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Patrick Rey and David Salant

Ecole d'économie de Toulouse (TSE) - Manufacture des Tabacs
Aile Jean-Jacques Laffont - 21, allée de Brienne - 31000 TOULOUSE
Tél : +33 (0) 5 61 12 85 89 - Fax : +33 (0) 5 61 12 86 37 - **www.TSE-fr.eu** - contact@TSE-fr.eu

Toulouse School of Economics

Abuse of Dominance and Licensing of Intellectual Property[1]

Patrick Rey[2] and David Salant[3]

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[2]Toulouse School of Economics (GREMAQ and IDEI); email: prey@cict.fr

[3]Corresponding author, Toulouse School of Economics (TSE), FTI Consulting, Columbia Center for Tele Information and Clemson Center for Research in Wireless Communications; email: dsalant@gmail.com, tel.: +1-415-312-2003

Abstract

We examine the impact of the licensing policies of one or more upstream owners of *essential* intellectual property (IP hereafter) on the variety offered by a downstream industry, as well as on consumers and social welfare. When an upstream monopoly owner of essential IP increases the number of licenses, it enhances product variety, adding to consumer value, but it also intensifies downstream competition, and thus dissipates profits. As a result, the upstream IP monopoly may want to provide too many or too few licenses, relatively to what maximizes consumer surplus or social welfare.

With multiple owners of essential IP, royalty stacking increases aggregate licensing fees and thus tends to limit the number of licensees, which can also reduce downstream prices for consumers. We characterize the conditions under which these reductions in downstream prices and variety is beneficial to consumers or society.

Keywords: Intellectual property, licensing policy, vertical integration, patent pools.

JEL Classification Numbers: L4,L5,O3

1 Introduction

In many high technology industries, the development of any new product or service often involves hundreds and thousands of patents. Of particular concern is the so-called patent thicket problem,[1] where independent licensing policies by the owners of complementary intellectual property may give rise to *royalty stacking* – a "horizontal" form of the double marginalization problem identified by Cournot (1838)[2] – and result in prohibitively high licensing fees. This patent thicket problem is often presented as a compelling rationale for significant reform of the patent system and/or licensing policies,[3] and has led competition authorities to apply "abuse of dominance" laws in order to reduce licensing fees.[4]

This patent thicket issue is particularly problematic when it involves many patent

[1]See e.g. Shapiro (2001) for further discussion. Empirical studies of the effects of patent thickets include Heller and Eisenberg (1998), Kiley (1992) and Kitch (2003) in bio-medical research, and Geradin, Layne-Farrar, and Padilla (2007), Schankerman and Noel (2006), Walsh, Arora and Cohen (2003) and Ziedonis (2003) in technology intensive industries.

There is a related literature analyzing hold-up problems in standard setting and joint licensing agreements. See Shapiro (2010), Lichtman (2006), Lemley and Shapiro (2007). See also Farrell et al. (2007) for a comprehensive discussion.

[2]Such double marginalization problems arise whenever complementary inputs are involved; following Schmidt (2008), the "horizontal" form refers to situations where the inputs are bought by the same customer (e.g., when a product developer needs several pieces of IP), whereas the "vertical" form arises when the inputs involve different stages of a vertical chain (e.g., when a consumer buys from a retailer, who in turn buys from a manufacturer; addressing the consumer needs thus requires both "production" and "distribution" services).

[3]See for example SCM v Xerox: Paper Blizzard for $1.8 Billion," New York Times, June 27, 1977. As technology has become increasingly complex, this concern has drawn both judicial and legislative scrutiny – see Business Week Online http://www.businessweek.com/magazine/content/07_20/b4034049.htm (May 14, 2007) and http://www.businessweek.com/smallbiz/content/may2007/sb20070523_462426.htm (May 23, 2007), as well as http://www.house.gov/apps/list/press/ca28_berman/berman_patent_bill.pdf and http://www.ip-watch.org/weblog/index.php?p=427.

For opposing views, see for example Geradin, Layne-Farrar, and Padilla (2007), who argue that the theoretical conclusion lacks empirical support. Elhauge (2008) argues that previous analyses tend to start with too low a benchmark for royalties and that other factors can offset the adverse effects (if any) of patent thickets on royalties.

[4]For example, in July 2007 the European Commission sent Rambus a *Statement of Objections*, stating that Rambus may have infringed then Article 82 of the EC Treaty (now Article 102) by abusing a dominant position in the market for DRAMs. After eighteen months of procedure, in December 2009 the European Commission accepted Rambus' offer – making it a binding commitment – to put a five-year worldwide cap on its royalty rates for products compliant with the standards set by the Electron Device Engineering Council (JEDEC).

holders. In practice, however, the reality is often not of thousands of patent owners, but of thousands of patents with a few owners; moreover, patents are often licensed in groups and not individually.[5] To be sure, even a few patent owners will tend to set royalties which in aggregate exceed monopoly levels, when acting independently. This type of double marginalization can result in excessive royalties from the patent owners' standpoint and tends to reduce the number of firms in the product market. When only prices matter in that market, this reduction in competition unambiguously harms consumers and society. The impact is less clear when variety matters; as some of the customers buying from a new entrant are switching away from rivals, the revenue they generate may exceed the social value created by entry. Excessive entry can involve inefficient duplication of fixed costs, and the resulting market segmentation can lead to higher prices that hurt consumers as well as reduce social welfare.[6] In such situations royalty stacking can have beneficial effects.

To see this, consider the case of an essential intellectual property (IP hereafter), which is necessary for competing in a product market. If the IP owners can jointly determine the number of licenses and appropriate the resulting profits, they will choose the number of licenses so as to maximize industry profits. In some markets, this may lead them to restrict entry, compared to what would be socially desirable; in such a case royalty stacking, which further restricts entry, hurts consumers as well as society. But in other markets, industry profit maximization may instead generate more entry than is socially desirable – implying that consumers would benefit from restricting entry.[7] Royalty stacking then comes as a blessing, by counterbalancing the

The US Federal Trade Commission (FTC) had similarly ordered Rambus to reduce its licensing rates on the basis of Section 2 of the Sherman Act (monopolization) and of Section 5 of the FTC Act (unfair competition) – see the FTC Final order and Opinion of 2 February 2007 in Docket No. 9302. However, the Court of Appeals for the District of Columbia repelled the order, and the US Supreme Court denied to review this ruling, which led the FTC to abandon the complaint.

[5]Goodman and Myers (2005) break down the composition of portfolios for the patents declared essential to 3G PP2 technology; they find that the largest IP holder owns approximately 65% of these patents, and that the three largest portfolios account for 80% of the total number. Parchomovsky and Wagner (2005) stress the importance of patent portfolios over individual patents.

