"Essential" Patents, FRAND Royalties and Technological Standards*

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Abstract

We abandon the usual assumption that patents bring known benefits to the industry or that their benefits are known to all parties. When royalty payments are increasing in one's patent portfolio, as is implicitly the case in FRAND agreements, private information about the quality of patents leads to a variety of distortions, in particular the incentives of firms to "pad" by contributing inessential patents. Three main results that emerge from the analysis are that: (i) the threat of court disputes reduces incentives to pad but at the cost of lower production of strong patents; (ii) mitigating this undesirable side-effect calls for a simultaneous increase in the cost of padding, that is, a better filtering of patent applications; (iii) upstream firms have more incentives to pad than vertically-integrated firms which internalize the fact that patent proliferation raises the share of profits going to the upstream segment of the industry but at the expense of its downstream segment. This seems consistent with recent evidence concerning padding.

1 Introduction

While firms try to differentiate themselves from competitors, they also benefit from having standards established: this facilitates in particular the access of consumers to other providers' consumers and allows economies of scale in the production of various inputs (e.g. chipsets, other electronic parts, etc). Coordination problems make reliance on market mechanisms ill-fitted for standard creation, especially when the standards to be developped are complex.[1] For this reason, different industries have established standard setting organizations (SSO) whose primary role is to facilitate coordination between firms in the industry and other stakeholders.

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[1] See Farell and Saloner (1988) on the tradeoff between cooperative and market based mechanisms for standardization. They consider a world where the technologies are already available and the question is whether one or two standards will eventually survive. In this paper, and in the reality of markets, standard creation is done in parallel with the development of technologies. Bolton and Farell (1990) analyze the costs of delay in adoption and duplication costs when solutions to problems are decentralized rather than centralized.

In telecommunications only, at least seven SSOs exist: Alliance for Telecommunications Industry Solutions (ATIS), European Telecommunications Industry Solutions (ATIS), European Telecommunications Standards Institute (ETSI), Internet Engineering Task Force (IETF), International Telecommunications Union (ITU), Open Mobile Alliance (OMA), and Telecommunications Industry Association (TIA). Each of these SSOs deals with many different standard processes (see Chiao et al. 2007, or Rysmann and Simcoe 2007) involving each hundreds of participants and thousands of patents. Because the creation of a standard often involves the combination of technologies that are complementary, antitrust authorities tend to have a permissive approach toward these cooperative efforts (see for instance Schmalensee 2009).

One dimension of uncertainty faced by the participants and contributors to the SSO is the level of royalties that will eventually be charged by the patent holders once the standard is established. These royalties depend on the contribution of each firm to the standard and also on the "essentiality" of their patents, that is, the possibility to use the standard without infringing on these patents. What firms may anticipate however is that patent owners may opportunistically charge high royalties. Indeed, once a standard emerges and is adopted, it is costly for a single firm to produce a good which differs from the standard, implying that firms may be vulnerable to ex-post opportunism by the holders of essential technologies embodied in the standard. This problem is particularly important when the creation of a standard requires the use of many different innovations, which is typically the case in high technology industries (in the case of mobile telephony for instance, a handset can require the use of more than one thousand technologies protected by patents).

Opportunistic behavior has two effects. The first is well documented in the literature and is related to its static effects: the anticipation of opportunistic behavior may discourage participation in SSOs. This has led SSOs to design rules of conduct to limit the possibilities of hold-up, in order to increase the willingness to participate in the development of a standard. FRAND is a leading example of such rules. In a FRAND agreement, firms agree to contribute to the standard all the patents that are "essential" to this standard and to settle on royalties that are "fair, reasonable and non-discriminatory".[2]

A second effect of opportunism is less well documented however, and is related to its *dynamic* effect: anticipating ex-post negotiation, firms may change their strategy of producing

[2]One of the most documented case of dispute is the Rambus case. Rambus was involved in the JEDEC (Joint Electron Device Engineering Council), the semiconductor engineering standardization body of the Electronic Industries Alliance but later withdrew from the organization. Following a series of suits against memory manufacturers for royalty payments on the SSDRAM and DDR technologies, three firms countersued for failure to disclose these technologies during the participation in JEDEC. In the US both Rambus'claim for royalty payments and the FTC request for penalties for attempt to monopolize the market of semiconducteurs were eventually rejected. More germane to this paper, the European Commission launched an investigation for "patent ambush" against Rambus leading to "unreasonable royalties" for some technologies.

patents, to alter their "quality" or to contribute patents which may not be really essential for the standard in order to increase their bargaining power.[3]

Our objective in this paper is to analyze how the nondiscriminatory and fairness dimensions of FRAND affect the incentives to invest in R&D and the quality of the patents that firms contribute in a standard. Because the literature on patents[4] focuses mainly on their strategic use in market settings, we cannot directly rely on it to understand the effects of cooperative agreeements like FRAND, especially if the focus is on the quality of the patents that will be considered essential for the standard.

A noted exception is the literature on patent pools.[5] Patent pools presume that firms agree on a well defined set of patents to share (and verify carefully the legal validity of the patents in the pool), and licensors can use the patents in the pool to develop their own technology. By contrast, in SSOs, the objective is to develop a common technology. The process of formation of the standard is dynamic and members (patent holders, producers of final goods and often network operators) define along the way which technologies are needed and identify which existing patents are essential for these technologies. In addition to the usual legal validity of the patent, there is also the issue of whether the patent is truly essential – from a technical point of view – for developing the standard. These specificities of SSOs introduce three important dimensions in the problem of licensing.

First, the process of verification of essentiality of the patents is more difficult than in patent pools since the technology against which essentiality is verified is evolving. Rysmann and Simcoe (2007) show that between 1990 and 2005 the number of disclosures within some of the main SSOs (ANSI, IEEE, IETF, ITU) has increased significantly (sometimes by a factor of five). The sheer number of disclosures makes verifiability of essentiality claims difficult. In addition, there is also a lot of uncertainty as to which patent applications will in fact be granted - due in particular to randomness of the work of patent offices: see the book by Jaffe and Lerner (2004) on the shortcomings of the US patent system for example - and to which patents will be upheld in courts – see also Guellec and van Pottelsberghe (2007) on the European situation.

Second, the probability that a given patent is essential or not is endogenous. This is because the definition of the standard will make some patents technically essential while they would not have been so in another standard. Or because firms are free to contribute patents to the standard

[3]For instance, it is not rare for firms to come to the bargaining table with a small set of well identified "strong patents" – often well known to the other members of the SSO, together with a larger set of "other patents". See for instance Hegde et al. (2007).

[4]In the following we will use "patent" and "patent family" interchangeably and assume that patent families have full geographical coverage.

[5]See for example Shapiro (2001), Aoki and Nagaoka (2004), Lerner and Tirole (2004) and Layne-Farrar and Lerner (2006).

and claim that they are essential, when they are not. For instance, in recent papers Goodman and Myers (2005) show that up to 80% of the patents that firms claimed to be essential for a mobile telephone standard were in fact not.[6] The tables below summarize their findings for two standards for mobile telephony ('D' denotes patents that were declared essential by the firms and 'J' those which were judged essential by the experts.

3GPP	D	J
Qualcomm	279	30
Ericsson	129	34
Nokia	94	40
Motorola	38	11

3GPP2	D	J
Qualcomm	340	54
Ericsson	16	3
Nokia	45	14
Motorola	37	14

Finally, since there is a lot of uncertainty about the quality of the standard that will be eventually produced, many royalties are negotiated ex-post in SSOs. This makes the problem of hold-up even more crucial than for other licensing environments since once a standard is developed and adopted by a fraction of the industry, the opportunity cost of not adopting the standard is large. Hence, the exact reason that makes participation in the SSOs beneficial (generate economies of scale and network effects) may also distort ex-post royalty negotiation in favor of patent holders in such a way that the ex-ante benefit of other members is small.

