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On sharks, trolls, and their patent prey—Unrealistic damage awards and firms' strategies of "being infringed"

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Abstract

Patent trolls (or sharks) are patent holding individuals or (often small) firms who trap R&D intensive manufacturers in patent infringement situations in order to receive damage awards for the illegitimate use of their technology. While of great concern to management, their existence and impact for both corporate decision makers and policy makers remains to be fully analyzed from an academic standpoint. In this paper we show why patent sharks can operate profitably, why they are of growing concern, how manufacturers can forearm themselves against them, and which issues policy makers need to address. To do so, we map international indemnification rules with strategic rationales of small patent-holding firms and large manufacturers within a theoretical model. Our central finding is that the courts' unrealistic consideration of the trade-offs faced by inadvertent infringers is a central condition for sharks to operate profitably.

JEL classification: M00; M11; M21; K00; K11; K33

Keywords: Patent; Patent shark; Patent troll; Damage award; Infringement

1. Introduction

"The operations of patent sharks sometimes compel an inventor to obtain patents for articles which are never meant to be placed on the market. A fellow often gets up a machine, and somebody else comes along, and by getting patents through for certain parts, can give the inventor a great deal of bother and make him pay well, even if the inventor gets control of it" (Thomas Edison, 1898).

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"Noblesse oblige", but property does not; legally speaking, at least, this is the case when it comes to *intellectual* property. Patent holders are – apart from very rare exceptions[2] – not obliged to engage in the production of goods using their protected technology. They may do whatever they want to with their inventions, and often they will consider it most profitable to sell their technology or license it against a royalty fee to a third party (see Arora et al., 2001; Arora and Ceccagnoli, 2006). The law explicitly supports this form of exploitation, offering various remedies to patent holders whose rights are being infringed—no matter whether the patentee uses its protected technology or not (see Lanjouw and Lerner, 2001; Schankerman and Scotchmer, 2001). In the ideal world envisaged by the forefathers of patent law (see Nordhaus, 1969), these remedies should "do justice" to the patent holder and restore his/her incentives to invent in the first place (see also Macdonald, 2004). They should set incentives for patent holders and other parties to enter sales or licensing negotiations from the outset so that no inventor has to fear any infringer at all.[3]

The above assumes a "credulous" patent holder who has to fear a deliberate infringer. But what if, conversely, R&D-intensive firms start to fear the existence of patent-holding individuals who have ulterior motives of free-riding on a product's core invention? As the introductory quotation shows, the great Thomas Edison recognized already a hundred years ago that a manufacturer who does not hold the rights to each and every invention embodied in its product may face harassment from such individuals.

What nobody could have foreseen then, however, and what has consequently not been discussed comprehensively in the literature on "systematic patent strategy" (see Blind et al., 2006; Macdonald, 2004),[4] are the even greater concerns of today's leading R&D multinationals of potentially overlooking these (often small) inventors' patents and being caught in the trap of inadvertent infringement. Today's patent "sharks" or "trolls"[5] seem to place their bets on precisely this corporate "negligence" or monitoring deficiency. Sharks or trolls have no intention of engaging in the production of the technology underlying their patents, but instead make money from royalty payments they obtain directly from their licensees or indirectly in terms of damage awards. Different from "classic" licensors, however, trolls intend to take their victims by "surprise" to facilitate their attempts to force manufacturers into unexpected licensing fees. The relevance this topic has assumed over time is dramatic, being reflected in a series of recent disputes[6] and

[2] These very rare exceptions come in the form of so-called "compulsory licences". According to Article 5 A. (2) of the Paris Convention for the Protection of Intellectual Property, "Each country of the Union shall have the right to take legislative measures providing for the grant of compulsory licenses to prevent the abuses which might result from the exercise of the exclusive rights conferred by the patent, for example, failure to work". If at all, such legislative measures are almost only discussed in the context of military or major pharmaceutical inventions. One recent example includes the discussion of granting compulsory licenses for HIV-related drugs to generic manufacturers in South Africa and Brazil in order to provide affordable medication to these poorer countries' people.

[3] It is on this background that one has to understand why even small individual inventors are at times entitled to significant damage awards, and why this can be desired from a social standpoint (this is less clear in the example illustrated in Footnote 4). An illustrative example is the case of Gaus. versus Conair (see "Jury blows away Conair with $28.5 M infringement award", Litigation Week, 11 February 2002) Dr. Gaus received a 28.5 million US$ compensation from the Conair corporation for the infringement of his patents on circuits used to protect users of hand-held hair dryers from being electrocuted when the dryers are immersed in water. Conair knew of Dr. Gaus' rights and willfully infringed them (Note: the actual sum awarded to Dr. Gaus in this case is likely a higher price than Conair would have been willing to pay for the technology had they acted legitimately. As will become clearer in Section 2 of this paper, Conair's willingness to pay for Dr. Gaus' patent before infringement should have amounted to at least a third of the awarded damages, however. The example only serves to illustrate why seemingly high remedies awarded to individual inventors may still be economically suitable at a second glance).

[4] See Blind et al. (2006) and Macdonald (2004) for two carefully compiled and recent surveys on the strategic use of patents. As both articles show, the "strategic use" of patents (the two most important types being blocking and cross-licensing with patent 'thickets' playing a major role for the latter), has classically been discussed from the perspective of those patent holders who either engage in the production of their own technological goods or consider themselves professional intellectual property suppliers who repeatedly interact with manufacturers. The strategy of "being infringed" as pursued by trolls is a different phenomenon. While not entirely new (see Section 4.1, quoting Lemelson versus Mattel), the broad systematic use of troll strategies appears to be very recent, however.

[5] The term 'patent troll' was originally used by an Intel executive in the early 1980s to denote patent-holding individuals who use patents "that they are not practicing and have no intention of practicing and in most cases never practiced" (Peter Detkin, former assistant general counsel at Intel, quoted in *Trolling for Dollars*, The Recorder, 30 July 2001). While today there is a consensus that trolls make it a business to press other firms for licensing fees, the question of how to define a "patent troll" properly is not a trivial one, and it was only recently addressed systematically by lawmakers (see "Patent Trolls: Fact or Ficition", Hearing before the Subcommittee on Courts, the Internet, and Intellectual Property of the Committee of the Judiciary, House of Representatives One Hundred Ninth Congress, 15 June 2006). For the purpose of this paper, we therefore present a more elaborate working definition of the term in Section 2.

[6] For example, Luxembourg-based InPro Licensing SARL has sued RIM, the maker of the blackberry handheld device, for infringement. In the suits brought against RIM in 2003 in Germany and the UK, rulings by the German Federal Patent Court

summarized most impressively in the following management statement by Peter Halkjaer, Senior IP Manager, Mobile Phones at Nokia:

> "From an IP management perspective, patent sharks currently pose one of the great challenges to our firm".

Without doubt, sharks create uncertainty for innovators and their activities may lead to damage awards which are a multiple of what the shark's victim, as legitimate licensee, would have been willing to pay *ex ante*. Hence, as we will show in more detail in this article, the shark business entails various economic inefficiencies. This is ever more puzzling because, while most of the publicly known shark cases took or take place in the US, the phenomenon is of great and growing concern also in other parts of the world.[7]

Thus, why do trolls exist at all? How can manufacturers forearm themselves against them? And what are the policy consequences? Despite the richness of prior contributions on economics of patent infringement (for example by Schankerman and Scotchmer, 2001; Crampes and Langinier, 2002; Bessen and Meurer, in press) and managerial aspects of patent licensing (e.g. Agrawal and Garlappi, 2002; Arora et al., 2001; Arora and Ceccagnoli, 2006) the literature does not seem to provide conclusive answers to these pressing questions.

As we will show in this paper, the simple yet unsatisfactory answer to the core question of "why patent sharks exist" (from which the other aforementioned questions derive) is: because their activity is not only profitable but also perfectly legal. As we will elaborate upon, the threat modern patent sharks can pose to innovative manufacturing firms strongly depends – among other factors, notably surprise – on the applicable law governing infringement as well as its practice by the courts. Surprisingly from an economic standpoint, damage awards may not only be calculated following different rationales within one jurisdiction, but it lies (to a large extent) within the discretion of the patent holder (and not the court!) to pick the type of remedy he/she prefers (namely "lost profits," "infringer's profits" (unjust enrichment), and "reasonable royalty rates"). The real problem occurs, however, as the courts' interpretation of these damage awards regulations in some cases renders "being infringed" a more profitable option than *ex ante* negotiation between the patent holder and the potential infringer—eventually opening the floodgates for the "troll business".

In more detail, in this paper we pick up on the "patent shark" phenomenon and examine it from a theoretical perspective, encompassing legal, managerial, and economic aspects. To understand this phenomenon, we take a game-theoretical approach to modeling the behavior of trolls and their victims. Here, we primarily sketch the decisions sharks may expect both their prey and courts to make within a complex technological and legal world, and focus less on the activities of the sharks themselves. This paper is dedicated to analyzing:

(a) which (managerial) incentives exist for firms to be infringed, and how legal rules governing damage award calculations affect these incentives,
(b) why the economic importance of the phenomenon of being infringed (i.e. acting as a shark) has probably increased over time,
(c) which actions appear appropriate to be taken by firms that are (potentially) threatened by sharks, as well as
(d) which discussions are required from a policy perspective in the light of the current business practice.

In line with the aforementioned questions, the paper's four-fold thrust is as follows:

(a) small firms, and in particular non-producing firms, have incentives to be infringed as they may be awarded remedies by the courts that are systematically higher than they could have obtained in

and the English High Court, early 2006, declared the disputed patent invalid (http://www.theregister.co.uk, 30 January 2006, http://www.reghardware.co.uk, 02 February 2006). While the decision in Germany is not yet final, the rulings confirm the general observation that troll patents are often of low quality. More prominent still is the legal battle between RIM and NTP, which was at times even threatening to shut down RIM's operations in the U.S. and issued a settlement for US$ 612.5 in March 2006 (news.com.com/2061-10801_3-6045871.html). Yet another example is Forgent Networks Inc., which has been suing various large companies for the alleged infringement of a patent (US patent No. 4,689,672) that, Forgent claims, covers parts of the JPEG image compression standard (http://www.eweek.com, 22 April 2004). By April 2005, Forgent had received more than US$ 100 million in licensing fees from 35 companies, and is suing 44 companies for infringement (http://www.theregister.co.uk. 25 April 2005). The patent had been granted in 1987 and had not been used for years, until Forgent started asserting it in 2002.