[6]For conditions under which there can be excessive or insufficient entry, see for example Lancaster (1975), Spence (1976), Dixit and Stiglitz (1977), Vickrey (1964) and Salop (1979), and Mankiw and Whinston (1986) for detailed analyses of monopolistic or spatial competition, and Katz (1980) for that case of a multiproduct monopolist; Tirole (1988, chapter 7) offers a good overview of this literature. More recently, Chen and Riordan (2007) show that the market may again provide too many or too few products in a spokes model of nonlocalized spatial competition.

[7]Let $\Pi(n)$, $C(n)$ and $W(n) = \Pi(n) + C(n)$ respectively denote industry profit, consumer surplus and social welfare, and n^{Π} and n^{W} denote the number of licenses that maximize industry profit and

bias towards excessive entry,[8] and can benefit both consumers and society; restricting entry can however lead to a number of licenses that is lower than socially desirable, to an extent such that consumers or society could be be harmed. We explore this issue using a standard framework of oligopolistic competition with product differentiation, in which IP owners can sell either fewer or more licenses than is socially desirable.[9]

Specifically, we adopt the well-known circular city model proposed by Vickrey (1964) and Salop (1979), in which the number of downstream competitors depends here on the license fees as well as on entry costs.[10] As observed by Spence (1975), the impact of entry on downstream market price is a key determinant of the desired number of licenses.[11] This market price, in turn, depends on the value of the marginal consumer served by each downstream firm. Having more downstream firms reduces transportation costs; as marginal consumers are the ones who benefit most from this, an integrated monopolist, controlling both the number of downstream outlets and their prices, would typically wish to have too many outlets.

We first consider, as a benchmark, the case of a single IP owner offering licenses for a fixed fee, on a non-discriminatory basis. The IP holder faces a trade-off: increasing the number of licenses enhances product variety, which creates added value; but it also intensifies downstream competition, which dissipates profits. As a result, the IP owner may issue either fewer or more licenses than is socially desirable

We then consider the case of two independent owners of complementary and essential IP. We find that the "patent thicket" reduces variety, as (horizontal) double

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social welfare. By a standard revealed argument, $C\left(n^W\right) < C\left(n^\Pi\right)$. Thus, whenever $n^\Pi > n^W$, consumers necessarily benefit from *reducing* the number of licenses from n^Π to n^W.

[8] In a different vein, Scotchmer (1991), Green and Scotchmer (1995), and Scotchmer and Menell (2007) stress that when early investors cannot capture the benefits accruing to subsequent investors, patent protection for complementary products should be strengthened. A key assumption for this result is that investment is sequential - different firms invest at different dates.

[9] The literature on variety has primarily focused on the polar cases of free-entry by mono-product firms (with either oligopolistic or monopolistic competition) and of a multi-product monopolist; we revisit this literature by studying instead the case where a few upstream firms (the IP owners) can affect entry and variety through their licensing terms. Also, while for expositional purposes we develop our analysis using a particular model of oligopolistic competition, our main insights would apply in other models where entry can be excessive.

[10] We will assume that any entry in the downstream market takes place at once and thus ignore the positive externalities that early adopters may exert on later ones; see Glachant and Meniere (2010) for an exploration of the role of patents on technology adoption when such externalities are present.

[11] Spence focused on quality choice, but the same insight applies to other dimensions such as variety, which an IP owner can control through the number of licenses.

marginalization leads to higher access charges and fewer downstream firms than does monopoly or joint licensing. But making the market less "segmented" also results in lower consumer prices, and the net effect benefits consumers; it may also increase social welfare when an IP monopolist (or a patent pool) would sell too many licenses.

Finally, we show that cross-licensing arrangements may alleviate the effect of royalty stacking, whereas vertical integration – namely, the acquisition of a downstream competitor by an upstream IP holder – does not affect the outcome in our setting.

The literature on IP licensing initially focused on the case of a single owner of (inessential) innovation that allows a reduction in cost in a downstream market. Arrow (1962) studied the impact of competition in that downstream market on the incentives to innovate, while most of the other pioneering work focused on specific modes of licensing such as the auctioning of a given number of licenses, flat rate licensing or per unit fees. Katz and Shapiro (1985,1986) focus on the use of flat rate licensing and study the incentive to share or auction an innovation. Kamien and Tauman (1986) show that flat rate licensing is indeed more profitable (for non-drastic, and thus inessential IP) than volume-based royalties in the case of a homogenous Cournot oligopoly.[12] This is partly a consequence of the fact that the licensing agreement offered to one firm affects its rivals' profits if they do not buy a license, and thus their bargaining position vis-à-vis the IP owner; such strategic effects do not arise in the case of essential (or, in their context, of drastic) innovation, since firms get no profit if they do not buy a license - whatever the agreements offered to their rivals. This optimality of flat rate licensing is somewhat at odds with what is observed in practice. This paradox triggered a number of authors to seek explanations for the use of royalties. For example, Muto (1993) shows that per unit fees can be more profitable in the case of Bertrand oligopoly with differentiated products;[13] Wang (1998) obtains a similar result in the original context of a Cournot oligopoly when the IP owner is one of the downstream firms, while Kishimoto and Muto (2012) extend this insight to Nash Bargaining between an upstream IP owner and downstream firms; and Sen (2005) shows that lumpiness, too, can provide a basis for the optimality of volume-based royalties.[14]

[12] See Kamien (1992) for an overview of this early literature.

[13] Hernandez-Murillo and Llobet (2006) consider monopolistic competition with differentiated products and introduce private information on the value of the innovation for the downstream firms.

[14] Faulli-Oller and Sandonis (2002) and Erutku and Richelle (2006) look at two part licensing policy when there is a differentiated product downstream duopoly and the upstream IP owner is vertically integrated with one of the downstream firms.

In a recent paper Schmidt (2008) provides an analysis of the patent thicket problem that is closely related to ours. He, too, considers a model with upstream IP owners and downstream competitors needing access to the IP. He finds that, when licensing agreements involve a simple per unit fee, vertical integration between an upstream IP owner and a downstream producer solves a "vertical" double mark-up problem – of successive monopolies – but gives the integrated firm an incentive to increase the licensing fees charged to others, so as to "raise rivals' costs".[15] Schmidt also finds that horizontal integration of IP owners is always beneficial, and reduces the "horizontal" double mark-up problem of complementary monopolies. While the model is in many respects more general (e.g., by allowing for more general demand specifications or alternative forms of oligopolistic competition), it does not consider the impact of horizontal integration of IP owners or patent pools on downstream market variety. In contrast, we show that horizontal integration or patent pools are not always beneficial when accounting for such impact.[16]

2 Framework

A single upstream firm owns a technology, protected by IP rights. These IP rights are a key input to be active in a downstream market. In the basic model the IP owner does not use the technology but licences it instead to downstream competitors; we subsequently consider the case of multiple, complementary IP owners, and also discuss the impact of vertical integration.