To make progress in the analysis of the quality consequences of FRAND agreements, we build a model where firms invest in R&D and end up producing a variety of inventions, some of which may become essential during the creation of a standard, where essentiality means that the invention once patented is both legal (i.e., does not infringe on existing patents) and is also technically crucial for the standard. The firm may also decide to patent some of the other inventions, or if these are already patented to "push them" through the standard process and bring these inessential patents to the standard, a practice we call "padding."

The sharing of profits however depends on the *total* number of patents submitted, unless some of these are knocked down in court. To model such profit sharing, we resort to the well-known Shapley value. Beyond its simplicity, we argue that the notion of symmetry embedded in this concept is naturally compatible with the principles behind FRAND. Moreover, we introduce a parameterization of the shares of profit going to the upstream and downstream segments of the industry (i.e., the patent holders and the makers of the final product), making the formu-

[6]This evaluation was made from a purely technical point of view, that is, ignoring the possibility for these patents to be infringing on other patents, that is their validity. On average, an expert spent one hour per patent to evaluate its essentiality.

lation pretty flexible.

Equipped with this bargaining solution, we show that firms indeed have incentives to pad in equilibrium, and that the number of essential and inessential patents covary. Hence, if a firm pads less, it also contributes fewer essential patents. We then analyze the possibility that firms dispute the essentiality of contributed patents. We derive a 'limit padding' condition, that is, a maximum level of patents submitted such that downstream firms, when correctly anticipating the proportion of essential patents, prefer not to dispute. When courts are not too expensive, that is, when the limit padding condition binds, a key result is that a reduction of the cost of going to court reduces padding (the number of inessential patents submitted) but also, by the covariation result, reduces the number of essential patents produced. This argues for an alternative, improved certification method to reduce padding. We show that an appropriate combination of lower court fees and better filtering of patents through higher 'padding costs' can simultaneously raise the number of essential patents while reducing (by the same amount) inessential patent contributions.

We finally turn to a situation where an upstream firm and a vertically-integrated firm are involved in patenting. Here, a key result, when court costs are high, is that the two firms, if equipped with the same patent production technology, will produce the same number of essential patents, but that the upstream firm will pad more than the vertically-integrated firm. The overall incentive to submit patents is indeed higher for the upstream firm because more patents mean more money for the upstream industry segment but less money for the downstream industry segment. Firms which are also active in the downstream market have therefore a lower incentive to submit patents. As court costs decrease, the limit padding condition for the upstream firm starts binding while it is not binding for the vertically integrated firm. This implies that the upstream firm will now produce fewer essential patents than the vertically integrated firm.

2 Model

2.1 Firms and Markets

There are $n+1$ firms, denoted $0, 1, 2, \ldots, n$. Firm 0 is specialized in producing patents and is not present in the downstream market; think of this firm as being "upstream". There are M downstream markets. There is only one firm present on a given market but a firm can be present in more than one market: a firm's market share is the ratio of the markets in which it is present to M and is denoted by α_i. The profit on a market is π from the new product and is 0

otherwise.

We want to distinguish between "essential" and "inessential" patents. Essential patents are patents that are truly essential to the standard and that will be found essential in the case of dispute with probability one. Inessential patents are patents that have successfully gone through the patent office and the SSO but that are not essential to the standard: this could be because the patent is "legally" weak as in Choi (2005), Farrell and Shapiro (2008), and will be found illegal in courts or because its contribution to the technology embodied in the standard is not essential, as in the tests made in Goodman and Myers (2005). In a first best world, patent holders should present only their essential patents to the standard; however when certification is difficult, patent holders may have incentives to engage in "padding" by presenting also inessential patents.

Firms typically do not "aim" to produce inessential patents. However, their R&D expenditures turn out to generate inventions that may or may not be essential for the standard which 'emerges in the end' (we leave in reduced form the question of which standard does emerge, a process which takes place largely after R&D expenditures have been incurred). It is then, in a second step, that firms may "disguise" some inessential inventions and successfully pretend they are essential; it is quite possible that these inventions might in fact have proved essential in case another standard would have emerged.

Here, firms anticipate that the new technology will require specific inventions and they decide to invest in R&D, knowing that it takes $\varphi(E)$ to produce and patent a number E of essential patents. Other patents can be generated through this process, and are added to the historical stock of innnovations of the firm. These inventions are for most of them inessential for the standard but can disguised as being essential at cost c.[7] To simpify we assume that the stock of inventions is large and that, for the equilibrium values we derive below, there are always enough inessential patents in the stock of the firm.

Since essential patents embody essential new research, their effect on the profit of the industry is greater than that of inessential patents. Without much loss of generality, we assume that inessential patents have no effect on profits while essential patents have. Because of market uncertainty, if E essential patents are contributed to the standard, the realization of market profit is a random variable π with mean $\pi(E)$, increasing and concave in E.

Concerning market structure, we will consider two cases. In the next section we consider the leading case when firms are specialized: firm 0 is the only producer of patents (we call this firm "upstream") and the other firms are producers of final goods on the downstream market only.

[7] This is consistent with the finding in Rysmann and Simcoe (2008) that among all patents contributed to an SSO, the most cited are the most recent.

Firm 0 could be also construed as a syndicate of patent holders. Our goal will be to analyze whether the upstream firm wants to pad and how changes in legal costs or the cost of creating inessential patents affect the level of padding and welfare.

In the reality of markets however, producers of patents can be vertically integrated, that is be present both as producers of patents and of final goods. We consider therefore in section 4 the case where firms 0 and 1 can produce patents; firm 1 will be called "vertically integrated." Firms 0 and 1 can both engage in padding and our objective here is to understand if there are different incentives for padding by an upstream or a vertically integrated firm. As we will see, everything else being equal in terms of patent production or stock of "essential" patents, upstream firms pad significantly more than vertically integrated firms in equilibrium. The generalization to the case where all firms are producers of patents but differ in their product market presence is straightforward.

Before turning to the analysis of these two cases, we discuss the royalty rates that participants to the standard will choose for a given number of patents that are deemed essential.

2.2 Fair Payoffs

We postulate that, when there are M markets and P patent families, each patent earns its owner a profit of $\phi_p(P, M)$ while each individual market earns its sole supplier a profit of $\phi_m(P, M)$. For the purpose of modeling bargaining, we consider each firm as an integrator of the technologies available in its supplier network (see for instance Kranton and Minehart 2000). There are K suppliers for each firm, and the "firm" can achieve the profit π only if all the managers of its suppliers have the patents needed for their technology. The profit levels $\phi_p(P, M)$ and $\phi_m(P, M)$ are defined as:

$$\phi_p(P, M) = \frac{M}{P+K}\pi \quad \text{and} \quad \phi_m(P, M) = \frac{K}{P+K}\pi. \tag{1}$$

The appendix provides cooperative foundations for these expressions, based on the well-known Shapley value. While the Shapley value is a cooperative game theoretical concept, we view it as a convenient shortcut for modeling the outcome of a potentially complex multilateral noncooperative bargaining (e.g., Gul 1989).

The reader should interpret the payoffs in (1) as the anticipation that the players have about the outcome of future negotiations rather than as an explicit pricing rule. Our results are robust to alternative payoff functions as long as these payoffs are increasing in the number of patents a firm contributes to the standard and in its market share on the downstream market.

Alternatively, these expressions can also be taken as a reduced form. In this perspective, beyond the convenient linear formulation, note that they imply that:

1. The 'downstream segment' is assumed to receive a total amount $MK\pi/(P+K)$ of profits while the 'upstream segment' receives a total amount $MP\pi/(P+K)$ of profits (total profits being $M\pi$). The ratio P/K is therefore a measure of the relative bargaining power between the upstream and downstream industry segments. While P represents the number of patents involved in the standard, K is a parameter that could be 'calibrated' to replicate the upstream and downstream profit shares in a particular market.