[7] The court cases brought by InPro against RIM (mentioned in the preceding footnote) took place in Germany and Britain, respectively. Another prominent example of a troll-like firm is Germany-based Teles AG. Since 2002, Teles has sued at least 10 firms in German courts for infringement of patents related to communication technology, among them Cisco, Nokia, and Deutsche Telekom (http://www.teles.de). In addition, interviews conducted by the authors suggest that the European troll cases reported in the press may only be the tip of the iceberg, since firms attacked by trolls often prefer to settle the dispute in a discreet manner.

licensing agreements with large patent holders before infringement;
(b) increasing complexity of some technology fields, the increasing number of patents worldwide, and the resulting difficulty in monitoring the existing state-of-the-art technology, as well as the increasing firm sizes of large patent holding and manufacturing corporations should – in accordance with observations from the real world – lead to an increase in the importance of the "shark business";
(c) large patent-holding and manufacturing firms are well-advised to spend extensive resources on ensuring access rights to technological substitutes of their core inventions as well as complementary technological assets, to allocate more money to technology monitoring, and to lobby for legislative changes;
(d) courts need to reflect upon their interpretation of existing legal regulations and work towards a truly welfare-maximizing patent indemnification rule.

The remainder of the paper is structured as follows: Section 2 provides the basis for understanding why innovators can create a profitable business from having their patents systematically infringed. We present a synopsis of international patent indemnification regulations and show how they should appear in the strategic rationales for different types of innovating firms. Section 3 picks up the issue in a formalized fashion and presents a formal theoretical model of technology choice and patent infringement. Here, we juxtapose outcomes in patent litigation cases according to existing indemnification regulations with alternative outcomes from realistic *ex ante* technology sales or licensing negotiations (avoiding infringement). We can show that hiding patent-protected technology to be infringed emerges as a dominant strategy for low-tech capacity-constrained innovators ("trolls"). Section 4 discusses the results from both a managerial and a policy perspective, and Section 5 concludes and provides an outlook on future research.

2. Theoretical considerations—institutional frame and managerial rationales

In this section we will elaborate on the theoretical legal and managerial considerations required to explain the existence of the "troll business" through our model in Section 3. To start with, we define the term "patent shark" or "patent troll" in more detail. We denote patent sharks or trolls as individuals or firms that seek to generate profits mainly or exclusively from licensing or selling their (often simplistic) patented technology to a manufacturing firm that, at the point in time when fees are claimed, already infringes on the shark's patent and is therefore under particular pressure to reach an agreement with the shark.[8]

In order to illustrate the prerequisites for being infringed becoming a profitable and legitimate strategy (see next section), this section is split into two parts. The first part contains a summary of the necessary legal information regarding international[9] patent indemnification rules in order to understand the damage award threat points that the law sets down for potential infringers. Eventually, as we will show, these threat points affect the choice to become a shark or not. We provide both a picture of the current legal regulations (Section 2.1.1) and a brief sketch of the most important changes that are underway (Section 2.1.2).

In the second part, we will show how these indemnification rules come to bear on strategic decision making. Here, we will distinguish between two distinctly different types of firms, using the capacity to manufacture the technological goods under consideration as the differentiating trait. Namely, these are (a) large firms with the capacity to supply the entire market with their technological goods, and (b) small firms lacking production capacity altogether. The stage set in this section will form the basis for the formal analysis in Section 3. Here, we will map the legal regulations and the managerial rationales, showing in particular how the indemnification rules create incentives for being infringed.

2.1. Patent infringement indemnification

2.1.1. A brief sketch of existing regulations

There are two types of complementary remedies against patent infringement: injunctive relief and damages. When a court grants injunctive relief, this (typically) means that it orders the infringer to refrain from producing and/or selling the infringing goods (see, e.g., Lanjouw and Lerner, 2001, on the managerial implications).[10] As for damages, most jurisdictions pro-

[8] To the best of our knowledge this definition should, for the most part, be in concordance with the attempts to define "patent trolls" during the House of Representative Subcommittee Hearings "Patent Trolls: Fact or Fiction" on 15 June 2006 (see above). See for example Mr. Edward Reines' definition on page 8 of the Hearing's report (serial nos. 109–104).

[9] In order to show the universal dimension of the problem, we will summarize the relevant jurisdictions of five of the major industrial nations worldwide. Moreover, we include the Netherlands in our survey, since Dutch courts have traditionally played an important role in the cross-border patent litigation jurisdiction.

[10] Often injunctive relief is considered to be the more important remedy from the perspective of the infringer as it creates immediate and

vide for at least two and sometimes up to three "standard methods" for indemnification assessment. Namely, these refer to the calculation of (a) lost profits, (b) an ordinary licensing fee (reasonable royalty), and (c) infringers' profits (unjust enrichment). In the following, we briefly present the biggest "generic" international denominator for each of these damage award rules (for a more detailed elaboration on the international differences see Heath et al., 2005).

2.1.1.1. Lost profits. Here, the patentee shall be reinstated in a position where he/she would have been but for the infringement, with the restriction that only losses from the patentee's own production are taken into account, *not*, e.g., from licensing. Note that this restriction marks an important discrepancy between the economic and the dogmatic (legal) notion of lost profits (see below for more details). The calculation method is accepted by all major jurisdictions (US: 35 USC Section 284; Japan: Section 102(1) Patent Act; Germany: Section 139 Patent Act; UK: Section 59 Patents Act; France: Art. L615-l(2) Intellectual Property Code). The leading US case required the patentee to show the following:[11]

(1) demand for the patented product (as indicated by past sales);
(2) absence of competing and non-infringing products (see below);
(3) ability of the patent owner to actually market the quantity of goods[12] for which lost profits are claimed[13];
(4) the amount of profit that would have been made in the absence of infringement.[14]

Where competing and non-infringing products are on the market, element (2) above requires a so-called market share analysis and an award based on a pro rata percentage of the infringer's sales.[15] Lost profits cannot be awarded where the infringing products do not qualify as a substitute for the ones of the patentee.[16]

2.1.1.2. Ordinary licensing fee. The most common form of claiming damages is the ordinary licensing fee (or "reasonable royalty") for three reasons. First, it is the form of indemnification where plaintiff and defendant can bilaterally agree on the size of the reward. Second, in contrast to the case where the plaintiff files for lost profits or infringer's profits, relatively little effort has to be expended by the rights-owner to prove his case. Finally, many patent owners do not wish to lay open their internal cost structures (which they would have to when filing for lost profits, but not in the case of an ordinary license fee).

It is standard practice to calculate a reasonable royalty "on the basis of what royalty a willing licensee would have been prepared to pay and a willing licensor to accept."[17] Two aspects appear particularly noteworthy. Despite its theoretical *ex ante* focus on what the patentee and the infringer would have agreed upon before infringement, the rule is interpreted with *ex post* knowledge and typically simplified in its application.[18] In the case of an innocent infringer, this means that his hypothetical non-infringing options in the case of complete information (e.g., inventing around) will not be taken into consideration. On the other hand, a deliberate infringer will not be made worse off than an ordinary licensee by this type of indemnification; as a matter of fact, sometimes the deliberate infringement might be more profitable than *ex ante* licensing: until about 1998, it was standard practice in Japan to use royalty rates calculated

significant 'losses' for them. Hence, the literature in the field focused on injunctions for a long time. The U.S. Supreme Court's recent decision in eBay Inc. v. MercExchange, L.L.C., however, has tilted the balance towards damages. The Court unanimously determined that the finding of patent infringement should not automatically imply the issuance of an injunction (http://www.supremecourtus.gov/opinions/05pdf/05-130.pdf). This case is in line with the envisaged changes to U.S. patent law. We thank one of our referees for sharing this thought with us.

[11] Panduit Corp. v. Stahlin Brothers Fiberworks. April 25, 1978, 575 F.2d 1152 (6th Circuit 1978).

[12] The *existing* law generally accepts that in the absence of marketing capacity, the patentee cannot claim lost profits due to a lack of causality.

[13] A requirement that is also specifically mentioned in Section 102(1) Japanese Patent Act and that has been applied in the UK decision Catnic Components v. Hill & Smith [2]. English High Court. 16 March 1983 [1983] F.S.R. 512. The German courts also require demand for the product and actual production capacity: German Federal Supreme Court, 10 July 1979, GRUR 1979, 869–872.

[14] Only Japanese (and Korean) patent law differs in this respect: Section 102(1) Japanese Patent Act allows the patentee to calculate his damages by multiplying the number of infringing products sold by the infringer by the profit the patentee would ordinarily realize when selling his own products. Such a calculation method has been explicitly rejected by the UK decision Gerber Garment Technology v. Lectra Systems. Patents Court, 20 March 1995 [1995] R.P.C. 383, and the German decision, Federal Supreme Court, 6 March 1980, GRUR 1980, 844—"Tolbudamid": "Uncertainty that one does not know if the defendant would have been able to achieve the same turnover in infringing products at higher prices."

[15] For example, US decision State Industries Inc. v. More-Flo Industries Inc., 883 F.2d 1573 (Fed. Cir. 1989); UK decision Catnic Components v. Hill & Smith [2]. English High Court, 16 March 1983, [1983] F.S.R. 512.

[16] US decision Bic Leisure Products v. Windsurfing International, 4 August 1993, lF.3d 1214 (Fed. Cir. 1993).

[17] UK decision Catnic Components v. Hill & Smith (see Footnote 13).

[18] Casucci (2000, 692/702).

by across-the-board industrial averages of royalty rates between Japanese companies for domestic patents.[19] This changed once the word "ordinary" was deleted from the wording of Section 102(2) Japanese Patent Act.