As mentioned in the introduction, we adopt the circular city model of Vickrey (1964) and Salop (1979). A mass one of consumers are uniformly distributed along a circle of length one. A consumer buying from a firm "located" at a distance d gets a utility r but incurs a "transportation cost" td. Any number of firms each willing to incur a fixed cost f can gain access to the technology and enter the market, serving consumers at no variable costs. For expositional simplicity, we ignore integer problems and treat the number of entrants as a continuous variable.

[15] See also Layne-Farrar and Schmidt (2009).

[16] For further analyses of the impact of licensing policy and vertical integration on downstream markets, see e.g. Fosfuri (2006), who stresses that competition among licensors triggers more aggressive licensing, Lerner and Tirole (2005), who study the choice among open licenses, and Rockett (1990), who notes that the licensor may choose a weak licensee, to avoid tough competition once the patent expires.

2.1 Private and social optima

Before studying the impact of access terms on downstream competition, it is useful to characterize the optimal degree of variety, both from the private standpoint of a fully integrated company, who would own and control the IP as well as the downstream firms, and from the social (i.e., total welfare) standpoint.

Lemma 1 *The industry is viable if consumers' reservation price is large enough, compared with production and transportation costs, namely, if $r^2/tf > 2$. In that case, ignoring divisibility problems, an integrated monopolist would issue $n^M \equiv \sqrt{\frac{t}{2f}}$ licenses, which is more than the socially desirable number of downstream firms, $n^W \equiv \sqrt{\frac{t}{4f}}$.*

Proof. An integrated monopolist would serve the entire market (or none) and distribute its outlets uniformly along the circle in order to minimize transportation costs and thus maximize demand. Setting up n outlets then allows the monopolist to charge $p(n) = r - \frac{t}{2n}$, and the resulting profit $p(n) - nf$ is maximal for $n^M = \sqrt{\frac{t}{2f}}$. By contrast, total welfare is equal to $r - T(n) - nf$, where $T(n) \equiv 2n \int_0^{1/2n} tx dx = \frac{t}{4n}$ denotes total transportation costs, and is maximal for $n^W \equiv \sqrt{\frac{t}{4f}}$. ■

When deciding whether to add a downstream outlet, an integrated monopolist – who fully internalizes the entry cost f – focuses on its impact on marginal consumers (since they are the ones that determine prices), which are those consumers furthest away from the existing outlets and thus could benefit most from the introduction of additional outlets. In contrast, total welfare takes into consideration the impact on all consumers, including inframarginal ones.[17] As a result, a fully integrated monopolist has an incentive to introduce excessively many downstream subsidiaries.

2.2 Downstream competition

We now describe the downstream equilibrium price and profits, assuming that n firms uniformly distribute themselves along the circle:

Lemma 2 *Suppose that n firms are uniformly distributed along the circle. There then exists a symmetric equilibrium, which is as follows:*

- $n < \underline{n} \equiv \dfrac{t}{r}$ *(local monopoly): downstream firms charge $p^m \equiv \dfrac{r}{2}$ and each obtain $\pi^m = \dfrac{r^2}{2t} - f$; the aggregate profit, consumer surplus and welfare all increase proportionally to n that range.*

[17] See Spence (1975).

- $n > \overline{n} \equiv \dfrac{3}{2}\dfrac{t}{r}$ *(Hotelling): the downstream margin reflects the degree of differentiation,* t/n*; increasing* n *reduces the resulting Hotelling (aggregate) profit,* $\Pi^H(n) \equiv \dfrac{t}{n} - nf$*, and benefits consumers via lower prices and enhanced variety.*

- $\underline{n} \leq n \leq \overline{n}$ *(market segmentation): downstream firms charge the maximal price that their marginal consumers are willing to pay and the aggregate profit coincides with that of an integrated monopoly,* $\hat{\Pi}(n) \equiv r - \dfrac{t}{2n} - nf$*; an increase in* n *allows firms to charge higher prices to their marginal consumers, which more than offsets the benefit of enhanced variety and reduces consumer surplus.*[18]

Proof. See Salop (1979).[19] ■

This simple and well-known discrete choice model is thus flexible enough to reflect the benefits of variety for consumers, as well as conflicting effects of entry on prices: when $n > \overline{n}$, entry drives down prices and aggregate profit, whereas when $\underline{n} < n < \overline{n}$,), through increased market segmentation entry allows instead firms to extract a bigger share of consumers' benefit from variety, resulting in *higher* prices and gross profits at the expense of consumers).[20]

2.3 Optimal licensing

Finally, we study the monopoly IP owner's optimal licensing policy, given its impact on the downstream market. To fix ideas, we assume that the IP holder charges a *fixed fee* ϕ per license (we later discuss alternative licensing arrangements) and consider the following timing:

- First, the IP owner sets the fee, ϕ, for its licenses; this fee is non-discriminatory and licenses are available to any firm wishing to enter the downstream market.[21]

- Second, potential entrants decide whether to buy a license or not; for the sake of exposition, we assume that firms entering the market locate themselves uniformly along the circle; this minimizes total transportation costs and is thus desirable for consumers as well as for the upstream firm.

[18] Consumer surplus is equal to $2n\int_0^{r/2t} txdx = nr^2/4t$ for $n < \underline{n}$, to $2n\int_0^{1/2n} txdx = t/4n$ for $\underline{n} \leq n \leq \overline{n}$ and to $r - t/4n - p^*(n) = r - 5t/4n$ for $n > \overline{n}$.

[19] Vickrey (1964) provided the first analysis of the third case.

[20] The spokes model of Chen and Riordan (2007) has similar features.

[21] Allowing for secret, possibly discriminatory licensing terms might give the IP owner an incentive to behave opportunistically and issue more licenses than it would otherwise. See Hart and Tirole (1990), O'Brien and Shaffer (1992) and McAfee and Schwartz (1994), or Rey and Tirole (2007) for an overview of this literature.

- Third, licensees compete in prices on the downstream market.