2. Every patent family holder receives the same royalty per unit of profit, and independently of the level of profit, and each downstream market contributes to patent family holder revenues to the same extent. This symmetry can in fact be seen as being in accordance with FRAND.

3. Beyond this, note that a rise in the number of patents (e.g. because of padding) will reduce the profit of both preexisting patent owners and downstream suppliers.

As we have already noted, padding is limited by the cost of generating patents, the competition from other patent holders in the standard and by the incentives of other parties to dispute the essentiality of patents in the standard. We turn to this now, and we analyze two situations in turn.

3 Padding in the Shadow of Disputes

A necessary condition for padding is that the set of essential patents is privately known to its owner. Since "fair" royalties are computed on the basis of the set of patents that are deemed essential to the standard, a lower production of essential patents can be compensated by a larger production of inessential patents without detection possibility by the other participants. This is no longer true in the case of certification or court disputes if the patent holder bears the cost of disputes on its inessential patents.

To highlight the role of disputes, we will focus here on the leading case where only firm 0 can produce patents and only firm 1 can dispute these patents in court. Hence, we assume implicitly that the other firms $2, \ldots, n$ are "small" or are facing large costs of going to court.[8]

[8] Alternatively, we could consider out-of-court settlements. In this case, discoveries that some patents are inessential do not become known to the other firms: firm 0 therefore bears a lower cost in the case of dispute since it can still ask the other firms to pay the high royalty rate corresponding to the total number of patents submitted. This suggests that firm 0 will pad more. However, if in the negotiated settlement firm 1 is able to extract some of the royalty gains of firm 0 from non-disclosure, this should induce firm 1 to dispute more often. The net effect will depend on the way negotiation

Because there is no ambiguity, we denote by E the number of essential patents of firm 0, by P the total number of patents contributed to the standard, hence $P - E = I$ is the number of inessential patents. Finally, we let d be the proportion of patents that firm 1 decides to dispute (or the patents over which firm 1 refuses to pay the royalty).

The cost of going to court is f per patent disputed and we assume that this cost is borne by the party who loses the dispute in court.[9] Hence if firm 1 disputes the essentiality of a patent and the court agrees, it is firm 0 which pays f, otherwise it is firm 1. As explained before, we assume for simplicity that only essential patents can be found essential in court.

It is convenient to consider a linear expected profit function: $\pi(E) = E\pi$ and a quadratic R&D cost $\varphi(E) = \mu E^2/2$. Note that the cost of one essential patent is $\mu/2$ while the industry profit per component when there is only one patent is $M\pi/K$. We assume throughout that the industry is *high profit* :

$$\frac{\mu}{2} < \frac{M\pi}{K}. \tag{2}$$

The marginal cost of inessential patents is constant and equal to c.

The timing is the following:

- Firm 0 chooses E and I at cost $\varphi(E) + cI$.
- Firm 1 observes the total number of patents $P = E + I$ and decides on the proportion d of patents to dispute.
- If after a dispute there are P' patents that have not been found inessential, royalty payments are decided on the basis of condition (1) with $P = P'$ patents.

An equilibrium is a pair (E, I) for firm 0 and a binary decision $d \in \{0, 1\}$ by firm 1 to dispute or not the patents of firm 0.

We proceed as follows:

- We first characterize the optimal choice of essential patents for a given total number of patents P assuming that firm 1 will not dispute the patents. We show that there is padding whenever the total number of patents is greater than a cutoff level P^{eq};
- As P increases, the number of essential patents and of inessential patents increases and there exists a cutoff value $P^{lim} > P^{eq}$ at which firm 1 is indifferent between not disputing and disputing given the optimal choice of firm 0.

is modeled and on the distribution of bargaining power between firm 0 and firm 1. See Choi (1998) and Farrell and Shapiro (2008) for models along these lines.

[9] This assumption simplifies the algebra without affecting the essence of the results.

- A revealed preference argument shows that there cannot be an equilibrium where firm 1 disputes patents with probability one.
- We then derive the optimum choice of firm 0, that is the number of patents it will effectively produce for the standard and show that there is "limit padding" in the sense that firm 0 produces the number of patents that make firm 1 indifferent between disputing and not the patents.[10]

Choice of Essential Patents when Firm 1 does not dispute

Assuming that firm 1 does not dispute any patent when there are P patents put forward by firm 0, the optimal choice of essential patents by firm 0 solves

$$\max_{E \leq P} \frac{P}{P+K} M\pi S - \mu \frac{E^2}{2} - c(P-E).$$

Ignoring the constraint, the unconstrained maximum is achieved at

$$\sigma(P) = \frac{1}{\mu}\left\{\frac{P}{P+K} M\pi + c\right\}. \tag{3}$$

The constrained maximum is $E(P) = \min\{\sigma(P), P\}$. A first observation is that there is no padding – that is $E(P) = P$ – if and only if P is smaller than a cutoff value. (All proofs missing in the text appear in the appendix.)

Proposition 1. *(i) There exists $P^{eq} > 0$ such that the optimal number of essential patents at P assuming that firm 1 does not dispute is*

$$E(P) = \begin{cases} P & \text{if } P \leq P^{eq} \\ \sigma(P) & \text{if } P \geq P^{eq}. \end{cases}$$

(ii) $E(P)$ is increasing and concave in P,

(iii) $P - E(P)$ is increasing in P, $(P - E(P))/P$ is increasing and concave in P.

In other words, without disputes, there is padding only for $P > P^{eq}$ and the level of padding is increasing in P, both in absolute number but also relative to the number of patents. Everything being equal, a larger number of patents indicates a higher proportion of inessential patents.

[10] Moreover, firm 1 does not randomize and uses the pure strategy of not disputing. This result is due to our assumption that disputes happen before the profit is known. If disputes can arise after firm 1 gets information about the market profit, there will be a dispute for high levels of profit and no dispute for low levels of profit: this is apparent by inspecting (5) below and interpreting π as the realized profit. We chose our timing because it is empirically reasonable (market profits are realized well after the royalty agreements are made) and because it captures in a simple way the role of court fees on padding behavior.

Limit Padding

Consider now the behavior of firm 1. If at P, firm 1 has beliefs E, and disputes a proportion d of patents, while firm 0 actually chooses a number $\hat{E}$ of essential patents, the payoffs for firms 0 and 1 are as follows

$$u_0(\hat{E}, d; P, E) = \frac{\hat{E} + (1-d)(P-E)}{\hat{E} + (1-d)(P-\hat{E}) + K} M\hat{E}\pi - fd(P-\hat{E}) - \frac{\mu\hat{E}^2}{2} - c(P-\hat{E}) \quad (4)$$

$$u_1(E, d; P) = \frac{\alpha_1 K}{E + (1-d)(P-E) + K} ME\pi - fdE.$$

Note that if firm 1 disputes the patents, it creates an industry wide externality since it becomes known which patents are truly essential. This externality translates into lower royalty payments for all firms.[11]

Since $u_1(E, d; P)$ is convex in d, the best response of firm 1 is either to dispute all patents ($d = 1$) or dispute no patent ($d = 0$). It is best for firm 1 not to dispute if and only if

$$\frac{\alpha_1 K}{P+K} ME\pi \geq \frac{\alpha_1 K}{E+K} ME\pi - fE$$

$$\text{or,} \qquad \frac{\alpha_1 K}{E+K} M\pi - \frac{\alpha_1 K}{P+K} M\pi - f \leq 0 \quad (5)$$

In order to avoid disputes, firm 0 must choose a minimum number of essential patents. However because firm 1 observes only P and not E, the condition must be met at the optimal choice for firm 0.