2.1.1.3. Infringers' profits (unjust enrichment). Some jurisdictions allow the patentee to recover the infringer's profits as one way of calculating damages. In Japan, this remedy is limited to cases where the patentee has actually used the patent.[20] In the UK, the claim for the infringer's profits is statute based (Section 60 UK Patent Act: "account of profits"), and in Germany based on the legal fiction that in using another's patent, the infringer undertook a business on behalf of the rights-owner, who would thus be entitled to obtain all profits made from such business.[21] Both jurisdictions allow fairly generous deductions where the infringer has used his own skill, labor and expenses in the marketing of the infringing products.[22] Granting "infringers' profits" is formally not allowed in France and the US. However, whether or not the US term "unjust enrichment" reflects a remedy that essentially corresponds to the notion of infringers' profits remains arguable from a dogmatic standpoint. In concordance with earlier works (see Schankerman and Scotchmer, 2001) and for the purpose of this simplified legal analysis, we subscribe to the view that unjust enrichment is a part of infringers' profits and we will hence treat the two terms synonymously for the rest of this article.

Table 1 recalls in which of the countries plaintiffs may choose among several calculation methods. Moreover it summarizes the calculation methods and how they are currently applied in some of the major patent jurisdictions.[23] In addition to showing the subtle differences between the countries, however, it also illustrates that the treatment of the different norms – namely lost profits, infringers' profits, and reasonable royalties – is, whenever applicable, internationally comparable to a large extent. This stresses the global importance of the phenomenon we analyze, which is also partly reflected in upcoming harmonization of international laws (see Section 2.2).

2.1.2. (Potential) changes underway

While Section 2.1 describes the current legal situation with respect to patent indemnification regulations in the six focal jurisdictions, we find it useful to highlight a few legislative changes that are either currently being discussed (in the U.S.) or have been passed at the supranational (European) level and now await conversion into national law. We focus only on a very few selected aspects, as a complete synopsis would be beyond the scope of this paper.

In the context of the US patent reform, the following amendments are currently under consideration. First, particularly with respect to the surge of patent trolls, a claim for treble damages in the case of willful infringement shall be limited to cases where the infringer has been furnished with a direct allegation of infringement.[24] Second, in order to allow competitors to switch to non-infringing alternatives in a timely fashion, it has been suggested that publication of all US patent applications after 18 months, no matter whether the filing of related applications abroad is intended or not, should be a requirement.[25]

In Europe, the "Directive 2004/48/EC of the European Parliament and of the Council on the enforcement of intellectual property rights" was passed on 29 April 2004. Among others, it foresees the harmonization of patent indemnification laws in the member countries of the European Union in that the three generic damage award calculations (see above) shall be applicable in all member states. In theory, the directive will also allow courts to apply the different damage award calculations (e.g. lost profits and ordinary licensing fees) simultaneously in one case in order to assess "realistic" damages. While passed in 2004 and required to be implemented by 31 May 2006 into national law, the directive is still to unfold its relevance in the future, as most member states have not yet implemented it.

[19] Such statistical averages were taken from Hatsumei Kyokai (Ed.), Jisshi ryôritsu (Use and Compensation) (Tokyo, 1980); Hatsumei Kyokai (Ed.), Gijutsu torihiki to royalty (Technology Transfer and Royalties) (Tokyo, 1992).

[20] Osaka District Court, 27 March 1980.

[21] For example, German Imperial Supreme Court, 22 October 1930, RGZ 130, 108.

[22] For the UK, Gerber v. Lectra (see Footnote 4); for Germany, Dusseldorf District Court, 25 July 1996, 4 O 217/95—"Winkelprofil III." However, according to the German Federal Supreme Court, the infringer cannot deduct costs that relate to general management expenses: German Federal Supreme Court, 2 November 2000, GRUR 2001, 329—"Gemeinkostenanteil."

[23] More detailed information on the individual country legislation can be found in the following references. Maloney (2000) for the US, Heath (2000) for Japan, Marshall (2000) for Germany, Cornish and Llewelyn (2000) for the UK, Petit (2000) for France, and Brinkhof (2000) for the Netherlands.

[24] See "Patent Trolls: Fact or Fiction", Hearing before the Subcommittee on Courts, the Internet, and Intellectual Property of the Committee of the Judiciary, House of Representatives One Hundred Ninth Congress, 15 June 2006, serial no. 109–105, p. 9.

[25] Ibid, pp. 10–11.

Table 1
Indemnification regulations within and across countries—an international comparison

	Lost profits	Licensing fee	Infringer's profits	Choice for plaintiff
U.S.	35 USC Section 284. Requirements: (1) demand; (2) marketing capacity; (3) absence of competition, non-infringing substitutes	Fall-back provision where lost profits cannot be or are not claimed	No	Yes
Japan	Section 102(1) Patent Act: multiplication of infringer's turnover with profits the patentee would have made for such a number of products. Marketing capacity of patentee must be proven	Section 102(3) Patent Act: fall-back provision; estimate of royalty rate	Section 102(2) Patent Act. Not applicable where patent was not used by patentee	Yes
Germany	Section 249 Civil Code: restitution of the *status quo ante*. Limitation by production capacity and proof that infringing product could act as a substitute	Most common form of calculation, normally agreed upon in court settlement. No "infringer's surcharge" can be claimed except for copyright matter (double royalty)	Based on the legal fiction that infringer undertakes a business allocated to the patentee. Deduction of infringer's expenses. Infringer's marketing efforts taken into account	Yes: claim for inspection of infringer's accounts allowed prior to choice of calculation base
UK	Yes, likelihood of having made the infringer's sales, deduction of infringer's efforts to commercialize	Yes, a notional royalty as the minimum of lost profits	Yes, but rarely requested	Yes, after review of the defendant's commercial documents
France	Only if patent is used; calculated by amount of counterfeit products, loss of turnover (determined *inter alia* by the quality of the patent) and amount of lost profits. Market share of patentee considered	Where the invention is not used. Infringer's turnover multiplied by an appropriate royalty rate	No, clarified in Patent Act 1968	If patent is actually used: Yes
The Netherlands	Same as Germany. Section 42(2) Patent Act 1910, Section 70(3) Patent Act 1995	Regarded as the minimum that can be claimed as lost profits	Section 43(3) Patent Act 1910; Section 70(4) Patent Act 1995: the infringer should not be allowed to keep his profits	Yes, after inspection of documents

2.2. The managerial perspective—innovation exploitation strategies as a function of production capacity and other factors

In order to convey the central thought of our paper clearly we need to describe the situation that we analyze in more detail. In doing so, we are setting the stage for the formal model (Section 3), which will pick up the central characteristics of our scenario.

One central assumption for the rest of the paper is that the technological goods are complex (see Merges and Nelson, 1990; Kash and Kingston, 2001); in other words there are various patentable inventions in one product. This assumption is fulfilled rather well (Cohen et al., 2000; Reitzig, 2004) in industries such as software, telecommunications, and consumer electronics—for which our analysis probably shows more relevance than for other industries (such as chemicals or textiles). In this situation, the different patentable inventions entering the product are technological complements. For the sake of clarity we assume that one or a few inventions of a product can be considered "core" inventions, which resulted from technologically sophisticated research and are difficult to substitute. The design of a product is centered on them and not on their complements (which may be acquired or created in-house). In line with the aforementioned thoughts we assume that the difficulty of (legally) inventing around a patent decreases with

decreasing technological sophistication of the patent (Gallini, 1992). Additionally, we assume that all firms are somewhat constrained (see also below) in their monitoring resources for existing technology. Moreover, we presume that decision makers act rationally to the extent that they have the necessary information at their disposal.

One of the major determinants in the choice of an innovation exploitation strategy is production capacity. To illustrate the importance of this determinant, we pick out the following two stylized extremes along the capacity spectrum and show the different innovation exploitation rationales for these firms in our setting.

2.2.1. Production capacity-unconstrained innovative firms

At one end of this continuum we consider R&D intensive and production capacity-unconstrained firms, i.e. firms that enjoy the (theoretical) possibility to fully saturate the market under consideration with goods from their own production. Unless such a firm's costs of production clearly exceed those of a competitor that is capacity-unconstrained as well,[26] our focal firm will be likely to pursue a strategy in which it seeks to exploit its innovations by selling self-produced goods (consistent with the fundamentals of the resource based view of the firm). To do so, the firm needs to ensure access to the core technologies of the product as well as the complementary ones required to produce it. Following Teece's (1986) logic, to pursue this type of exploitation strategy the firm needs to dedicate extensive resources to the development of the "core" components (that are probably not for sale and for which technological alternatives cannot easily be developed).

The rational management of such a firm will incorporate considerations regarding both *passive* and *active* (though possibly inadvertent) patent infringement in its rationale. Depending on the set of applicable legal regulations in a particular case of *passive* infringement (i.e. the focal firm's patent is illegitimately used by a third party), the firm's management may pick the type of remedy that suits the firm best—that is, the one yielding the highest payoff. Moreover, the firm will try to incorporate the chance of *actively* infringing a third party. Assessing the importance of this eventuality, however, will be far more difficult for the focal firm, at least if the infringement is inadvertent (i.e. the firm has no intent to infringe). This is for two reasons. First, the payable amount to the (infringed) patent holder will depend on this third patent holder's own innovation exploitation strategy, which is in turn affected by the options the law provides. Second, however, the *pure chance* for the focal firm to actively infringe a third party is also determined by the innovation exploitation strategy pursued by the third party as will become clearer in the following.

2.2.2. Production capacity-constrained patent holders

At the other end of the capacity continuum we consider patent holders (small firms or individual inventors) who do not possess any capacity of their own to produce technological goods, and may also lack other complementary assets (in particular, complementing technologies). These firms will differ from each other with respect to the technological sophistication of their inventions.

Among production capacity-constrained innovators that are truly innovative (i.e., ones that generate potential core inventions), the two most important types are dedicated R&D firms and high-tech (university) start-ups (see Lowe and Ziedonis, 2006; Mowery et al., 2001). Dedicated R&D firms that engage in repeated sales and licensing negotiations with manufacturers will likely invent high quality components (both core and complementary components) that are of real value to the purchasing or in-licensing firms.[27] Next to these specialized R&D/IP vendors, high-technology (university) start-ups will generate sophisticated R&D of a kind that may become a "core" component of a product, even though they are unlikely to engage in repeated interaction with a manufacturer. Both of the aforementioned firm types seek to sell their intellectual property to firms that do have access to production capacity,[28] and both will consider active and passive patent infringement in their innovation rationales. However, in contrast to the capacity-unconstrained innovators, passive infringement is likely to be a greater managerial concern than active infringement. Active infringement plays an insignificant role for IP vendors and high-tech start-ups since neither intends to produce a product by itself. On the other hand, the firms' profit maximizing rationales require

[26] Note: strictly speaking it does not have to be only one competitor who is capacity-unconstrained; it could also be a group of individually capacity-constrained competitors operating at (overall) lower costs of production. Transaction costs and economies of scale render this very unlikely, however.