It can be checked that, as n increases, the equilibrium profit of a downstream firm (gross of the license fee ϕ), $\pi^*(n)$, first remains constant at the local monopoly level, π^m (as long as n remains below $\underline{n}$), and then strictly decreases: $\hat{\Pi}(n)/n$ decreases with n when $n > \underline{n}$, and $\Pi^H(n)/n$ always decreases with n. If follows that, by setting the licensing fee to $\phi^*(n) = \pi^*(n)$, the IP owner can induce exactly n firms to enter, and capture all of the donwstream firms' profits. This upstream IP owner will thus choose the fee so as to maximize downstream industry profits:

$$\max_n n\pi^*(n) = \Pi^*(n).$$

Without loss of generality, we can restrict attention to $n \geq \underline{n}$. Moreover, the IP holder will never choose $n > \overline{n}$, as Hotelling competition would dissipate profit ($\Pi^H(n)$ decreases with n). Thus, the IP holder will never choose $n > \overline{n}$. Over what is the relevant range $[\underline{n}, \overline{n}]$, industry profit coincides with the integrated monopoly profit ($\Pi^*(n) = \hat{\Pi}(n)$), which is concave and maximal for $n = n^M$. Therefore, the industry profit is globally quasi-concave and the upstream firm will find it optimal to induce the entry of n^Π downstream firms, where

$$n^\Pi \equiv \min\left\{n^M, \overline{n}\right\}.$$

It can be checked that: (i) the IP holder makes positive profits whenever the industry is viable (i.e., $r^2/tf > 2$); (ii) $n^M > \overline{n}$ if and only if $r^2/tf > 9/2$; and (iii) $n^W > \overline{n}$ if and only if $r^2/tf > 9$. Since $n^M > n^W$ from Lemma (1), we have:[22]

Proposition 3 *Suppose that the market is viable: $r^2/tf > 2$; then:*

- *if $r^2/tf < 9$, the IP owner lets too many firms enter the downstream market, compared with what would be socially desirable;*
- *if instead $r^2/tf > 9$, the IP owner lets too few firms enter the downstream market.*

Thus, when variety is "cheap" (i.e., the fixed cost f is small) and/or "not highly regarded" (i.e., the transportation cost t is small, implying that variety is not very

[22] When $r^2/tf < 4$, dowstream competition is viable but implementing the welfare optimum involves $n^W < \overline{n}$ and requires prices below $p^*\left(n^W\right) = p^m$, so as to keep serving all consumers. The number of firms that maximizes welfare, *given the resulting downtream equilibrium price* $p^*(n)$, is then $\underline{n}$, which thus exceeds n^W but remains below $n^\Pi = \overline{n}$.

valuable) compared with the intrinsic value of the good (as measured by r), the upstream IP holder issues too few licences: it would be desirable in that situation to have more firms in the downstream market, but competition would dissipate the profits that the IP owner can recover. When instead variety is costly and/or particularly valuable (i.e., f and t are large), the IP holder issues too many licenses: increasing variety raises the price that marginal consumers are willing to pay, which then increases industry profit in spite of the increased competition. This ambiguity in the comparison between the privately and socially desirable numbers of firms reflects a similar ambiguity for the licensing fees: the IP owner charges an excessively high fee when $r^2/tf > 9$, but charges instead too low a fee when $r^2/tf < 9$.

Finally, it can be noted that the IP owner's inability to fully control the downstream firms' pricing policies limits the risk of excessive entry. In the present set-up, where a fully integrated industry would generate more variety than is socially desirable (i.e., $n^W < n^M$), the IP owner's inability to prevent profit dissipation through Hotelling-like product market competition tends to limit the number of downstream firms, which, in turn, reduces the scope for excessive entry (e.g., when $n^\Pi < n^W < n^M$).

3 Complementary technologies

We now consider a situation where here are two upstream firms, U_1 and U_2, which own IP rights. We assume that each upstream firm controls an essential technology and.that these two technologies are perfect complements: downstream firms require access to both technologies to be able to compete in the downstream market, and no downstream firm can even operate without access to both technologies. When a single firm owns both technologies, or alternatively when the IP owners set-up a patent pool, the firm or the pool could issue a joint license covering technologies. Then the analyis of the case of a single IP owner case would apply. We now contrast the outcome of *independent licensing* by two IP owners with the case of a single IP owner or a pool issuing joint licenses.

For this case of two IP holders independently marketing their rights, the timing of licensing and pricing decisions is adjusted as follows:

- First, each IP owner, $i = 1, 2$, simultaneously and independently sets its license fee, ϕ_i.
- Second, potential downstream entrants decide whether or not to buy the li-

censes; as before, those that enter locate themselves uniformly along the circle.

- Third, downstream competitors set their prices.

As already mentioned in the introduction, independent licensing creates a "horizontal" double marginalization problem that leads to higher total fees. It may even trigger a "coordination breakdown" where both IP owners charge prohibitively high fees, thereby discouraging any downstream firm from entering the market: indeed, any pair of fees satisfying $\phi_1, \phi_2 \geq \pi^m$ constitutes indeed an equilibrium. As such equilibria rely on weakly dominated strategies, we focus our discussion on equilibria in which each IP owner charges a fee below the monopoly profit π^m.

Given its rival's equilibrium fee $\phi^e < \pi^m$, U_i can induce the entry of n_i firms by setting its own fee to $\phi_i^*(n_i)$, such that

$$\pi^*(n_i) = \phi_i + \phi^e. \tag{1}$$

Each U_i will thus want to choose n_i (or ϕ_i) so as to maximize:

$$\Pi_i = n_i \phi_i^*(n_i) = n_i (\pi^*(n_i) - \phi^e) = \Pi^*(n_i) - n_i \phi^e.$$

We show in the Appendix that the unique equilibrium (excluding weakly dominated strategies) is symmetric ($\phi_1 = \phi_2 = \phi^D$, where the superscript D stands for "Double marginalization"), yields higher (total) fees (i.e., $2\phi^D > \phi^\Pi$), and leads to a number of firms equal to:

$$n^D \equiv \frac{r}{2f}\left(\sqrt{1 + 6\frac{tf}{r^2}} - 1\right),$$

which is such that $\underline{n} \leq n^D < n^\Pi = \min\{n^M, \overline{n}\}$. Comparing the outcomes of independent and joint licensing yields:

Proposition 4 *Suppose that the market is viable: $r^2/tf \geq 2$; then, compared with single or joint licensing, independent licensing by two IP holders leads to:*

- *higher upstream fees but lower downstream prices;*
- *fewer downstream firms and lower industry profits but higher consumer surplus;*
- *higher (resp., lower) social welfare if $r^2/tf < \rho = 54/7$ (resp., $r^2/tf > \rho$).*

Proof. See Appendix A. ■

As expected, double marginalization from independent licensing raises the total fee charged for a license and thus reduces the number of licenses that are issued.

Compared with joint licensing, this can only reduce industry profit. The impact of this royalty stacking on social welfare is less clear-cut. To be sure, it is undesirable when too few licenses would be issued under joint licensing (that is, when $r^2/tf > 9$ from Proposition 3). When instead, joint licensing generates excessive entry, double marginalization counters this bias and can enhance welfare. In particular, independent licensing is always beneficial when these IP owners would still issue too many licenses (which is indeed the case when $r^2/tf < 25/4$), as double marginalization then brings the number of licenses closer to the social optimum (since $n^\Pi > n^D > n^W$). In the intermediate range (that is, when $25/4 < r^2/tf < 9$), royalty stacking reduces variety more than is socially desirable but still enhances welfare as long as it does not "overshoot," i.e., for r^2/tf below the threshold level, $\rho = 54/7$.