Can we have an equilibrium in which firm 1 disputes all P patents with probability one? In such a case, firm 0 will still choose $\hat{E}$ in order to maximize the payoff given by (4). However, if $E^d(P)$ is the optimum, it must be the case that $P = E^d(P)$, that is, firm 0 should abstain from any padding: It would rationally expect that such padding would be successfully undone by the dispute and would only imply a cost of $f(P - E^d(P))$ for firm 0. But if, in equilibrium, there are no inessential patents, it will be anticipated by firm 1, which will find it optimal not to dispute the patents, which is a contradiction. We have the following result:

Lemma 1. *In equilibrium, the padding constraint (5) is satisfied.*

[11] Hence, disputing the patents of firm 0 has the flavor of a public good, as noted also by Farrell and Shapiro (2008). If more than one firm can dispute patents, there is a free rider problem since each firm will prefer another firm to dispute in order to benefit from the externality without having to bear the court costs. We should expect that in equilibrium, the level of patents for which a given firm is indifferent between disputing or not will increase: in other words, the process of ex-post certification by disputes will be even less efficient in preventing padding than under our assumption.

When $P > P^{eq}$, by substituting $\sigma(P)$ for E in (5) we need,

$$\Delta(P) \leq f$$

where

$$\Delta(P) = \frac{\alpha_1 K}{\sigma(P) + K} M\pi - \frac{\alpha_1 K}{P + K} M\pi$$

has the following properties.

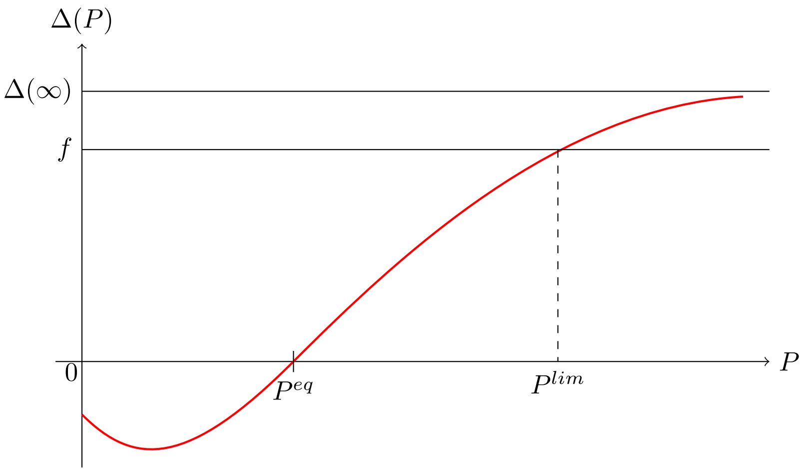
Lemma 2. *Let* $\Delta(\infty) = \mu \frac{\alpha_1 K M\pi}{M\pi + c + \mu K}$.

i. If $\Delta(\infty) \leq f$*, then (5) is satisfied for all values of* P*.*

ii. If $\Delta(\infty) > f$*, then there exists a unique value* $P^{lim} > P^{eq}$ *such thaT (5) binds.*

iii. $\Delta'(P) > 0$ *for all* $P > P^{eq}$*.*

As we show in the proof of the lemma, the function $\Delta(P)$ has typically the following graph.[12] We have also illustrated the case (ii) of the lemma where the limit padding constraint binds.[13]



The condition $\Delta(\infty) > f$ holds when f is small enough; moreover from (iii), the value of P^{lim} for which (5) binds is an increasing function of f. This is indeed intuitive: decreasing the cost of going to court will make firm 1 more aggressive in disputing patents when P is greater than P^{eq}.

We consider the two regimes of high and low court costs in turn. While the case of high court fees is of lesser interest here, it provides the benchmark to evaluate the role of disputes as a disciplining device for firm 0. Moreover, the technical analysis is broadly similar, so that the

[12] It may not be decreasing at zero, but is always increasing beyond P^{eq}.

[13] Obviously the economically relevant part of the graph is when $P \geq P^{eq}$.

high-court-fee case will be helpful to derive the main result of this Section, namely Proposition 5.

Note that in both cases, despite the fact that firm 0 could decide to limit the number of patents and produce only essential patents, its desire to extract higher royalty payments will lead the upstream firm to increase the number of patents offered in the standard and in the process will produce inessential patents.

3.1 Two Regimes

3.1.1 High Court Fees: $\Delta(\infty) \leq f$

In this case, there is no dispute for any value of P. To derive our result, it will be helpful to split the space of P's, into $P \leq P^{eq}$ and $P > P^{eq}$.

When $P \leq P^{eq}$, there is no padding and firm 0 chooses P to maximize $u_{0-}(P) = \frac{P^2}{P+K}M\pi - \mu\frac{P^2}{2}$. The derivative of this function is :

$$u'_{0-}(P) = \frac{P^2 + 2PK}{(P+K)^2}M\pi - \mu P. \tag{6}$$

and the sign of the derivative is the same as the sign of $\frac{P+2K}{(P+K)^2}M\pi - \mu$. This function is decreasing in P and has value $\frac{2M\pi}{K} - \mu$ at $P = 0$, and is therefore positive by (2). As $P \to \infty$, the function has limit equal to $-\mu$. It follows that:

Lemma 3. *The function $u_{0-}(P) = \frac{P^2}{P+K}M\pi - \mu P$ is single peaked.*

This optimal value of P can be smaller or greater than P^{eq} depending on the value of c. If c is "small" however, the optimum is greater than P^{eq} and therefore it is optimal for firm 0 to choose $P = P^{eq}$.

Corollary 1. *There exists $\hat{c} > 0$ such that for all $c < \hat{c}$, the maximum payoff to firm 0 over $P \leq P^{eq}$ is attained at P^{eq}.*

Consider now the case $P > P^{eq}$. There is padding and firm 0 chooses P to maximize

$$u_{0+}(P) = \frac{P}{P+K}M\pi\sigma(P) - \mu\frac{\sigma(P)^2}{2} - c(P - \sigma(P)).$$

By the envelop theorem,

$$u'_{0+}(P) = \frac{K}{(P+K)^2}M\pi\sigma(P) - c.$$

From proposition 1, the ratio $\sigma(P)/(P+K)^2$ is decreasing in P. Hence the sign of $u'_{0+}(P)$ is "decreasing " and $u_{0+}(P)$ is single peaked. While there is a change of regime at P^{eq}, it is possible to show that the payoff is differentiable at P^{eq},[14] and therefore that for $c < \hat{c}$, $u'_{0+}(P^{eq}) = u'_{0-}(P^{eq})$ is positive. It follows that there is an interior solution $u'_{0+}(P) = 0$. Because $P = P^{eq}$ is feasible, this interior solution is also a global maximum.

Proposition 2. *Suppose that court fees are high and that the cost of inessential patents is small ($c < \hat{c}$). Firm 0 chooses optimally to produce inessential patents: the number of patents P^{no}, $P^{no} > P^{eq}$ solves*

$$\frac{K}{(P+K)^2} M\pi\sigma(P) - c = 0.$$

When the cost of producing inessential patents, c, is instead greater than the cutoff $\hat{c}$, firm 0 will not pad: the optimum when $P \leq P^{eq}$ is strictly lower than P^{eq}, implying $u'_0(P^{eq}) < 0$, while the optimum when $P \geq P^{eq}$ is at P^{eq}, implying a global maximum less than P^{eq}. This is rather intuitive: inessential patents increase the revenue only through the level of royalties but not through the level of market profits: if the cost of inessential patents is high enough, they become a poor substitute for essential patents in raising total profits since essential patents increase both the royalty rate and the market profit π.

3.1.2 Low Court Fees: $\Delta(\infty) > f$

The analysis in the regime $P \leq P^{eq}$ is the same as before and P^{eq} is the optimal choice when c is small.

In the regime $P \geq P^{eq}$, consider P^{no} defined in Proposition 2, the optimum when firm 0 does not face disputes, and P^{lim} the level of patents at which firm 1 is indifferent between disputing and not when firm 0 chooses $\sigma(P)$ essential patents. Since when there is no dispute the payoff to firm 0 is single peaked, it optimally chooses $P^d = \min(P^{lim}, P^{no})$.

If $P^d = P^{no}$, we are done.