[27] An example is the UK-based IP vendor ARM, which sells designs for semiconductors.

[28] The biotechnology sector provides a wide series of examples. The business plans of so-called dedicated biotechnology firms (DBFs) build on the intent to be taken over by a large manufacturing pharmaceutical producer.

safeguarding their inventions against manufacturers who could – if there were no legal remedies – oust their "innovative suppliers". Again depending on the set of applicable legal regulations, in a case of passive infringement the specialized IP vendors and the high-tech start-ups will be able to pick the remedy that maximizes their individual profits. As will become clearer during our discussion, the incentives that patent indemnification rules create for these firms do not render being infringed a dominant strategy.

Finally, however, there also exist firms holding patents to minor technological solutions that can serve as technological complements to a core invention. These patents may result from the firms' own (technically unsophisticated) research, or may have been bought (for details see Section 4.3). Some of them concentrate their "R&D" efforts on particular minor complementary technological components to a core invention held by a manufacturing firm. Oftentimes, the technological subtlety of these firms' inventions is considered marginal and they could easily be substituted by alternative technological solutions so that *ex ante* licensing negotiations with manufacturers will most likely lead to negligible profits for these innovators. Their activities can only be understood when incorporating the passive infringement rationale into their strategy. As a matter of fact, these firms hope to be infringed and do everything they can to keep their patent-protected technology as invisible as possible until it is illegitimately used by a manufacturer. Such unpleasant surprises for the manufacturer can occur for three reasons: the patent was a "submarine",[29] the manufacturer expected that the patent would never be used in litigation against him/her, or the patent slipped the manufacturer's attention despite monitoring. While submarine patents are restricted to the U.S., both other reasons are relevant globally (we will elaborate on these issues in Section 4.2).

As the following model and discussion will show, these firms can generate enormous profits from betting on being infringed. They are the "sharks"—and it is both the patent law and its interpretation by the courts that forms their basis of existence.

3. Infringement rules and market characteristics—a model

In order to illustrate the fundamental mechanisms that lead to the existence of the "shark" business we develop a simple microeconomic model. Despite its simplicity it captures most of the parameters describing the managerial perspective delineated in Section 2.2, particularly technology monitoring efforts, invent around costs, and institutional legal details regarding indemnification calculations.[30] To focus on the main mechanisms of the shark business and to keep the model tractable and transparent, some of the relevant variables (e.g. product complexity) are not explicitly parameterized and some simplifying assumptions are introduced.[31] As Section 4 will show, however, the effects of these non-parameterized variables can be discussed verbally.

3.1. Sharks' rationales and actions

In order to study a fully-fledged "game" between sharks and their prey we would need to model the (strategic) rationales of both players as well as the reaction connectivity of their actions. In the following, we take a short-cut in order to concentrate on the core of this paper's contribution (the systematic effects that render the shark business profitable). We therefore assume that a small capacity-constrained patent holder of a non-

[29] So-called "submarine patents" are possible due to the policy of the USPTO to disclose patent applications only at the time when the patent is granted. This policy was generally in force until 1999, and since then has been restricted to cases in which the applicant states that no patent application for the same subject matter "has been or will be made outside the United States" (US Patents Act, Section 122 (2) (B) (i)). So, even in 2006, trolls – if they target the US market exclusively – can effectively hide their patent from potential infringers for a long time. We thank one of our referees for sharing this thought with us. A closely related practice is the filing of "continuation patents" (Graham, 2004), which is also restricted to the US. Continuations share the priority date of the parent application, but may be submitted any time before the parent application and all related (earlier) continuations are decided upon. Thus, also continuations may serve trolls in hiding their patents for long periods of time.

[30] We know of no other theoretical contribution parameterizing all of these variables in order to better understand the mechanisms that drive patent infringement. The paper that comes closest to our approach is by Bessen and Meurer (in press). In their article, the authors include two of the aforementioned parameters as variables in a model of endogenous patent dispute resolution; namely, these are invent-around and technology monitoring. While we share the perceived importance of including these two variables in the theory of patent infringement with Bessen and Meurer (in press), the goals, foci and results of the two papers differ substantially. This is not least because the introduction of damage award calculation details is necessary to understand the profitability of the shark business.

[31] For example, we do not model the uncertainty potential infringers face when assessing whether they actually illegitimately use a third parties' technology or not once they have discovered it (see Bessen and Meurer, in press, for an elaboration of this idea). We will critically reflect on the impact of these assumptions during our discussion and in the conclusions.

sophisticated technology has no options but to either approach a manufacturer before infringement (in order to license out his/her technology), or, conversely, to press the manufacturer for royalties after infringement (i.e. act like a shark). We neglect the possibility that the small firm, before patenting, may have the additional option of picking the technological area where it wants to make its investment; nor do we consider the possibility that the small patent holder may lose its infringement case in court (see Bessen and Meurer, in press, for an elaboration of this aspect). We assume, however, that the small patent holder can anticipate his/her prey's actions quite accurately. Being a shark will consequently be his/her dominant strategy if profits from being infringed exceed the profits from offering the technology to a manufacturer before infringement.

3.2. Manufacturers' rationales and actions

A company M ("manufacturer") is considering entering a certain market. Producing the respective good requires solving a technical problem, to which technology T is the most obvious, but not the only solution. As part of its new product development process, M puts some effort into checking if T is patented. Depending on the result of this monitoring, its prior beliefs about the likelihood of T being patented, cost factors, and sales expectations, M decides whether to enter the market or not, and if so, with what technology. If T really has been patented by a firm PH ("patent holder"), this firm could negotiate a license with M, or it could sue M for infringement if T was used illegitimately. We assume that PH has no production capacity of its own. This setup corresponds to Section 2.2.2, with M having a (potentially large) manufacturing capacity and PH having none.

In more detail, the manufacturer's logic is described by the decision tree depicted in Fig. 1 (which the shark can anticipate). From the perspective of the "innocent" manufacturer it is *nature* that, in Stage 1, decides whether technology T is patented (probability p_p) or not.[32] M's prior belief is that T is patented with probability p_{pM}, which will in general be different from p_p. In Stage 2, M decides how much effort x (measured in monetary units) to put into checking whether T is patented. In Stage 3, nature decides if – in the case that T *is* patented – M finds out about this fact. This discovery takes place with probability $p_{find}(x) = 1 - e^{-ax}$, where a is a constant parameter.[33] M is aware of this probability. Depending on the outcome of its patent search, M performs Bayesian updating to adapt its beliefs about the patent protection of T, to either 1 (if a patent has been found) or to $p'_{pM}(x) = p_{pM}\, e^{-ax}/(p_{pM}\, e^{-ax} + 1 - p_{pM})$ (if no patent has been found). The latter term thus gives the perceived probability of patent protection conditioned on negative results after incurring the search cost x.

Stage 4 is only relevant if a patent exists and M has found out about it. In this case, M and the patent holder PH negotiate whether to stipulate a licensing contract and at what fee. In all other cases, no action is taken at this stage. Finally, in Stage 5 M decides whether to enter the market, and with what technology. We assume that M has the option of substituting T with an alternative technology T_{ia}. Compared to using T, this invent-around causes additional (fixed)-development costs of c_{ia} since, as we assumed, T is the most obvious solution to the problem. Without restriction of generality, we set the development cost of T to zero since we treat this case as our benchmark (no matter whether T is a sophisticated core technology or not, see Section 2). The height of the invent-around costs parameterizes the sophistication of the technology. For simplicity we assume, in case a patent on T has been identified and using T_{ia} instead is considered, that M can verify at a fixed cost (contained in c_{ia}), and with certainty, that T_{ia} is not patent protected. While this assumption differs from our modeling of how M checks the patent protection of T, it is a second order effect and neglecting it allows us to keep the model tractable.

We do not model market interaction, but instead simply assume that M sells Q units of the good at a price p, with variable cost c_v of production and zero fixed costs (apart from development costs).[34] If infringement occurs, we assume that it is detected with probability p_d.

In order to quantify the expected payoffs, we introduce the following further notation. LF denotes the license fee to be paid by M in case a licensing contract is closed (node A in the decision tree). The damages to be

[32] Note that this seeming exogeneity is unrealistic if we assume that sharks make dedicated investment in certain technological areas; however, also aforementioned, to start with we neglect this complication.

[33] A similar, though more general, shape of the function $p(x)$ describing the probability of success of monitoring is used by Crampes and Langinier (2002) who focus on the patent holder's monitoring effort.

[34] Instead, we could introduce a fully blown market interaction stage. In this stage, M would either sell as a monopolist to a set of buyers defined by a demand curve or M would compete with one or more other firms. However, what is relevant to our analysis is solely the outcome of the market stage in terms of price P and quantity Q, since the patent holder does not appear in the market interaction. Thus, modeling this stage explicitly would only burden our model and distract from the actual issue.