As royalty stacking always reduces industry profits, it must benefit consumers whenever it enhances welfare. More surprisingly, independent licensing *always* benefits consumers – when royalty stacking reduces welfare, it is not by harming consumers, but by hurting profits more than benefitting consumers. To understand why independent licensing benefits consumers, note first that under joint licensing, the IP owners always seek to avoid standard Hotelling competition because it dissipates (aggregate) profits, and thus issue fewer than $\overline{n}$ licences. Therefore, the IP owners never issue so many licenses as to leave marginal consumers with a positive surplus. By reducing downstream variety, independent licensing benefits (infra-marginal) consumers, and increases consumer surplus Consumers may even prefer this double marginalization situation to *royalty-free* licenses, unless the royalty-free equilibrium results in significantly more than $\overline{n}$ firms.[23]

4 Extensions and discussion

We consider here alternative organizations and market structures. We first show that cross-licensing agreements can be a substitute for joint licensing and solve double marginalization problems. We then note that vertical integration appears to have little impact on the equilibrium outcome in this model. Finally, we discuss the

[23] Consumer surplus decreases with n in the range $[\underline{n}, \overline{n}]$ and then increases with n for $n > \overline{n}$. Let denote by n^f the number of downstream firms when licenses are free (i.e., such that $\pi^*\left(n^f\right) = 0$) and by $\hat{n} > \overline{n}$ the number of firms that yields as much surplus as n^D. Then, as long as $n^f \leq \hat{n}$ (that is, when f is "large enough"), the outcome of IP duopoly and double marginalization is better for consumers than the free-entry equilibrium – in that case, the number of firms that maximize consumer surplus, subject to non-negative profit constraint, is $\underline{n}$; when $n^f > \hat{n}$, however, consumers would prefer to have "as many firms" as possible and free-entry would work better for them.

robustness of our insights to alternative royalty schemes.

4.1 Cross-licensing

The IP holders could instead opt for cross-licensing agreements, allowing them to issue "complete" licenses covering both technologies, subject to one IP owner paying the other a unit fee for each license the IP owner issues to a downstream firm. Suppose first the IP holders enter into a *reciprocal* cross-licensing agreement allowing *each of them* to issue complete licenses, by paying the other a fee equal to ψ. As we show in Appendix B, as long as the reciprocal fee ψ is not too large (namely, $\psi \leq \phi^D$), Bertrand competition between the two upstream firms leads them to set their fees (for complete licenses) to

$$\Phi_1 = \Phi_2 = \Phi \equiv 2\psi.$$

Each U_i is then indifferent between issuing a license and earning $\Phi - \psi = \psi$, or letting the other IP holder issue the license and earning ψ. (If $\psi > \phi^D$, implying $\psi > \phi^R(\psi)$, the IP owners would instead have an incentive to undercut each other). Clearly, as long as this equilibrium prevails, it is optimal for the IP holders to adjust the *upstream* cross-licensing fee ψ to $\phi^\Pi/2$, so as to drive the *downstream* licensing fee $\Phi = 2\psi$ to ϕ^Π and share the integrated monopoly profit. Conversely, $n^\Pi > n^D$ ensures that $\phi^\Pi/2 < \phi^D$, implying that setting ψ to $\phi^\Pi/2$ indeed yields the desired outcome. Such a cross-licensing arrangement thus formally achieves the same outcome as a merger or patent pool.

If instead each U_i independently sets its upstream fee ψ_i, then cross-licensing can again mitigate double marginalization problems but does not eliminate them entirely:

Proposition 5 *Suppose that the two IP holders enter into a cross-licensing agreement, allowing them to issue complete licenses for the technology by paying the other an upstream fee per license issued; then:*

- *by agreeing on a reciprocal upstream the IP holders achieve the same outcome as under joint licensing;*
- *if instead the IP holders set their upstream fees independently, there are multiple equilibria, with a number of downstream firms lying in $[n^D, n^C]$, where $n^D < n^C < n^\Pi$.*

Proof. See Appendix B. ■

4.2 Vertical integration

Vertical integration has little impact here, whatever the number of IP owners. To see this, note first that vertical integration: (i) does not change the profit function, and therefore has no effect on the behavior of non-integrated downstream firms; and (ii) does not affect the behavior of the subsidiary either since, once it has sold its licenses, the variable profit of an integrated firm coincides with that of its downstream subsidiary. Therefore, as before, a total licensing fee $\phi(n) = \pi^*(n)$ will again induce the entry of exactly n downstream competitors (integrated or not).

When the integrated firm is the sole IP holder, it then wants to set n so as to maximize:

$$\pi^*(n) + (n-1)\phi(n) = n\pi^*(n),$$

and again chooses to let n^Π firms (including its own subsidiary) enter the downstream market.

When instead there is another IP holder, who sets a licensing fee ϕ^e, the integrated IP holder U_i will again seek to let n_i firms so as to maximize:

$$\pi^*(n_i) - \phi^e + (n_i - 1)(\pi^*(n_i) - \phi^e) = \Pi^*(n_i) - n_i\phi^e,$$

and thus its licensing behavior is thus the same as if it was not integrated. As a result, the equilibrium outcome is the same, whether the IP holders are vertically integrated or not. The same reasoning applies to both IP holders when they are each integrated with a single distinct downstream subsidiary. We thus have:

Proposition 6 *Vertical integration by one or more IP holders, each with a single downstream firm, does not affect the equilibrium outcome.*

The neutrality of vertical integration relies here on the fact that the final demand is inelastic (and in equilibrium the IP holder has always an incentive to issue sufficiently many licenses to cover the market). As Schmidt (2008) observed, when the final demand is elastic, vertical integration can alleviate (vertical) double mark-up problems, enhancing coordination between upstream and downstream pricing decisions within the integrated firm, as well as providing the integrated IP owner an incentive to increase its licensing (unit) fees, in order to "raise rivals' costs" and benefit from the resulting foreclosure effect;[24] vertical integration may also allow the IP

[24]See Ordover, Salop and Saloner (1990) and Salinger (1988). More recently, Allain, Chambolle and Rey (2011) show that vertical integration can discourage downstream innovation when downstream firms must exchange sensitive information with their suppliers in order to implement an innovation.

owner to better exert its market power,[25] or induce the downstream subsidiary to become less aggressive.[26]

Remark: Joint licensing. Proposition 6 extends to joint licensing. If for example a pool sets the licensing fee ϕ and redistributes half of the profit to each IP owner, the pool manager will pick the total number of firms n (by setting $\phi = \pi^*(n)$) so as to maximize:

$$\pi^*(n) + \frac{(n-2)\phi}{2} = \pi^*(n) + \frac{(n-2)\pi^*(n)}{2} = \frac{n\pi^*(n)}{2} = \frac{\Pi^*(n)}{2}.$$

The pool manager thus again maximizes total profits and chooses $n = n^{\Pi}$.