If $P^d = P^{lim}$, firm 1 is indifferent between disputing and not. Could we have equilibria in which firm 1 disputes with probability $\gamma > 0$? No, because firm 0 strictly prefers $\gamma = 0$ to $\gamma > 0$, and would infinitesimally reduce its total number of patents to make it strictly optimal for firm 1 to stop disputing altogether. Consequently, the unique equilibrium behavior at P^{lim} is for firm 1 not to dispute the patents.

Proposition 3. *Suppose that court fees are low and that the cost of inessential patents is low ($c < \hat{c}$). Firm 0 produces $\min(P^{lim}, P^{no})$ patents and there is no dispute in equilibrium.*

[14] To see this, use $P^{eq} = \frac{1}{\mu}\{\frac{P^{eq}}{P^{eq}+K} M\pi + c\}$ and substitute $\mu = \frac{M\pi}{P^{eq}+K} + \frac{c}{P^{eq}}$ in u'_{0-}.

3.2 Comparative Statics and Policy Implications

Within our model, we can analyze the role played by the courts (f) and certification or other ways to make padding more difficult (c could be the cost of certifying patents, either via the patent system or via the standard). It is useful to summarize our previous findings and illustrate the roles of c and f in the different regimes.

A key result is Proposition 1, which establishes the covariation between essential and inessential patents, or between the level of R&D and padding. This is an implication of FRAND and of the fact that the share of industry profits accruing to the upstream firm is increasing in the number of patents it brings to the standard. Indeed, when there are fewer inessential patents, the share of profits accruing to the upstream firm decreases, the marginal revenue from essential patents is also lower and the upstream firm will invest less in R&D.

There are three relevant cutoff values for the total number of patents P, $P^{eq}(c),\ P^{no}(c),\ P^{lim}(c, f)$ and we now make explicit their dependence on the parameters c and f.

$P^{eq}(c)$ is the cutoff value of P where firm 0 is indifferent between starting to pad or not. This value is increasing in c: intuitively, as the cost of padding increases, the upstream firm is more willing to invest in R&D rather than go for inessential patents in order to increase its revenues.

$P^{no}(c)$ is the optimal number of patents that the upstream firm will bring to the standard, assuming that it does not face the possibility of dispute (for instance if f is large). As we know, this value is greater than $P^{eq}(c)$ – and there is padding – if and only if c is smaller than $\hat{c}$. As c increases, it is more costly to pad, and the upstream firm should pad less. However, it can be shown that is also the case that the number of essential patents decreases (note that this last result does not follow immediately from proposition 1 however, which assumes c to be constant).

Proposition 4. *Suppose that $c < \hat{c}$ and that the equilibrium number of patents is $P^{no}(c)$. Then, locally, as c increases, the number of essential patents and the number of inessential patents decrease.*

Hence, when disputes are not effective, it is not possible to simultaneously decrease the level of padding without depressing the level of R&D: increasing c will limit the number of inessential patents but at the cost of reducing the total industry profit, and the value of the standard itself.

Consider now the case where disputes can be effective. $P^{lim}(c, f)$ is the number of patents for which the downstream firm is indifferent between disputing and not the patents of the upstream firm. The consequences of a variation of an increase in c are more subtle than in the previous case. There are two effects at play. First as c increases, there is the usual substitution effect: for a given number of patents, the upstream firm will have relatively more essential patents than inessential patents. Second, there is the effect on limit padding: because of the substitution effect, the downstream firm disputes less aggressively, hence the limit padding constraints of the upstream firm is weakened and it will *increase* the number of patents it brings to the standard.

The substitution effect goes in the direction of a decrease in padding; however the other effect goes, via the covariation result, in the direction of an increase in padding. The net effect is a priori ambiguous. However, we prove below that the net effect is positive, thus overturning the results of the previous proposition.

As f decreases, the downstream firm finds it less costly to dispute patents and the limit padding constraint is strengthened, leading to a decrease in the number of inessential patents that are submitted. However, by the covariation result, it is also the case that the number of essential patents (or R&D investment) decreases. Hence, like in the previous situation, the use of f only cannot limit padding without adverse effects on R&D incentives.

Proposition 5. *Suppose that $c < \hat{c}$ and that the equilibrium number of patents is $P^{lim}(c, f)$.*
(i) As f decreases locally, the total number of patents, the number of essential patents and the number of inessential patents decrease.
(ii) As c increases locally, the total number of patents, the number of essential patents and the number of inessential patents increase.

An increase in the cost of inessential patents *does not limit* padding, but has the desirable effect to increase the quality of the standard. At the same time, Proposition 5 illustrates how using f only will have the undesirable consequence of reducing the investment in R&D, and the quality of the standard. In particular, this illustrates a limitation of courts for disciplining firms in standards: while lower court fees will reduce padding, they also reduce the value of the standard since a lower number of essential patents is produced. This suggests that non-court based certification processes may be better able to correct for padding without destroying incentives to produce essential patents. One possibility would be for the participants to the standard to share the costs of an ex-ante certification process. There are indications that the industry is experimenting in this direction (see `http://www.3glicensing.com/` for certification by neutral third parties in 3G licensing pools).

Interestingly, combining a decrease in f with an increase in c can also achieve the goal of reducing padding while providing incentives to increase the quality of the standard. Because $P^{lim}(c, f)$ is increasing in c and in f, it is indeed possible to find a positive variation dc of c and a negative variation df of f such that the total variation of the number of patents is zero.

Since f does not affect the substitution effect, the increase in c will then lead to an increase in the proportion of essential patents and a decrease in padding.

Proposition 6. *Suppose that $c < \hat{c}$ and that the equilibrium number of patents is $P^{lim}(c, f) < P^{no}(c)$. There exist $dc > 0$ and $df < 0$ such that the number of patents stays constant, but the number of inessential patents decreases.*

The policy implications of the model are nontrivial because of the covariation between essential and inessential patents. This covariation further suggests that it may be possible for the upstream firm to *over-invest* in R&D in order to increase its share of the industry profits. Indeed, while in standard moral hazard situations, there is a tendency for underinvestment because the agent does not get the full marginal return of its investment, in our model there is an additional effect at play, due to the dependence of the share on the contribution of the agent.[15]

4 Competitive Padding

The previous section shows that padding is likely to be an equilibrium outcome of the patent application process: royalty revenues are increasing in one's contributions and as long as the cost of producing inessential patents is small enough, a patent producer will find it beneficial to pad. One specificity of the previous section is that it has treated all patent contributors symmetrically, by assuming that patent contributors are not active on the downstream market. Since in the reality of markets, patent contributors are also often producers of final goods, it is natural to understand whether the presence of a patent producer active on the downstream market will lead to a change in the equilibrium choice of padding by the upstream firm.

We will first ignore the possibility of disputes here and assume that only firms $0, 1$ can produce patents.[16] Since there is no possibility of dispute, the analysis will highlight the disciplinary role of competition for padding among heterogenous firms.

Let S_0, S_1 be the numbers of essential patents of firms $0, 1$: only i knows S_i. In addition to these essential patents, these firms can present inessential patents (or "pad") and we denote by I_i these numbers. The sum of the essential and inessential patents is denoted by $P_i = E_i + I_i$ for firm i and the total number of patents is denoted by $P = P_0 + P_1$.

Since there is no possibility of dispute or of certification, for a given realization of π, the payoff to patent holders is obtained by multiplying the Shapley value of a patent by the number of

[15] If $\pi(E)$ is linear in E, one can show that there is always underinvestment. However if the expected profit is not linear, the condition for having over-investment is $\pi'(E^*)(E^* + K) < \pi(E^*)$.