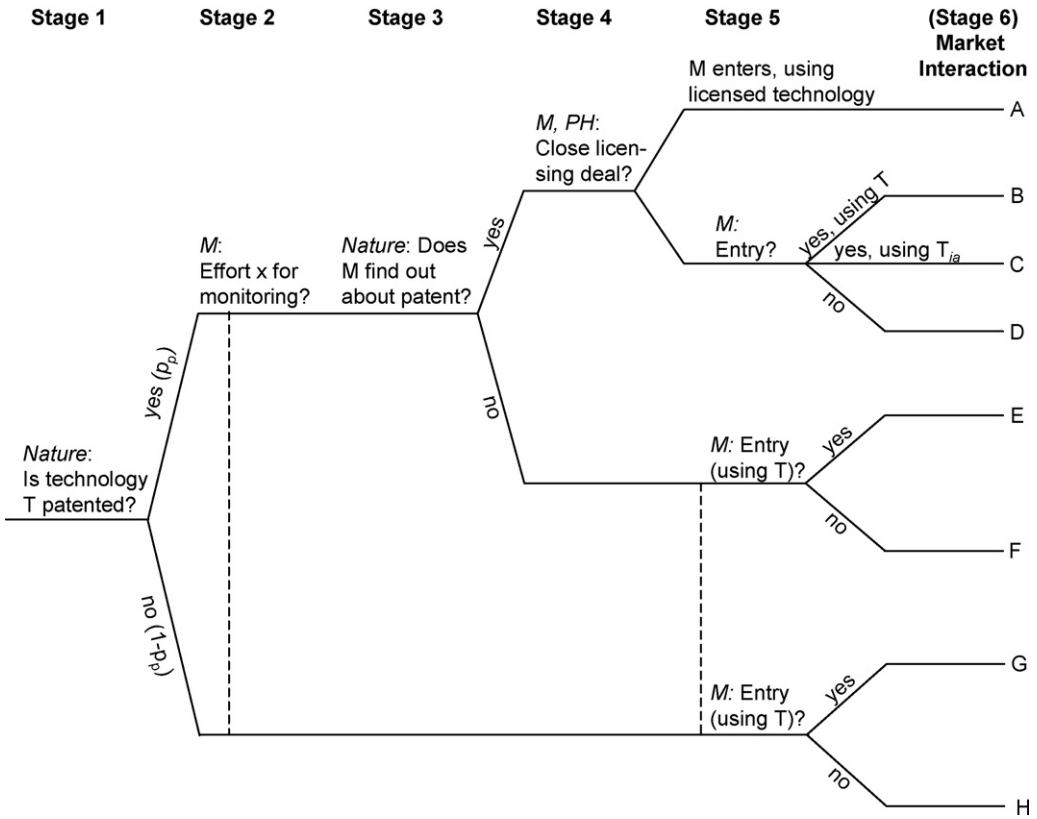

Fig. 1. Excerpt of the "game" between shark and manufacturer. The tree shows the decision-making rationale of the manufacturer. Dashed lines indicate information sets.

paid by M in case of enjoined infringement (nodes B, E) are denoted by d. Finally, p_{dM} is the probability, as perceived by M, that infringement will be discovered. Just as M's prior belief p_{pM} about the probability of patent protection on T may differ from p_{p}, also p_{dM} may differ from the "true" value p_{d} Denoting by $\Pi_0 \equiv Q(p - c_{\mathrm{v}})$ the gross profit (excluding all costs except variable costs of production) M makes on the market (Stage 6 of the tree), we obtain the following equation for M's expected net profit Π, conditioned on the search effort x (see Appendix A for more details):

$$\begin{aligned} E[\Pi\,|x] = {} & p_{\mathrm{pM}}(1 - \mathrm{e}^{-ax}) \\ & \times \max\{\Pi_0 - \mathrm{LF}, \Pi_0 - d, \Pi_0 - c_{\mathrm{ia}}, 0\} \\ & + (1 - p_{\mathrm{pM}}(1 - \mathrm{e}^{-ax})) \\ & \times \max\{p'_{\mathrm{pM}}(p_{\mathrm{dM}}(\Pi_0 - d) + (1 - p_{\mathrm{dM}})\Pi_0) \\ & + (1 - p'_{\mathrm{pM}})\Pi_0, 0\} - x \end{aligned} \tag{1}$$

From Eq. (1), one can calculate M's optimal search effort x^*, given its beliefs. We refrain from rendering this rather complex expression. Still, the formal presentation shows two main aspects.

First, M might underestimate the probability of existing patent protection ($p_{\mathrm{pM}} < p_{\mathrm{p}}$) as well as that of infringement being discovered ($p_{\mathrm{dM}} < p_{\mathrm{d}}$), leading to a suboptimal (too low) level of monitoring.[35]

Second, and most importantly: the cost of inventing around the patented technology becomes relevant as a threat point in various *ex ante* licensing negotiation scenarios. As Eq. (1) shows, in a real *ex ante* (i.e. before infringement) licensing negotiation, M will at most be willing to pay d or c_{ia} as a royalty to PH, depending on which of the two figures is smaller. Fig. 2 illustrates this consideration showing three different profit curves for M in each of the figures (a) and (b).

Gross profit Π_0 as a function of quantity sold, Q, is shown as the top line in both Fig. 2a and b. For illustration purposes, we set the contribution margin $(p - c_{\mathrm{v}})/p$ to 5%. That is, the curve Π_0 equals 5% of revenues. Parallel to the top lines in Fig. 2a and b run the curves $\Pi_0 - c_{\mathrm{ia}}$, in both figures, which become relevant to M

[35] Note that we arrive at this result without even assuming that the shark strategically patents in the technological domain of the manufacturer. The effect may be even stronger if we relax this latter assumption.

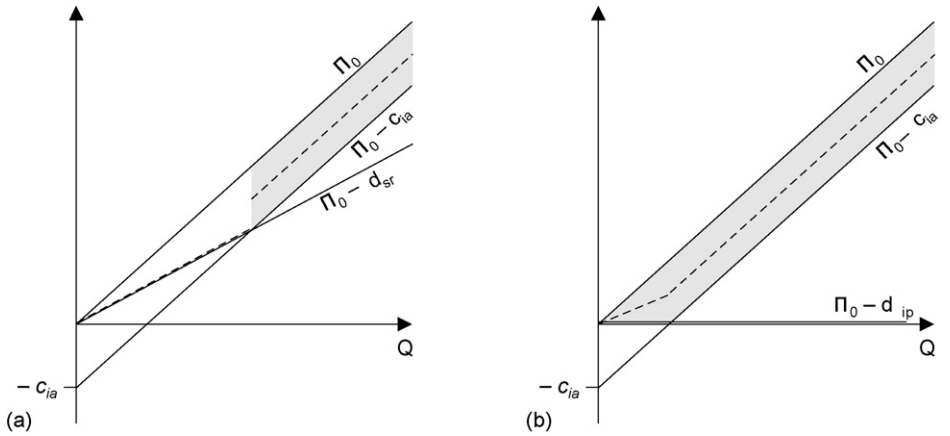

Fig. 2. Payoffs of M as a function of output quantities, for different scenarios (excluding monitoring cost x). Shaded areas and broken lines indicate possible outcomes of *ex ante* licensing negotiations.

in case it has discovered the patent on T and decides to use the non-infringing technology T_{ia} instead (node C). Finally, M's profit curves for the case of enjoined infringement ($\Pi_0 - d$) are shown for different damage calculation rules: Fig. 2a shows the case of "infringer's profits" ($\Pi_0 - d_{ip}$), in which, by definition, M's net profit equals zero. Fig. 2b, in contrast, depicts the case of a "reasonable royalty" ($\Pi_0 - d_{sr}$), where we assume that the court applies a standard royalty rate of 2% of sales. Despite their general importance as the third possible indemnification (see Section 2.1), "lost profits" do not require separate treatment in our model and hence no separate illustration, since they refer to the shark's "own production" (see Section 2.1), which is set to 0 by definition.

The implications of our model findings are discussed in the following.

4. Results and discussion

We now employ the model developed above to discuss the main questions of our article, namely why patent sharks exist, why the shark business is seemingly growing, which countermeasures manufacturers can take, and, finally, which policy debates appear relevant. Wherever relevant, we will briefly elaborate on the importance of the findings for particular jurisdictions using our overview presented in Table 1.

4.1. Patent sharks—maximizing profits from suing inadvertent infringers

In the middle branch of our tree (nodes E and F in Fig. 1) the potential infringer is not aware of the patent on technology T held by firm 1 (we briefly commented on the possible reasons for his/her surprise in Section 2.2.2 and elaborate on this rationale in Section 4.2). If, as we assume, T is the cheapest and most obvious solution to the technical problem at hand, then the likelihood of firm M inadvertently infringing T rather than unconsciously inventing around the patent is high (that is, firm M is likely to end up in node E). As we will show, existing patent indemnification remedies induce incentives for the patentee PH to trap manufacturers in such situations (node E) and act as trolls. In more detail we argue that courts' unwillingness to consider hypothetical invent-around costs as a benchmark for the size of damage awards in tort cases is the key to the success of PH's strategy.

To better understand this rationale, we need to juxtapose the outcome of realistic *ex ante* licensing negotiations between M and PH with the fictitious *ex post* treatment of inadvertent infringement cases in court. We commence by linking back to our model and describing profit-maximizing rationales for manufacturers in situations of complete information about patented technology.

In the scenario where M has discovered that technology T is patent protected and M enters into licensing negotiations with the patent holder PH, the outcome of the bargaining process depends on both players' threat points. For the purpose of our paper, two major scenarios must be distinguished: either that inventing around the patent is a feasible alternative to paying damages/licensing, or that it is not.

When inventing around the patent is more attractive for M than paying the (anticipated) damages d, then M is willing to pay a royalty of at most c_{ia} to PH, while

PH demands a licensing fee that is at the very least positive. PH cannot credibly threaten to leave the negotiation table since, in this case, M would enter the market using a non-infringing technology. Hence, depending on the two parties' respective negotiation power any licensing fee between zero and c_{ia} is possible, as shown by the shaded areas in Fig. 2a and b. The dashed lines within the shaded areas indicate the Nash bargaining solution, which divides the surplus equally between the players.

For those cases in which inventing around the patent is not an option, outcomes differ between the two indemnification regimes as depicted in Fig. 2a and b. When a standard royalty rate is applied (Fig. 2a), then player PH *can* credibly threaten to terminate the negotiations, since in this case M would still enter the market using the infringing technology. Hence, the licensing fee will be equal to the anticipated damages, d_{sr} (the "classical" equilibrium outcome as assumed in most prior literature, see Schankerman and Scotchmer, 2001). In contrast, when damages equal infringers' profits (Fig. 2b), then the threat to stop negotiating is again not credible, since in this case M would not enter the market (yielding a profit of zero for PH). Hence, as in the case above, all outcomes between the two threat points (zero, Π_0) are possible, depending on the players' negotiation power.

