts regarding a focal firm's expectations of IP protection. In a dominant-strategy Nash Equilibrium, the results supported the conventional intuition that higher expectations of patent protection for a focal firm can increase the likelihood that this firm manages its technology with patent protection, possibly increasing the net value it expects to capture for its technology and its incentive to participate in technological endeavours. Conversely, also in a dominant-strategy Nash Equilibrium, legal shifts increasing other firms' concomitant expectations can have the adverse effect on the focal firm's expected value, potentially reducing in turn its incentive to participate in technological development. Last, in a two-firm mixed-strategy Nash Equilibrium, the effects of legal shifts on a focal firm vary with respect to the other firms' parameters, through firms' interactions. Depending on the decision a focal firm must make to keep its *vis-à-vis* indifferent, a legal shift that increases the focal firm's expectations of patent protection over its invention can increase as well as reduce the probability with which it seeks patent protection. This last result is counter-intuitive.

Interestingly, in the model, interactions between technology management mechanisms had been kept low. They only took place through patent litigation interplay. A strong assumption consisted in considering that a firm's choice of secrecy expectations is independent of other firms' concomitant choices, for either secrecy or IP protection. One of the reasons supporting this decision was to keep the model manageable. Considering that a single interactive scenario was sufficient to identify counter-intuitive effects of legal shifts in a mixed-strategy equilibrium, finding a way to extend these interplays to an extent closer to reality could produce meaningful results. They could reduce, amplify or transform this model's findings. Likewise, a detailed application in a multi-firm environment would produce interesting developments. Other potentially fruitful adaptations of the model could analyze in greater detail distinctions between the effects of patent validity and patent enforceability, which in this model were captured with a single individualized parameter. As well, inventive processes were determined by nature. Integrating the experimentation stages of making inventions, and interactions with legal standards and shifts, could provide significant insights. There are so many possibilities, and they are left to inventive and innovative minds—this paper's contribution to knowledge flows.

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