[16] The extension to the case where all downstream firms can contribute is straightforward. Proposition 7 generalizes simply: all firms produce the same number of essential patents but the number of inessential patents is *decreasing* in the market share.

patents he contributes and the payoff to a downstream firm by multiplying the Shapley value of a market by the market share $\alpha_i M$ of this firm. Since firm 1 is vertically integrated, its expected payoff is the sum of these two values, where the expectation is taken with respect to $F(\pi, E)$. Hence,

$$\begin{aligned} u_0(E,I) &= \frac{E_0+I_0}{E+I+K}M\pi(E) - cI_0 - \varphi(E_0) \\ u_1(E,I) &= \frac{E_1+I_1+\alpha_1 K}{E+I+K}M\pi(E) - cI_1 - \varphi(E_1) \\ u_i(E,I;M) &= \frac{\alpha_i K M\pi(E)}{E+I+K}, \qquad i \geq 2 \end{aligned}$$

Let us now take derivatives for firm 0:

$$\frac{\partial u_0}{\partial I_0} = \frac{P_1+K}{(E_0+I_0+P_1+K)^2}M\pi(E_0+E_1) - c \tag{7}$$

and:

$$\begin{aligned} \frac{\partial u_0}{\partial E_0} =& \frac{P_1+K}{(E_0+I_0+P_1+K)^2}M\pi(E_0+E_1) \\ &+ \frac{E_0+I_0}{E_0+I_0+P_1+K}M\pi'(E_0+E_1) - \varphi'(E_0). \end{aligned}$$

Setting both of these derivatives to zero, we have:

$$\frac{E_0+I_0}{E_0+I_0+P_1+K}M\pi'(E_0+E_1) = \varphi'(E_0) - c.$$

Similarly, for firm 1, we have:

$$\frac{\partial u_1}{\partial I_1} = \frac{P_0+K(1-\alpha_1)}{(P_0+E_1+I_1+K)^2}M\pi(E_0+E_1) - c$$

and:

$$\begin{aligned} \frac{\partial u_1}{\partial E_1} =& \frac{P_0+K(1-\alpha_1)}{(P_0+E_1+I_1+K)^2}M\pi(E_0+E_1) \\ &+ \frac{E_1+I_1+\alpha_1 K}{P_0+E_1+I_1+K}M\pi'(E_0+E_1) - \varphi'(E_1). \end{aligned}$$

Setting these derivatives to zero, we have:

$$\frac{E_1+I_1+\alpha_1 K}{P_0+E_1+I_1+K}M\pi'(E_0+E_1) = \varphi'(E_1) - c.$$

The first-order conditions on inessential patents for the two firms imply:

$$P_0 = P_1 + \alpha_1 K.$$

But having these convex costs of producing essential patents means that putting together the last condition for each of the two firms implies:

$$E_0 = E_1$$

Note that it would be socially optimal for firms not to produce inessential patents and to produce essential patents in order to maximize $M\pi(E) - \varphi(E_0) - \varphi(E_1)$, yielding a first best optimum of

$$I^{FB} = 0, \qquad E_0^{FB} = E_1^{FB} = E^{FB} \quad \text{s.t. } M\pi'(2E^{FB}) = \varphi'(E^{FB}) \tag{8}$$

In equilibrium, we have instead:

$$\frac{P_0}{P_0 - \alpha_1 K + K} M\pi'(2E_0) + c = \varphi'(E_0). \tag{9}$$

Proposition 7. *Suppose that f is large.*

i. In equilibrium, firms 0 and 1 produce the same number of essential patents.

ii. Firm 0 produces $\alpha_1 K$ more inessential patents than firm 1.

Firm 0 thus contributes more patents to the standard but these are inessential ones, not essential ones, which come equally from both firms. The incentive to submit patents is higher for firm 0 because more patents mean more money for the upstream industry segment but less money for the downstream industry segment. Firms which are also active in the downstream market have therefore a lower incentive to submit inessential patents. And as far as essential versus inessential patents are concerned, since this is done for a given total number of patents submitted, two firms with identical technologies will make the same choices, namely they will equate the marginal cost of producing essential patents with c, the assumed constant marginal padding cost.

When firms $0, 1$ can dispute each other patents, we can generalize the previous observation that the expected profit of a firm is convex in the proportion of the patents it disputes, and that there is no dispute in equilibrium. Here, the no-dispute conditions are

$$
\begin{aligned}
fE_0 &\geq \Delta_1(P, E) \qquad (10)\\
fE_1 &\geq \Delta_0(P, E)
\end{aligned}
$$

where

$$
\begin{aligned}
\Delta_0(P, E) &= M\pi(E)P_0 \left[\frac{1}{P_0 + E_1 + K} - \frac{1}{P + K}\right]\\
\Delta_1(P, E) &= M\pi(E)(P_1 + \alpha_1 K) \left[\frac{1}{P_1 + E_0 + K} - \frac{1}{P + K}\right]
\end{aligned}
$$

are the gains from disputing the other firm's patents. As f is *large*, disputes do not constrain the choices of each firm and we have the same equilibrium as in the no-dispute case, that is,

$$E_0^* = E_1^*, P_0^* = P_1^* + \alpha_1 K.$$

Note that in this case,

$$\Delta_0(P^*, E^*) < \Delta_1(P^*, E^*) \qquad (11)$$

Suppose that f decreases up to the point where $fE_0^* = \Delta_1(P^*, E^*)) - \epsilon$, where ϵ is "small". Then by (10) and (11) only firm 0 faces the dispute constraint at the previous equilibrium. To avoid dispute, it is then necessary that the new equilibrium settles at $P_0(f) < P_0^*$ since $\Delta_1(P, E)$ is increasing in P_0. By covariation, it follows that $E_0(f) < E_0^*$. Firm 1 facing a firm 0 contributing less patents will then contribute more patents than before: both $P_1(f) > P_1^*$ and $E_1(f) > E_1^*$. Hence $E_1(f) > E_0(f)$ while $P_0(f) > P_1(f)$. As ϵ is small, we still have $\Delta_0(P(f), E(f)) < \Delta_1(P(f), E(f))$. As f continues to decrease, $P_0(f), E_0(f)$ decrease while $P_1(f), E_1(f)$ increase. This process continues until $\Delta_0(P(f), E(f)) = \Delta_1(P(f), E(f))$, which is obtained for a value $\hat{f}$.

Proposition 8. *Let $P_i(f), E_i(f)$ the equilibrium number of patents when the cost of dispute is f. There exists $\hat{f} < \Delta_0(P^*, E^*)$ such that the following holds.*
(i) If $f > \Delta_1(P^*, E^*)$, then $P_i(f) = P_i^*, E_i(f) = E_i^*$ and firms have the same number of essential patents.
(ii) If $f \in (\Delta_1(P^*, E^*), \hat{f})$, $\Delta_1(P^*, E^*)$, $P_0(f), E_0(f)$ decrease and $P_1(f), E_1(f)$ increase when f decreases. Firm 1 has more essential patents than firm 0.

5 Conclusion

By abandoning the usual assumption that patents bring known benefits to the industry or that their benefits are known to all parties, we have been able to derive several results. In particular, we have shown that the threat of court disputes reduces incentives to pad but at the cost of lower production of essential patents. Second, we have shown that upstream firms have more incentives to pad than vertically-integrated firms, which internalize the fact that patent proliferation raise the share of profits going to the upstream segment of the industry but at the expense of its downstream segment.

These results seem consistent with empirical results obtained by Goodman and Myers (2005) for the case of mobile telephone standards. Indeed, they show that: (i) all major patent producers seem to exaggerate claims of essentiality, and (ii) the extent of exaggeration seems to be much more significant in the case of a firm like Qualcomm, which is 'more upstream' than its main rivals.[17] While this deserves some further investigation, this is evidence consistent with our analysis.

Our results on court disputes have potentially significant policy implications. They show that easier court access can have an undesirable side-effect in terms of essential patent production. This calls for combining easier court access with an increase in the cost of padding, that is, better filtering of patent applications. Looking for an 'operational' way of limiting padding while simultaneously encouraging innovation constitutes an interesting avenue for further research. While this model is a useful starting point in this respect, it would benefit from extensions.