Interestingly, however, the following insight holds irrespective of the relevant indemnification rule and the distribution of bargaining power between the different players: above a certain threshold quantity of sold goods, M's profits in the case of successful *ex ante* licensing negotiations theoretically exceed his/her (counterfactual) profits in case of conviction of patent infringement. Moreover, this difference increases with M's output quantity. Also, it will be the more pronounced the lower the cost c_{ia} of inventing around, in other words, the more obvious the troll's technology.

Sharks can come into existence because the law, at least currently, refuses to accept this fundamental logic as delineated in the last paragraph. In the case of infringement, no matter whether inadvertent (middle branch of our tree) or wilful (upper part of the tree), the patentee enjoys the freedom to pick the remedy that maximizes his/her profits. Depending on the jurisdiction of concern (see Table 1) the patentee will be able to claim the full infringers' profits, which might far exceed the realistic royalty fee. But even if the law "only" offers a reasonable royalty fee as compensation for the infringement, "being infringed" may be far more profitable than entering real licensing negotiations *ex ante.* This is due to the problem that courts refuse to assess counterfactual invent-around costs during the trial—leading to a distorted calculation of the "reasonable royalty rate" that may again exceed a realistic *ex ante* licensing fee by far. Take the following case as an example and concentrate on the damage award figures (rather than the well-known "submarine" tactics).

In 1990, individual inventor Jerome H. Lemelson appealed at the US District Court for the Northern District of Illinois, Eastern Division against an earlier judgment according to which Mr. Lemelson had been granted damage awards for the non-willful infringement of his patent on a coupling technology used by Mattel, Inc. in one of the corporation's toy trucks. Mr. Lemelson tried to prove that Mattel, Inc. had willfully infringed on his patent, and in accordance with US law he sought to be reimbursed with a triple licensing fee. Mr. Lemelson's idea of multiple damages at the appellate court was denied; however, the single royalty rate he was granted for the inadvertent (!) infringement by Mattel Inc. still amounted to 24,780,000 US$. The royalty rate was calculated using the standard remedy calculations for royalty rates as a standard 4.5% industry percentage of all truck toy sales of Mattel Inc. between 1971 and 1986. From an economic standpoint, this result seems very odd. As a matter of fact, if the aforementioned damage award captured the hypothetical *ex ante* bargaining process correctly, this would mean that Mattel, Inc. would have had a willingness to pay roughly 25 million US$ to Mr. Lemelson. Given the status of Lemelson as an individual inventor, his need to access complementary assets to produce a competitive toy truck himself, Mattel Inc.'s likely low costs of developing an alternative coupling mechanism, and the obvious lack of willfulness on the part of the infringer, we leave it to the reader to judge whether he/she is convinced that the actual reimbursement Mr. Lemelson received reflects an economically suitable damage award or whether the result is an outcome of a standard application of a legally accepted, but economically incommensurate, remedy calculation.

Towards the end of this section, we would like to pick up on two issues which are also nicely illustrated by the aforementioned example.

Often, cases of this kind are used as examples to illustrate the value of hiding patented technology (submarines). A closer look, however, reveals that keeping an invention secret is not a sufficient condition for trolls to run a profitable business. Hiding does increase the odds that the potential infringer will overlook the patent, which is a *necessary* condition for the troll to succeed. However, only the unrealistic treatment of fictitious *ex ante* licensing negotiations gives value to "hiding technology". Conditional on the patent not being found by the infringer, this inadequate legal treatment constitutes

a *necessary* and *sufficient* condition for the troll business to be profitable.

Moreover, at this point we briefly recall that in our model we have abstracted from the fact that a typical "troll patent" usually covers only one technology among many others contained in a complex product. However, as the example also shows, sharks do not need to worry too much about the marginality of their inventions. Lemelson's invention was only one among many others used in the product, and still led to a royalty rate of 4.5%. Thus, even under more realistic assumptions than we could model, being a "troll" emerges as the legitimate dominant strategy for small low-tech inventors. This does not mean that it is not problematic, as we will show more clearly in the following.

4.2. Why "being infringed" is a strategy of growing concern

In our eyes, the Mattel case gives reason to believe that the calculation of standard royalty rates creates incentives for small patentees to be infringed by large firms. It is true that the particular setup of the aforementioned case is US-specifie and that, in order for a similar case to happen nowadays (i.e. after the U.S. adjusted their patent disclosure policies) the plaintiff would have to forego filing for related patents outside the U.S. On balance this means that "submarine" patenting strategies, which have always been restricted to the U.S., still work in this country basically as they did before. Trolls are now only restricted in so far as they can no longer additionally file for (non-submarine) patents outside the U.S.

The increasing shark activity outside the U.S.,[36] however, illustrates that submarine patents and continuations are not to be the only source of "surprise" for large R&D manufacturers. There are two other potential reasons.

First, a published patent or patent application may have slipped the manufacturer's attention despite monitoring. Given the overall surge in patenting (see also Macdonald, 2004, p. 141; Blind et al., 2006, p. 656 ff.),[37] monitoring costs for existing patented technology have massively increased. It thus seems fair to assume that the overall risk of neglecting prior art has risen (see Lemley, 2000; Quillen and Webster, 2000 for an elaboration of this argument; these thoughts were furthermore supported by interviews that the authors conducted with several Heads of patent departments of leading R&D intensive firms). Inadvertent infringement is particularly likely if the manufacturer develops a technical component in a complex technological industry where several (patented) inventions enter the final product (see Merges and Nelson, 1990; Kash and Kingston, 2001; Ziedonis, 2004), and that particular technical component does not reflect one of the firms' core R&D products. Patents on trivial or already existing inventions are particularly hard to monitor, since the engineer intending to use them may not perceive them as patentable at all and hence may not find a patent search worthwhile. Manufacturing outside a firm's home territory or importing the aforementioned technological components increases the risk of inadvertent infringement even further.

Secondly, another potential reason for "litigation surprises" is that the manufacturer did not consider a patent *known* to him – or even all patents within a certain technology class – a threat at the time he/she started manufacturing since it was owned by a "non-litigious" patentee. Such "non-aggression" pacts may be explicit, based on cross-licensing, or implicit, based on industry culture and mutual deterrence. Troll surprise may then arise when the patent changes ownership (often due to the patentee's bankruptcy),[38] when it is licensed to a troll, or when the patent holder changes its business model from "producing" to "trolling".[39] And as a matter of fact we think therefore that, even though submarine patents may be abolished in the near future, the overall importance of the shark phenomenon increases.

Sharks' chances of running a profitable business in these industries are furthermore enhanced by the irreversibility of substituting infringing components with alternative technologies after a certain point. To manage the complexity of firm boundary spanning R&D projects, hardware and software standards have assumed major importance in these technologies. Once certain specifications of a standard are frozen, the substitution of one infringing technology with an easy-to-invent alternative entails the adjustment of such a large number of product components that inventing around (though *ex ante* cheap) becomes extremely costly *ex post* (see Bekkers et al., 2002).

[36] See our introductory cases in Footnotes 6 and 7.

[37] See the statistical bulletins of the European and the US Patent Office for impressive evidence.

[38] It appears an interesting question both for practitioners and for legal scholars if cross-licensing agreements can contain provisions granting the licensee an option to buy the patent in case of the licensor's bankruptcy. We thank an anonymous reviewer for sharing this idea with us. Such provisions would help to forearm against trolls in the case of (explicit) cross-licensing. However, all *implicit* "non-aggression pacts" would have to be made explicit lest the door for trolls remains open, entailing potentially onerous transaction costs.

[39] Prominent examples of the three types are Acacia Technologies (acquisition of patents), InPro (licensing), and Patriot Scientific Corporation (changed business model).

Our model captures the above considerations. M might underestimate the probability of existing patent protection ($p_{pM} < p_p$) as well as that of infringement being discovered ($p_{dM} < p_d$). Both assumptions seem quite realistic given that the activity of patent trolls has increased considerably in recent years. Hence, large manufacturers might not yet be accustomed to the number of "troll patents" and the degree of monitoring trolls exert. Since monitoring is one of the troll's main business activities, and since monitoring a few potential (large) infringers is both feasible and potentially most profitable for the troll, the "true" probability p_d is likely to be close to 1.

Underestimating the above probabilities implies that M chooses too low a value for its monitoring effort x^*, as Eq. (1) shows. When p_{pM} becomes smaller, then the benefits of searching for the patent – and thus, if it is found, of being able to maximize profits within the (advantageous) first line of Eq. (1) – decrease. When p_{dM} becomes smaller, then the outcome of the second line's maximization becomes more attractive, again making maximization along the first line's entries relatively less desirable. In addition, $E[\Pi|x]$ is overestimated (for any given value of x, and in particular for x^*), potentially leading to market entry decisions which should not have been taken.[40]

Finally, the creation, in 1982, of the US Court of Appeals for the Federal Circuit (CAFC) is generally seen to have strengthened the position of patent applicants and patent holders (e.g., Lerner, 1994; Lanjouw, 1994; Lanjouw and Shankerman, 1997; Kortum and Lerner, 1999). This fact is illustrated by a CAFC decision in 2002, which basically dismissed obviousness as an argument for rejecting a patent application (Hall and Harhoff, 2004). The authors quote deputy commissioner Esther Kepplinger saying this ruling means that "we cannot reject something just because it is stupid".[41] Given the focus of patent trolls on technically simple technologies, this ruling further simplifies their activity.

4.3. Potential counteractions by manufacturers

From the above discussion it appears intuitive that manufacturing firms are well-advised to prepare for shark attacks. Understanding the strategies that sharks pursue is key to designing effective counteractions.

One of the approaches that manufacturers can pursue is to increase their monitoring efforts. Being faced with a potentially increasing "infringement" business, the allocation of resources to this activity may require a timely revision. "Freedom to operate" reports need to become an even more crucial element in functional IP management, eventually co-determining the choice of a firms' entire technological trajectory.