4.3 Alternative licensing arrangements

The IP holders could better control price and variety through the use of more complex licensing arrangements. For example, in the absence of informational problems, two-part tariffs would generally allow an upstream monopolist to replicate the fully integrated monopoly outcome. Similarly, more sophisticated licensing schemes than the fixed licensing fees considered above could help the IP holders to overcome double marginalization problems. In a previous version of the paper,[27] we showed that in our simple setting *per unit* fees actually suffice to avoid double marginalization problems and achieve the fully monopoly outcome – whether the IP holders are vertically integrated or not; by contrast, royalty percentages based on (variable) profits still give rise to some double marginalization problems.

5 Conclusion

Patent thickets have long been a concern due to the potential for delaying product deployment and adversely affecting consumers. We examine the implications of such patent thickets for downstream market structure and product variety as well as prices and welfare. In the absence of vertical licensing agreements, it is well known that there can be excessive entry, due e.g. to business stealing effects, or insufficient entry,

[25] In case of secret contracting, vertical integration may help limiting the risk of opportunistic behavior that would otherwise lead the IP owner to issue too many licenses (see See Hart and Tirole (1990) and the discussion in footnote 21), since issuing an additional license then hurts the integrated subsidiary as well as the other downstream competitors.

[26] See Chen (2001), who stresses that the downstream subsidiary will internalize the impact of its behavior on the sales of the integrated supplier.

[27] See Rey and Salant (2010).

if firms entering the market appropriate only part of the surplus they generate. We revisit this issue, taking into account the gatekeeper role that upstream IP owners play through their licensing policies, and show that royalty stacking can play a beneficial role for consumers and society in situations of excessive variety.

We adopt a standard horizontal differentiation framework and first consider the case in which a single owner of essential IP controls entry in the downstream market and can appropriate the resulting profits through licensing fees. The IP holder internalizes any business stealing effect, and can choose to sell a larger or smaller number of licenses than is socially optimal. Granting too many licenses occurs when variety is particularly valuable or very costly, in which case issuing additional licensees allows the IP to extract a larger share of the surplus that consumers derive from enhanced variety. When instead downstream products are close substitutes, competition dissipates profits and the IP holder tends to issue too few licenses or, equivalently, charges too high fees for these licenses.

When there are two or more upstream IP owners, royalty stacking reduces both the number of licensees and industry profits but, by limiting market segmentation, it also leads to lower prices and higher consumer surplus. Independent licensing can also enhance social welfare, except if it excessively limits the number of licenses, in which case profits fall by more than consumer benefits increase, and social welfare is reduced.

As royalty stacking always reduces IP holders' profits, they have an incentive to develop licensing arrangements, such as patent pools or cross-licensing agreements, that allow them to solve the double marginalization problems. We also show that, as vertical integration does not alter the behavior of affiliated downstream subsidiaries, it has no effect on the equilibrium outcome and thus does not affect our analysis. Finally, we discuss the robustness of our insights to alternative types of licensing schemes, such as per-unit fees or profit-based royalties.

Products offered in high technology industries are often quite differentiated and embody the (sometimes extensive) patent portfolios of a few firms. Our analysis indicates that royalty stacking in such industries may have a more ambiguous impact than the patent thicket literature suggests.

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Appendix

A Proof of Proposition 4

Given the two IP owners' fees ϕ_1 and ϕ_2, the number of downstream firms entering the market is given by $n^*(\phi_1 + \phi_2)$, where

$$n^*(\phi) \equiv \begin{cases} (\pi^*)^{-1}(\phi) & \text{when} \quad \phi < \pi^m, \\ \text{any } n \leq \underline{n} & \text{when} \quad \phi = \pi^m, \\ 0 & \text{when} \quad \phi > \pi^m. \end{cases}$$

Each U_i then obtains a profit equal to

$$\Pi_i = n^*(\phi_1 + \phi_2)\,\phi_i.$$

As already noted, independent licensing may trigger a "coordination breakdown", where both IP owners charge fees higher than the monopoly profit π^m and no downstream firm enters the market. These equilibria however involve weakly dominated strategies, and we now focus instead on equilibria in which both upstream firms charge a fee lower than π^m.

Fix the rival's fee $\phi_j < \pi^m$ and suppose first that U_i considers inducing a number $n_i > \overline{n}$ of downstream firms, by setting a fee ϕ_i such that $\phi_i + \phi^e = \pi^*(n_i) = \pi^H(n_i)$; U_i would then rather increase ϕ_i in order to reduce n_i to $\overline{n}$, since its profit, given by

$$\Pi_i = n_i\phi_i = n_i\left(\pi^H(n_i) - \phi^e\right) = \Pi^H(n_i) - n_i\phi^e,$$

decreases in n_i (since $\Pi^H(n)$ decreases in n). Therefore, U_i will never issue more than $\overline{n}$ licenses. Similarly, setting $\phi_i = \pi^m - \phi_j$ induces any $n \leq \underline{n}$ firms to enter and gives U_i a profit

$$\Pi_i = n_i\left(\pi^m - \phi_j\right),$$

which is positive and proportional to the number of firms; hence U_i will never issue less than $\underline{n}$ licences.

Thus, without loss of generality, we can assume that U_i sets a fee ϕ_i such that $\phi_i + \phi_j \in [\overline{\pi}, \pi^m]$, where

$$\overline{\pi} \equiv \pi^*(\overline{n}) = \frac{4r^2}{9t} - f,$$

so as to induce a number of firms $n_i \in [\underline{n}, \overline{n}]$, given by $\phi_i + \phi_j = \pi^*(n_i) = \hat{\pi}(n_i)$, that maximizes

$$\Pi_i = n_i\phi_i = n_i\left(\hat{\pi}(n_i) - \phi_j\right) = \hat{\Pi}(n_i) - n_i\phi_j = r - \frac{t}{2n_i} - n_i\left(f + \phi_j\right). \qquad (2)$$

Ignoring the constraint $n_i \in [\underline{n}, \overline{n}]$ would lead U_i to choose

$$n_i = n^M \left(f + \phi_j\right) = \sqrt{\frac{t}{2\left(f + \phi_j\right)}}, \tag{3}$$

which is larger than $\underline{n}$ when $\phi_j \leq \pi^m$ and is also smaller than $\overline{n}$ as long as

$$\phi_j \geq \hat{\phi} \equiv \frac{2r^2}{9t} - f,$$

where $\hat{\phi} < \pi^m$ and $\hat{\phi} > 0$ is equivalent to $\overline{n} < n^M$. Therefore:

- if $\overline{n} < n^M$, U_i's best response to $\phi_j \leq \pi^m$ is to induce a number of firms equal to $\overline{n}$ for $\phi_j \leq \hat{\phi}$ and to $n^M \left(f + \phi_j\right)$ otherwise, where $n^M (f + \phi)$ denotes the integrated monopoly outcome for a fixed cost equal to $f + \phi$ instead of f; the corresponding fee is then $\phi_i = \phi^R \left(\phi_j\right)$, where $\phi^R (.)$ is defined by:

$$\phi^R (\phi) \equiv \begin{cases} \overline{\pi} - \phi & \text{when } \phi \leq \hat{\phi}, \\ \hat{\pi} \left(n^M (f + \phi)\right) - \phi & \text{when } \hat{\phi} \leq \phi \leq \pi^m. \end{cases}$$

- if $\overline{n} \geq n^M$, U_i's best response to $\phi_j \leq \pi^m$ is always to induce a number of firms $n_i = n^M (f + \phi_i)$ with a fee equal to $\hat{\pi} \left(n^M \left(f + \phi_j\right)\right) - \phi_j$.

In both cases, in the range $\phi \in [0, \pi^m]$ the resulting number of firms is $n^R (\phi) \equiv \min \left\{\overline{n}, n^M (f + \phi)\right\}$, which weakly decreases from n^Π to $\underline{n}$ as ϕ increases, whereas the best response ϕ^R is continuous and decreases from $\phi^R (0) = \phi^\Pi$ to $\phi^R (\pi^m) = 0$: the slope is equal to -1 for $\phi > \hat{\phi}$ and, for $\phi > \hat{\phi}$, using

$$\hat{\pi} \left(n^M (f + \phi)\right) - \phi = \frac{r}{\sqrt{\frac{t}{2(f+\phi)}}} - \frac{t}{2\frac{t}{2(f+\phi)}} - (f + \phi) = \frac{r}{\sqrt{t}} \sqrt{2 (f + \phi)} - 2 (f + \phi).$$

we have:

$$\frac{d\phi^R}{d\phi} (\phi) = \frac{r}{\sqrt{t}} \frac{1}{\sqrt{2 (f + \phi)}} - 2 = n^M (f + \phi) / \frac{t}{r} - 2,$$

where $n^M (f + \phi)$ decreases from $\frac{3}{2} \frac{t}{r}$ to $\frac{t}{r}$ as ϕ increases from $\hat{\phi}$ to π^m; the slope thus lies between $-1/2$ and -1. Therefore, the best responses $\phi_i = \phi^R \left(\phi_j\right)$, for $i \neq j = 1, 2$, cross once and only once in the range $[0, \pi^m]$. Therefore, there is unique equilibrium in this range, which is moreover symmetric: $\phi_1 = \phi_2 = \phi^D$ and $n_1 = n_2 = n^D$. Furthermore, since $\overline{\pi} - 2\hat{\phi} = f > 0$, we have $\overline{\pi} - \hat{\phi} > \hat{\phi}$, as illustrated by Figure 1; the equilibrium thus satisfies $\phi^D > \hat{\phi}$ and $n^D < \overline{n}$, and is therefore characterized by:

$$n^D = n^M\left(f + \phi^D\right) = \sqrt{\frac{t}{2\left(f + \phi^D\right)}} \text{ and } 2\phi^D = \hat{\pi}\left(n^D\right) = \frac{1}{n^D}\left(r - \frac{t}{2n^D}\right) - f.$$

These two conditions imply:

$$2\phi n^2 = t - 2fn^2 = rn - \frac{t}{2} - fn^2,$$

and thus:

$$fn^2 + rn - \frac{3t}{2} = 0, \tag{4}$$

which has a unique non-negative solution:

$$n^D \equiv \frac{r}{2f}\left(\sqrt{1 + \frac{6tf}{r^2}} - 1\right).$$

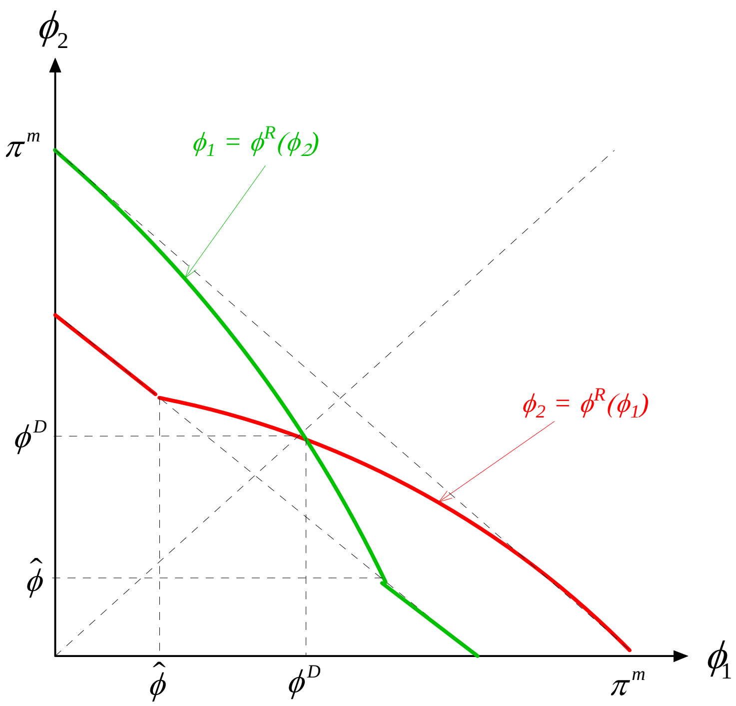

Figure 1: Best response fees for complementary technologies

It is straightforward to confirm that double marginalization leads to fewer licenses being issued. This is obvious in the case of coordination breakdown, where no license is issued; and when the upstream firms coordinate on the above equilibrium, $\phi^D > \hat{\phi}$ implies $n^D = n^R\left(\phi^D\right) < n^R(0) = n^{\Pi}$.