Some of our assumptions could be relaxed. As long as there are no disputes, the model behaves in the same way if there is a stochastic R&D technology. [18] Introducing disputes raises additional difficulties however, that are beyond the scope of this paper. It would be also reasonable to link the level of R&D to the number of inessential patents that a firm can contribute. If more R&D implies both more essential but less inessential patents, the relationship between R&D level and padding may be non-monotonic.

The patent dispute process could be generalized, to allow for the optimality of 'partial disputes', i.e., on a subset of the patent portfolio. And, very importantly, we have kept the choice of standard in 'reduced form', while it would be very interesting to explicitly link this choice to the outcome of the R&D investment process. These extensions are beyond the scope of this

[17]Geradin et al. (2007) classify in their analysis Qualcomm as an upstream firm and Nokia, Ericsson and Motorola as vertically integrated.

[18]If E is now a random variable with distribution parametrized by the level of investment, the covariation result will still hold if more R&D implies a first order stochastic shift in the distribution of essential patents because $\frac{E+I}{E+I+K}M\pi(E)$ has positive cross partials for any $E \geq 1$.

paper but constitute interesting avenues for future research.

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7 Appendix

7.1 Fair payoffs: foundation

We show in this appendix that the "fair" payoffs expressed in (1) can be obtained using the Shapley value (see Myerson, 1977, for a general theoretical discussion, Hart and Moore 1990, for an application to incomplete contracting and Layne-Farrar et al., 2006, for an application to mobile-phone patents.) Specifically, assume that:

- There is a set $\mathcal{P}$ of patents that are claimed to be essential to the production of a product. Since each patent is assumed to be controlled by one manager, they all have to have agreed to license their patent for production to go ahead.

- There are K managers in the supplier network in a given market, hence there are MK managers; all managers in one market are strict complements in the sense that their firm can produce the new product only if all managers have contracted with the patent holders.

By assuming extreme decentralization of both the patent decisions and the production decisions, we in fact parameterize the relative bargaining powers of the upstream and downstream segments of the industry.

The Shapley value is defined axiomatically and its "fairness" interpretation comes from its axiom of symmetry. The "nondiscriminatory" ingredient in FRAND can be interpreted as requesting that the royalty paid by firms is the same for each individual market, independently of market share, and that patent holders should receive the same per-patent royalty independently of their total portfolio. This is equivalent to assuming that each patent and each market are treated as a separate entity. Hence there are effectively $p + MK$ players: p patent holders and K managers per market. Because of symmetry, we know that the payoff to a manager on each market is the same, and that the payoffs to the patents are the same.

Remember that if for a given a set of players $\mathcal{N}$, the total payoff to a coalition E is described by a function $v(E)$, the Shapley value is defined as follows. Consider a random order on $\mathcal{N}$, let S_i be the set of all players preceding i in this random order. The marginal contribution of i is $v(S_i \cup \{i\}) - v(S_i)$, and the Shapley value is given by

$$\phi_i = E\left[v(S_i \cup \{i\}) - v(S_i)\right]$$

where E is the expectation operator when all $|N|!$ orders over $\mathcal{N}$ are assigned equal probability. It follows that if two players have the same marginal contributions if they occupy the same position in an order that their Shapley value are the same.

Consider the case of a unique market, hence when there are $P + K$ players. Since firms need all the patents in $\mathcal{P}$ in order to use the standard, and since the profit of a firm is realized only if its K managers have acquired the patents, any coalition not containing all the patents or all the managers would not produce a profit.

Hence each patent and each manager has a positive marginal contribution of π if and only if it is "last" in the order on the $P+K$ players. It follows that each manager and each patent holder receives $\pi/(P+K)$. Since on a market the K managers belong to the same firm, the firm receives $K\pi/(P+K)$. We prove now that this value is the same independently of the number M of markets:

Lemma 4. *Consider P essential patents and M markets, the Shapley value for each patent and for a firm present on a market are respectively*

$$\phi_p(P,M) = \frac{M\pi}{P+K} \quad \textit{and} \quad \phi_m(P,M) = \frac{K\pi}{P+K}. \tag{12}$$

Proof. We index patents by $i = 1,\ldots,P$ and we index managers by $k(m,i), i = 1,\ldots,K, m = 1,\ldots,K$ where $k(m,i)$ is the i-th manager present on market m. By assumption all managers $k(m,i), i = 1,\ldots,K$ belong to the same firm. Let $\mathcal{K}_{\mathcal{M}}$ be the set of managers.

By symmetry, we know that all patents have the same Shapley value ϕ_p and all managers in market m have the same Shapley value. Hence, if there are N players, it is enough to determine the Shapley value $\phi_p(\mathcal{N})$ common to all patent holders and the Shapley value $\phi_{j(m,k)}(\mathcal{N})$ of all the K managers in market m, where $m = 1,\ldots,M$. The value of a firm present in a market is then $K\phi_{j(m,k}(\mathcal{N})$

We use the following property of the Shapley value : balanced contribution (Myerson 1977) requires that what player i contributes to player j is equal to what player j contributes to player i. Or if $\mathcal{N}$ is the set of players, that:

$$\phi_i(\mathcal{N}) - \phi_i(\mathcal{N} - \{j\}) = \phi_j(\mathcal{N}) - \phi_j(\mathcal{N} - \{i\})$$

In our case, $\mathcal{N} = \mathcal{P} \cup \mathcal{K}_{\mathcal{M}}$. Letting i be a patent and $j(m,k)$ be a manager, we know that $v(\mathcal{N} - \{i\}) = 0$ since no new product can be put to the market if one essential patent is missing and $v(\mathcal{N} - \{j(m,k)\}) = (M-1)\pi$ since if one component is not present a product cannot be produced on market m.

In the game $\mathcal{N} - \{j(m,k)\}$ all players $j(m,k')$ have zero marginal contributions, hence their Shapley value is equal to zero: $\phi_m(\mathcal{N} - \{j(m,k)\}) = 0$. It follows that balanced contribution implies:

$$\phi_p(\mathcal{N}) - \phi_p(\mathcal{N} - \{j(m,k)\}) = \phi_{j(m,k)}(\mathcal{N}), \text{for each } m,k \tag{13}$$

To show (12), we proceed by induction on the number of markets M . From the text, the result is true for $M = 1$. We suppose it is true for $M-1$ and we show that the result is true for

M.

Since for each coalition E, $v(S - \{j(m,k)\}) = v(S - \cup_{k=1}^{K}\{j(m,k)\})$, the marginal contributions of all players are the same when the set of players is $\mathcal{N} - \{j(m,k))\}$ and when it is $\mathcal{N} - \cup_{k=1}^{K}\{j(m,k)\})$. In the later case, the game is in fact the one with $M-1$ markets and the Shapley values are given by (12).

In the initial game with $\mathcal{N}$, all managers are symmetric and therefore have the same value. Hence, by efficiency, we have

$$P\phi_p(\mathcal{N}) = M\pi - MK\phi_{j(m,k)}(\mathcal{N}) \tag{14}$$

Hence, (12), (13) and (14) imply

$$\begin{aligned} & \phi_{j(m,k)}(\mathcal{N}) = \frac{M\pi - MK\phi_{j(m,k)}(\mathcal{N})}{P} - \frac{(M-1)\pi}{P+K} \\ \Leftrightarrow \quad & \phi_{j(m,k)}(\mathcal{N}) = \frac{\pi}{P+K} \end{aligned}$$

implying as claimed that $\phi_m(\mathcal{N}) = \frac{K\pi}{P+K}$ proving the induction hypothesis and the lemma. □

7.2 Proof of Proposition 1

Part (i) follows from the fact that:

$$\sigma'(P) = \frac{M\pi K}{\mu(P+K)^2} = \frac{M\pi}{\mu(P+K)}\frac{K}{P+K} > 0$$

which is less than 1 whenever $\sigma(P) \leq P$, i.e. whenever:

$$\frac{M\pi}{\mu(P+K)} \leq \frac{P - c/\mu}{P} < 1.$$

This implies that $S(P)$ and $P - E(P)$ are increasing in P. Moreover, $\sigma''(P) < 0$, which implies (ii). Finally, $\sigma(P)/P$ is decreasing and convex in P, which implies (iii).