But monitoring will always be imperfect, even if data base research is supported by exploiting social networks (see Singh, 2005; Sorenson et al., 2005) especially if the "creativity" of sharks increases. Take the following as an indication: with dedicated investment funds today starting to buy patent portfolios of bankrupt estates with the intent to pressurize potential infringers it will be ever harder for a manufacturer to foresee where the dangers eventually lurk.[42]

For these reasons R&D intensive manufacturers are well-advised to create independence from particular technological solutions. Designing technological standards and products in such a fashion that non-core elements can be substituted by a range of alternatives appears more important than ever before. Building technological solutions based on open-source standards will further reduce the likelihood of ending up in inadvertent infringement, for two reasons. First, not only the focal firm, but also other parties have an interest in searching for potentially infringed patents. Second, disclosing a development as open source immediately turns it into prior art, such that (at least in principle) no patents on the inventions contained in the development can be granted anymore.

Finally, however, large innovators may exploit one of their comparative advantages; namely, using their political influence to lobby for regulations which put an end to the business of "being infringed".[43] This option may be

[40] More details are provided in Appendix A. We do not examine the effects of uncertainty associated with the outcome of court cases and assume that patent holders will always win. Including the possibility that courts may "mistakenly" rule in favor of the infringer (see Bessen and Meurer, in press) would likely lead to downward corrections of optimal values for x.

[41] Source: David Streitfeld, "Note: This Headline is Patented" (L.A. TIMES, 07 February 2003).

[42] To understand this logic consider the following: in complex technologies (Merges and Nelson, 1990) large R&D intensive manufacturers often enter multilateral cross-licensing agreements with other players (see Hall and Ham Ziedonis (2001) for a study in the semiconductor industry). In the case of inadvertent infringement by either one of the parties, disputes will often be resolved backstage; hence, "overlooking" another player's IP is far less dangerous than that of a shark. If, however, a player goes bankrupt and sharks manage to buy this ex-player's portfolio out of the bankruptcy estate, the ex-player's initially harmless patents become a real danger for the remaining manufacturer.

[43] For example, Microsoft and other large corporations are lobbying legislation for a patent reform which was introduced in the House of Representatives in June 2005. Among other things, it proposes to "limit a patentee's access to injunctions by requiring a

a very feasible one, since, as the following Section 4.4 will show, there are various objectively good arguments to support such an initiative.

4.4. The policy side—considerations for an optimal infringement rule

Whereas "being infringed" is an interesting and profitable strategy for small innovators, it poses great problems to large R&D intensive manufactures, and potentially to society. From a policy perspective, an optimal patent indemnification rule should maximize welfare that is generated for all parties, including sharks, R&D intensive manufacturers, and consumers. Designing such an optimal indemnification rule would be beyond the scope of this paper. Nevertheless, we would like to introduce some basic considerations that will shed light on some of the deficiencies of the current regulations.

The economic purpose of the patent system is to provide incentives for innovation by allowing the patentee to control the use of the patented technology for a limited period of time. The social gains derived from these incentives and the patent system's disclosure function are weighed against the inefficiencies resulting from market power, the cost of the patent system, and the restrictions imposed on subsequent innovators.[44] The question of how to strike the optimal balance – in particular the issue of patent length and patent breadth – is complex even in a world without patent infringement.[45]

The trade-off, however, does become even more difficult in a world where infringement can take place. If we take the – plausible – short cut that the patent granting system should define how much an innovator is rewarded for his/her invention, then allowing (not prosecuting) infringement cannot be considered socially beneficial since it would distort optimally chosen innovation incentives due to the patentee's shaken trust in the system. Thus, if some kind of 'infringement' (use of the patented technology by others than the holder) was deemed overall beneficial by policy makers, then it should make sense to define the underlying patent more narrowly in the first place (thus defining an otherwise infringing act as a legitimate one).[46] Following this rationale, we can subscribe to the view that damages should at least cover the losses the innovator incurred due to infringement. That is, he/she should be put into a position "but for" the infringement.

The question then is what the patentee's damages amount to? Here, we need to distinguish two major scenarios. When joint profits of patent holder and infringer are *decreased* by the infringer's use of the technology, then the patentee's "lost profits" are unambiguously defined as the difference between its profits *without* and *with* the use of the technology by the infringer.

However, when their joint profits are *increased* through the infringement – as is the case, e.g., for research tools (Schankerman and Scotchmer, 2001) as well as in our model – then the situation is less clear-cut, and we have to consider two further sub cases.

First, consider the case of full information and non-substitutable technologies (sub case 1). Absent infringement, the two parties would have negotiated a licensing contract. As to the licensing fee, we lean on the rationale put forth by Schankerman and Scotchmer (2001) arguing that the outcome of *ex ante* licensing negotiations will depend on what the law promised the patentee as a remedy in the case of infringement. Since the latter refers to the outcome of hypothetical *ex ante* licensing negotiations, the *ex post* remedy and the *ex ante* licensing fee will be self-enforcing. Infringement should not take place in equilibrium (see the upper branch of our tree). Quite obviously, from a real-world perspective this theoretical view is unsatisfactory, if only for the fact that it cannot explain infringement as anything but an "out-of-equilibrium" event.

The situation differs when incomplete information and substitutive technologies are introduced (sub case

likelihood of irreparable harm" (Steptoe and Johnson LLP, 2005, http://www.steptoe.com/publications/PI10264.pdf). While not obviating the troll business altogether, this proposal would weaken their position considerably. Also, a post-grant review in the style of the opposition procedure at the European Patent Office is favored by the lobbyists (news.zdnet.com, 13 September 2005).

[44] See, e.g., Blair and Cotter (2001, 45 and 46), Gallini and Scotchmer (2002) and Henkel and von Hippel (2003).

[45] The economic analysis of incentives to innovate and the role of the patent system goes back at least to Arrow (1962), Nelson (1959), Nordhaus (1969), and Schmookler (1966). See Gallini and Scotchmer (2002) for a comprehensive discussion, and Grossman and Helpman (1991) in the context of economic growth. See Gilbert and Shapiro (1990) and Klemperer (1990) for an economic model assessing the effects of patent breadth.

[46] In the extreme case, "defining the patent more narrowly" may mean not granting it at all—that is, in general terms, to increase the threshold level of non-obviousness and the quality of prior art search. As mentioned earlier, many troll patents have been characterized as trivial and/or non-novel, and some have indeed been invalidated for that reason (e.g., the U.S. Patent Office found that prior art "completely anticipated the broadest claims of the patent" No. 4,698,672 owned by Forgent Networks, see http://www.pubpat.org/Chen672Rejected.htm). Thus, increasing patent quality clearly is another important avenue for obstructing the troll business. Of course, a more restrictive granting policy must be implemented carefully to avoid "good" applications being erroneously rejected alongside trivial ones.

2). With incomplete information, inadvertent infringement does take place in equilibrium (node E in the tree). At the same time, it implies that the assessment of hypothetical *ex ante* licensing negotiations by courts becomes much more difficult, since an inadvertent infringer did not even have the chance to enter such negotiations. Had he/she done so, he/she would have considered the option to use a substitutive technology instead. As we have argued above, neglecting this option of inventing around the patented technology can lead to highly exaggerated estimates of hypothetical *ex ante* licensing fees.

The fact that these latter cases of inadvertent infringement are not treated realistically by the courts may explain why we observe significant numbers of patent infringement cases, even though classical theory (sub case 1) cannot explain them. In our eyes, there is therefore a pressing need for a theoretical elaboration of the economics of patent infringement. While the details of this research must be left to future studies, we do, with all due modesty, strongly encourage legal policy makers to consider these downsides of current indemnification practice, especially in light of the rising risk of unconscious infringement. Introducing hypothetical invent around costs as an element in the equation to calculate damages in inadvertent infringement cases strikes us as necessary. We recommend such a reconsideration despite the notorious difficulties that courts face when assessing counterfactual situations (like hypothetical invent around scenarios). By passing its Directive 2004/48/EC on the enforcement of intellectual property rights, the European Parliament and the Council signaled their insight and their wish that patent indemnification needs to become "more realistic". In particular, Article 13 1a explicitly encourages the consideration of "all appropriate aspects" to determine the proper damage award. This, however, should also entail aspects regarding the infringed (and not only the infringing) party and their ulterior motives for being infringed. Quite clearly, however, the consideration of such additional parameters must not relieve manufacturers of their responsibility to keep monitoring prior art technology altogether. Trading off these parameters to design an optimal infringement rule will be a challenging task.

5. Conclusions and outlook on future research

Motivated by the vast gap between the managerial relevance of patent trolls on the one hand and the theoretical understanding of the profitability of their business on the other, this paper sought to answer four different questions; namely, why sharks exist, why their importance has increased, what countermeasures manufacturers can take, and what policy debates should be held. We addressed these questions by mapping international legal indemnification rules for patent infringement with managerial rationales of capacity-constrained holders of (simplistic) patents who – by assumption – have two choices: they may enter licensing deals about their technologies with potentially interested manufacturers shortly after discovery/patenting, or they may wait to be infringed (i.e. act like a shark).

By doing so, we were able to show that a necessary and, conditional on the patent not being found by the potential infringer, *sufficient* condition for these firms to act most profitably as sharks is the inadequate (unrealistic) treatment of hypothetical *ex ante* (i.e. before patent infringement) licensing negotiations between the patent holder and infringer in courts. In other words: under current indemnification regulations, "being infringed" is the dominant innovation exploitation strategy for small, capacity-constrained firms owning trivial patents. This central finding seems to hold across all the jurisdictions we studied, although it is particularly relevant in countries such as Germany where infringers' profits are awarded as one potential remedy. However, as we also demonstrated, even in countries where reasonable royalties are the only possible indemnification for a shark, the mistakenly high benchmark using standard industry rates overcompensates the troll and renders being infringed valuable.[47]

We further argued that the increasing technology monitoring efforts for victims of trolls, namely large manufacturing R&D intensive firms, due to ballooning numbers of patent applications, probably led to the increase of sharks' relevance for innovators. It facilitates

[47] It strikes us as extremely counterintuitive to base the royalty rate calculation in the case of inadvertent infringement on the average percentage of standard industry contracts. The latter are outcomes of *real* licensing negotiations, while an inadvertently infringed patent has *never* been subject to such negotiations. Most likely, a problematic selection separates the different cases, however. A patent holder who anticipates the outcome of *ex-ante* licensing negotiations to lie below the average industry royalty rate has an incentive to avoid such negotiations; instead he/she will aim at being awarded damages *ex-post* and act as a troll. This incentive is larger the higher the damage awards are, and should be particularly pronounced whenever "infringer's profits" can be awarded (see Fig. 2b). In contrast, a patentee holding rights to a technically sophisticated core technology will often not be satisfied when awarded a standard royalty rate *ex-post*, such that for those patent holders "being infringed" becomes less attractive than negotiating *ex-ante*.