7.3 Proof of Lemma 2

Differentiating $\Delta(P)$, we have,

$$\begin{aligned}\Delta'(P) &= \alpha_1 KM\pi \left\{ -\frac{\sigma'(P)}{(\sigma(P)+K)^2} + \frac{1}{(P+K)^2} \right\} \\ &\propto -\frac{K}{(P+K)^2}\frac{M\pi}{\mu}\frac{1}{(\sigma(P)+K)^2} + \frac{1}{(P+K)^2} \\ &\propto \frac{1}{(P+K)^2}\left[1 - \frac{M\pi}{\mu}\frac{K}{(\sigma(P)+K)^2}\right].\end{aligned}$$

The term in brackets is an increasing function of P since $\sigma(P)$ is an increasing function of P. Hence, the sign of $\Delta'(P)$ is "increasing" in P: if $\Delta'(P) > 0$, then $\Delta'(P')$ for all $P' > P$.

We note that $\Delta(0) < 0$ (since $\sigma(0) > 0$), $\Delta(P^{eq}) = 0$, and that $\Delta(\infty) = \mu\frac{\alpha_1 KM\pi}{M\pi+c+\mu K}$. Hence, there is a cutoff value of P such that Δ' is positive only when P is larger than this cutoff value.

Now, if $\Delta(\infty) < f$, $\Delta(P) < f$ for all P and (i) follows.

If $\Delta(\infty) > f$, there exists a unique value - strictly greater than P^{eq} - such that $\Delta(P) = f$, and at this value $\Delta(P)$ must be increasing in P, proving (ii) and (iii).

7.4 Proof of Lemma 3

Since the sign of the derivative is first positive and then negative, $u_{0-}(P)$ is single peaked. The zero of the derivative is attained at the positive root of $\mu P^2 + (4\mu K - M\pi)P + 4\mu K^2 - 2KM\pi = 0$. Simple algebra shows that the positive root is $\frac{1}{2\mu}\left(M\pi - 2K\mu + \sqrt{M\pi(M\pi + 4K\mu)}\right)$.

7.5 Proof of Corollary 1

From the definition of P^{eq}, we have

$$\mu = \frac{M\pi}{P^{eq}+K} + \frac{c}{P^{eq}}. \tag{15}$$

If $S(P) = P$, $u_0'(P) = 0$ at $\hat{P}$ such that

$$\mu = \frac{M\pi}{\hat{P}+K} + \frac{2KM\pi}{(\hat{P}+K)^2} \tag{16}$$

Note that in (16), $\hat{P} > \frac{M\pi}{\mu} - K$ and that $\hat{P}$ is not a function of c. When $c = 0$, $P^{eq} = \frac{M\pi}{\mu} - K$, and therefore $P^{eq} < \hat{P}$ for low enough values of c. Precisely, the result holds for all $c \leq \hat{c}$ such that $\mu \geq \frac{M\pi}{\hat{P}+K} + \frac{c}{\hat{P}}$ for then it is necessary to set $P^{eq} \leq \hat{P}$ in order to restore the equality in (15).

The condition is equivalent to having c lower than a cutoff level $\hat{c}$:

$$\hat{c} = \hat{P}\left(\mu - \frac{M\pi}{\hat{P}+K}\right).$$

7.6 Proof of Proposition 4

The implicit function theorem applied to to the expression in Proposition 4 implies that the sign of $dP^{no}(c)/dc$ is the same as the sign of:

$$\begin{aligned}
&\frac{K}{(P^{no}+K)^2} M\pi \frac{d\sigma(P^{no},c)}{dc} - 1 \\
&= \frac{K}{(P^{no}+K)^2} M\pi \frac{1}{\mu} - 1 \\
&= \frac{c}{\mu\sigma(P^{no},c)} - 1 \\
&< 0
\end{aligned}$$

where the last equality follows the definition of $P^{no}(c)$ and the inequality the definition of $\sigma(P, c)$.

7.7 Proof of Proposition 5

We denote the partial derivative of $\sigma(P, c)$ with respect to P by $\sigma_P(P, c)$.

(i) Remember that $P^{lim}(c, f)$ solves $\Delta(P, c) = f$. As f increases, the left hand side must increase; because the left hand side is increasing in P (Lemma 2), it follows that $P^{lim}(c, f)$ is increasing in f. Since the number of essential patents $\sigma(P, c)$ is independent of f and is increasing in P, the number of essential patents also increases. Finally, the variation of padding is

$$\frac{\partial}{\partial f}\left(P^{lim} - \sigma(P^{lim}, c)\right) = \frac{\partial P^{lim}(c,f)}{\partial f}\left(1 - \sigma_P(P^{lim}, c)\right)$$

which is positive if $\sigma_P(P^{lim}, c)$ is less than one. However, since $P^{lim} > P^{eq}(c)$ and since $P^{eq}(c)$ intersects the diagonal from above, the slope at P^{eq} is less than unity. By concavity of $\sigma(P, c)$ in P it is also the case that $\sigma_P(P^{eq}(c), c)$ is less than unity.

(ii) As c increases, $\sigma(P, c)$ increases by $1/\mu$; hence $\Delta(P, c)$ decreases. To restore the equality $\Delta(P, c) = f$ it is necessary to increase P, proving that $P^{lim}(c, f)$ increases with c. To facilitate the exposition we will write P^{lim} instead of $P^{lim}(c, f)$. For essential patents,

$$\frac{d\sigma(P^{lim}, c)}{dc} = \frac{\partial P^{lim}}{\partial c}\sigma_P(P^{lim}, c) + \frac{1}{\mu}$$

which is positive since $P^{lim}(c,f)$ is increasing in c. For inessential patents,

$$\frac{d(P^{lim}-\sigma(P^{lim},c))}{dc}=\frac{\partial P^{lim}}{\partial c}\left(1-\sigma_P(P^{lim},c)\right)-\frac{1}{\mu} \tag{17}$$

By the implicit function theorem,

$$\begin{aligned}\frac{\partial P^{lim}}{\partial c}&=-\frac{\partial\Delta/\partial c}{\partial\Delta/\partial P}\\&=-\frac{\frac{-1}{\mu(\sigma+K)^2}}{\frac{-\sigma_P}{(\sigma+K)^2}+\frac{1}{(P+K)^2}}\\&=\frac{1}{\mu}\frac{(P+K)^2}{(\sigma+K)^2-\sigma_P(P+K)^2}\\&>\frac{1}{\mu}\frac{1}{1-\sigma_P}\end{aligned}$$

The last inequality follows the fact that when $P>P^{eq}$, $\sigma<P$. Substituting $\frac{\partial P^{lim}}{\partial c}>\frac{1}{\mu}\frac{1}{1-\sigma_P}$ in (17) we get

$$\frac{d(P^{lim}-\sigma(P^{lim},c))}{dc}>0$$

Proving that when c increases, both essential and inessential patents increase in numbers.

7.8 Proof of Proposition 6

Let $dP^{lim}=\frac{\partial P^{lim}}{\partial c}dc+\frac{\partial P^{lim}}{\partial f}df$. Since by (i) and (ii), the partial derivatives are positive, there exist $dc>0$ and $df<0$ such that $dP^{lim}=0$. Now, we have

$$\begin{aligned}d\sigma(P^{lim},c)&=\sigma_P(P^{lim},c)dP^{lim}+\frac{1}{\mu}dc\\&=\frac{1}{\mu}dc\\&>0.\end{aligned}$$

Obviously, because $dP^{lim}=0$ and the number of essential patents increases, the number of inessential patents must decrease.