'trapping' manufacturers by 'hiding' patented technologies in confusing patent thickets—a second necessary condition for sharks to operate. Moreover, the strengthening of patent holder's rights in certain jurisdictions (e.g. the US) most likely enabled sharks to operate more profitably, too. We illustrated that R&D intensive manufacturers are well-advised to revisit their budget allocations for technology monitoring efforts and to patent alternatives to their core inventions (in complex industries), and that concerted lobbying efforts to change patent indemnification laws may be promising; especially since, as we showed, sharks potentially dissipate social value by reducing manufacturers' incentives to innovate. And since they do so, sharks are a matter of concern for policy makers who – in our eyes – urgently need to revisit the practice – rather than the law itself – of patent indemnification. In more detail, we suggest that inadvertent infringers' trade-offs before infringement be more realistically captured by courts than is currently the case. The dangers associated with the malassessment of counterfactuals (like the manufacturer's invent around option *ex ante*) – a classical argument potentially to be brought forth against our conclusion – does, in our eyes, not vindicate the simplistic current practice by the courts that strengthens the trolls' positions.

As is common in research, this paper left us with as many questions as it did answers. Some of the questions strike us as relevant avenues for further research.

One trajectory of research is theoretical and of concern for theoretical scholars in the areas of law and economics. In Section 4.4, we showed that the current theory on patent infringement stops short of explaining the large number of infringement cases. According to Schankerman and Scotchmer (2001), patent infringement does not take place in equilibrium. While we acknowledge their circular logic of self-enforcing royalty rates and damage awards in the case of complete information about prior technology, we also showed that inadvertent infringement follows a different logic. Elaborating on this line of thought may refine our theoretical understanding of patent infringement (see also Bessen and Meurer, in press) and may help to suggest a differentiated optimal indemnification rule.

A second trajectory of further research is empirical by nature. Here, various questions appear intriguing to us, of which we briefly mention the two most interesting ones.

As Table 1 of this article shows, national idiosyncrasies in the jurisdiction of patent indemnification exist. If our model assumptions are correct and of relevance, then we would expect that shark strategies as well as their profitability differ from country to country. "Infringers' profits" (as long as Directive 2004/48/EC is not fully adopted by all the EC member states) in Germany may represent better bait than reasonable royalties in, say, France. Despite the theoretical possibility of sharks suing multinationals in various countries of jurisdiction, we would expect to see a concentration on certain national markets where, among other things, patent indemnification rules and practice would create incentives for initiating a troll business.

Finally, we deem it an extremely interesting question to further inquire empirically into the increasing professionalism of the trolls. R&D manufacturers are observing with growing concern how parts of patent portfolios are strategically bought out by dedicated investment funds, for example during bankruptcy proceedings. As mentioned in Sections 2.2.2 and 4.2, there have been cases where several patents, originally 'harmless' for all manufacturers since they had been used in multilateral cross-licensing negotiations between the different players prior to one of them filing Chapter 13, had become dangerous all of a sudden when they fell into the hands of the non-manufacturing investment fund. While the details of these particular cases are often not public, various other indications of such an increase in shark professionalism have been discussed in the popular media. One of the firms receiving ambivalent criticism is Nathan Myhrvold's "Intellectual Ventures". Specializing in the exploitation of inventions without engaging in production themselves, Intellectual Ventures both performs internal research and buys third parties' patents in industries that are of relevance to them. These latter activities, officially dedicated to forearming clients of Intellectual Ventures (namely R&D intensive manufacturers!) against potential sharks, have been criticized as troll-like activities by the firm itself.[48] No matter which standpoint one takes, the rising intensity and complexity of the patent acquisition and sales business and the engagement of non-producers lift this source of "patent surprises" to a whole new level, massively complicating the problem of cross-licensing, whose empirical relevance is, in our view, important to study.

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[48] See Newsweek electronic edition, 22 November 2005 (accessible at http://www.msnbc.msn.com/id/6478691/site/newsweek/).

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Appendix A. Appendix

In the following, we elaborate on the derivation and analysis of Eq. (1), which has the following shape:

$$\begin{aligned} E[\Pi\,|x] = {} & p_{\mathrm{pM}}(1-\mathrm{e}^{-ax})\max\{\Pi_0 - \mathrm{LF}, \Pi_0 \\ & -d, \Pi_0 - c_{\mathrm{ia}}, 0\} + (1 - p_{\mathrm{pM}}(1-\mathrm{e}^{-ax})) \\ & \times \max\{p'_{\mathrm{pM}}(p_{\mathrm{dM}}(\Pi_0 - d) + (1-p_{\mathrm{dM}})\Pi_0) \\ & +(1-p'_{\mathrm{pM}})\Pi_0, 0\} - x \end{aligned} \tag{1}$$

Given M's prior belief that a patent exists with probability p_{pM} and that, conditional on the patent's existence, M will discover it with probability $(1-\mathrm{e}^{-ax})$, the term $p_{\mathrm{pM}}(1-\mathrm{e}^{-ax})$ denotes the overall probability (as perceived by M before searching) of M finding a patent on T if it expends the search effort x. Having found a patent, M maximizes its profits according to the first line of Eq. (1).

Correspondingly, the term $(1-p_{\mathrm{pM}}(1-\mathrm{e}^{-ax}))$ in the second line describes the probability (as perceived by M before searching) that M will not find a patent on T, given its effort x. Conditional on not having found a patent, M updates its belief about the probability that a patent nonetheless exists, following the rules of Bayesian updating, to

$$p'_{\mathrm{pM}}(x) = \frac{p_{\mathrm{pM}}\ \mathrm{e}^{-ax}}{p_{\mathrm{pM}}\ \mathrm{e}^{-ax} + 1 - p_{\mathrm{pM}}}$$

If no patent exists (probability $(1-p'_{\mathrm{pM}})$), then the expected payoff from entering the market simply amounts to Π_0. If a patent exists, then the expected payoff is given by $(p_{\mathrm{dM}}(\Pi_0 - d) + (1-p_{\mathrm{dM}})\Pi_0)$, with p_{dM} denoting the probability, as perceived by M, that its illegitimate use of the patented technology will be discovered and infringement will be enjoined. The second line of Eq. (1) can be simplified, yielding

$$\begin{aligned} E[\Pi\,|x] = {} & p_{\mathrm{pM}}(1-\mathrm{e}^{-ax}) \\ & \times \max\{\Pi_0 - \mathrm{LF}, \Pi_0 - d, \Pi_0 - c_{\mathrm{ia}}, 0\} \\ & +(1 - p_{\mathrm{pM}}(1-\mathrm{e}^{-ax})) \\ & \times \max\{\Pi_0 - p'_{\mathrm{pM}}p_{\mathrm{dM}}d, 0\} \end{aligned} \tag{1'}$$

From this equation one can calculate M's optimal search effort x^* by differentiating with respect to x, setting the result to zero, and solving for x. In doing so, one has to distinguish between the cases that maximization in the second line of Eq. (1′) yields either 0 or $\Pi_0 - p'_{\mathrm{pM}}p_{\mathrm{dM}}d$. In case the maximization yields 0, we obtain

$$\begin{aligned} & \frac{\mathrm{d}}{\mathrm{d}x}E[\Pi\,|x] \\ & = ap_{\mathrm{pM}}\ \mathrm{e}^{-ax}\max\{\Pi_0 - \mathrm{LF}, \Pi_0 - d, \Pi_0 - c_{\mathrm{ia}}, 0\} - 1. \end{aligned}$$

Setting this expression to zero and solving for x yields x^* (the equation holds in the range where $\Pi_0 - p'_{\mathrm{pM}}p_{\mathrm{dM}}d < 0$):

$$x^* = a^{-1}\ln(ap_{\mathrm{pM}}\ \max\{\Pi_0 - \mathrm{LF}, \Pi_0 - d, \Pi_0 - c_{\mathrm{ia}}, 0\}).$$

It becomes immediately clear that a too low prior belief about p_{pM} on the part of M implies a too low search effort. The case $\Pi_0 - p'_{\mathrm{pM}}p_{\mathrm{dM}}d > 0$ is a more complex. Using the abbreviation

$$B = \max\{\Pi_0 - \mathrm{LF}, \Pi_0 - d, \Pi_0 - c_{\mathrm{ia}}, 0\},$$

we obtain the following equation for the derivative of $E[\Pi|x]$:

$$\begin{aligned} \frac{\mathrm{d}}{\mathrm{d}x}E[\Pi\,|x] = {} & ap_{\mathrm{pM}}\ \mathrm{e}^{-ax}(B - \Pi_0 + p'_{\mathrm{pM}}p'_{\mathrm{dM}}d) \\ & +(1 - p_{\mathrm{pM}}(1-\mathrm{e}^{-ax}))p_{\mathrm{dM}}d\frac{\mathrm{d}p'_{\mathrm{pM}}}{\mathrm{d}x} - 1 \\ = {} & ap_{\mathrm{pM}}\ \mathrm{e}^{-ax}\left(B - \Pi_0\right. \\ & \left.+p_{\mathrm{dM}}d\frac{p_{\mathrm{pM}}\ \mathrm{e}^{-ax}}{1 - p_{\mathrm{pM}}(1-\mathrm{e}^{-ax})}\right) \\ & +adp_{\mathrm{pM}}p_{\mathrm{dM}}\ \mathrm{e}^{-ax}\frac{1-p_{\mathrm{pM}}}{1 - p_{\mathrm{pM}}(1-\mathrm{e}^{-ax})} \\ & -1. \end{aligned}$$

Setting this term to zero and multiplying by $1-p_{\mathrm{pM}}(1-\mathrm{e}^{-ax})$ yields a quadratic polynomial in e^{-ax} solving for e^{-ax}, taking the logarithm, and dividing by $-a$ yields x^*. However, the resulting equation is rather involved, and actually more difficult to interpret than the original Eq. (1). We thus refrain from displaying the full expression for x^*, instead providing in the main text a discussion of Eq. (1).

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