This reduction in the number of licenses can only be socially harmful when too few licenses would be issued even under joint licensing, that is, when $r^2/tf > 9$. Conversely, it can only enhance welfare when too many licenses remain issued under independent licensing (implying $n^{\Pi} > n^D > n^W$, so that independent licensing brings the number of licenses closer to the social optimum), which is the case when $r^2/tf < 25/4$. In the intermediate range (that is, when $25/4 < r^2/tf < 9$), royalty stacking counterbalances IP owners' bias towards excessive variety and can thus enhance welfare provided it does not "overshoot". Since $n^{\Pi} = \overline{n}$ in that range ($n^M > n^{\Pi} = \overline{n}$ when $r^2/tf > 9/2$, and $25/4 > 9/2$), independent licensing is socially beneficial when welfare is higher with n^D than with $\overline{n}$, that is, when:

$$r - \frac{t}{4n^D} - n^D f = \frac{r}{12}\left(17 - 7\sqrt{1 + \frac{6tf}{r^2}}\right) > r - \frac{t}{4\overline{n}} - \overline{n}f = \frac{r}{6}\left(5 - \frac{9tf}{r^2}\right),$$

which boils down to $r^2/tf < \rho$, where $\rho = 54/7$ lies indeed between $25/4$ and 9.

B Proof of Proposition 5

We analyze here the situation where the upstream firms allow each other to license their own technology. We will denote by ψ_i the (upstream) fee that U_i charges to U_j for each license it issues, and by Φ_j the (downstream) fee charged by U_j for a "complete" license covering both technologies. The timing is as follows:

- first, the IP owners set the upstream fees ψ_1 and ψ_2 (more on this below);
- second, the IP owners set their downstream fees Φ_1 and Φ_2;[28] the downstream firms then decide whether to buy a license and enter the market.

We first characterize the continuation equilibria of the second stage, for given upstream fees ψ_1 and ψ_2. We then consider two scenarios for the first stage: in the first scenario, the IP owners jointly agree on a reciprocal fee $\psi_1 = \psi_2 = \psi$; in the second scenario, the two IP owners sets their fees simultaneously and independently.

B.1 Competition on complete licenses

We take here the upstream fees ψ_1 and ψ_2 as given and consider the second stage, where the two IP owners charge fees Φ_1 and Φ_2 for "complete" licenses; downstream

[28] Each IP owner could also offer partial licenses, covering its own IP, at a fee ϕ_i; for the sake of exposition, we will assume that they only offer "complete" licenses – the resulting equilibria can be supported by setting $\phi_1, \phi_2 > \pi^m$.

entrants then buy a license from the cheapest licensor and, given $\Phi = \min\{\Phi_1, \Phi_2\}$, the number of entrants is equal to $n^*(\Phi)$.

Note first that each U_i is unwilling to sell a complete license for a fee Φ_i lower than U_j's upstream fee ψ_j. Therefore, if $\min\{\psi_1, \psi_2\} > \pi^m$, then no license is issued and both IP owners get zero profit. If $\min\{\psi_1, \psi_2\} = \pi^m$, there are multiple continuation equilibria, in which the upstream firms set downstream fees exceeding π^m or serve up to $\underline{n}$ licences at a fee $\Phi = \pi^m$, thereby sharing up to $\underline{n}\pi^m$.

We now turn to the case $\min\{\psi_1, \psi_2\} < \pi^m$ and consider first a candidate equilibrium where $\Phi_1 = \Phi_2 = \Phi$. Each U_i can then obtain $n(\Phi)\psi_i$ by increasing its fee Φ_i (letting the other IP owner sell its license to all downstream entrants) and can also obtain $n(\Phi)\left(\Phi - \psi_j\right)$ by slightly undercutting its rival. Therefore, it must be the case that $\Phi = \psi_1 + \psi_2$. Conversely, $\Phi_1 = \Phi_2 = \psi_1 + \psi_2$ constitutes an equilibrium as long as no U_i benefits from undercutting its rival, which is the case when

$$\Phi_i < \psi_1 + \psi_2 \implies n^*(\Phi_i)\left(\Phi_i - \psi_j\right) < n^*(\psi_1 + \psi_2)\psi_i,$$

or, using $\varphi_i \equiv \Phi_i - \psi_j$ as the decision variable, when

$$\varphi_i < \psi_i \implies n^*\left(\varphi_i + \psi_j\right)\varphi_i < n^*\left(\psi_i + \psi_j\right)\psi_i. \tag{5}$$

Since the profit function $n^*\left(\varphi_i + \psi_j\right)\varphi_i$ is strictly quasi-concave in φ_i[29] and maximal for $\varphi_i = \phi^R\left(\psi_j\right)$, (5) boils down to $\psi_i \leq \phi^R\left(\psi_j\right)$; this symmetric equilibrium thus exists when $\psi_1 \leq \phi^R(\psi_2)$ and $\psi_2 \leq \phi^R(\psi_1)$ (implying $\psi_1, \psi_2 < \pi^m$, see Figure 1).

Consider now a candidate equilibrium in which $\Phi_i < \Phi_j$, implying that the two IP owners obtain respectively (posing $\varphi_i = \Phi_i - \psi_j$):

$$\begin{aligned} \Pi_i &= n^*(\Phi_i)\left(\Phi_i - \psi_j\right) = n^*\left(\varphi_i + \psi_j\right)\varphi_i, \\ \Pi_j &= n^*(\Phi_i)\psi_j = n^*\left(\varphi_i + \psi_j\right)\psi_j. \end{aligned}$$

U_i should not be able to gain from small deviations, which implies $\varphi_i = \phi^R\left(\psi_j\right)$ (and thus $\Phi_i = \Phi^R\left(\psi_j\right)$, $n = n^R\left(\psi_j\right)$), and should not gain either from letting U_j sell at Φ_j, which requires $\Pi_i = n^R\left(\psi_j\right)\phi^R\left(\psi_j\right) \geq n^*(\Phi_j)\psi_i$; Φ_j must therefore be "large enough" (any $\Phi_j > \pi^m$, for which $n^*(\Phi_j) = 0$, would do). In addition, U_j should not gain from undercutting U_i, that is:

$$\Pi_j = n^R\left(\psi_j\right)\psi_j \geq \max_{\Phi \leq \Phi^R\left(\psi_j\right)} n^*(\Phi)(\Phi - \psi_i). \tag{6}$$

[29] It coincides with the industry profit, which is strictly concave, when $\varphi_i + \psi_j \in [\overline{\pi}, \pi^m]$, drops to zero when $\varphi_i + \psi_j > \pi^m$ (and lies anywhere between 0 and $\underline{n}\pi^m$ when $\varphi_i + \psi_j = \pi^m$), and is equal to $\Pi^H\left(n^*\left(\varphi_i + \psi_j\right)\right)$ when $\varphi_i + \psi_j < \overline{\pi}$, in which case it strictly increases with φ_i.

As already noted, the profit function $n^* (\Phi) (\Phi - \psi_i) = n^* (\varphi_i + \psi_j) \varphi_i$ is quasi-concave in Φ, and it is maximal for $\Phi = \Phi^R (\psi_i)$. Therefore:

- if $\psi_i > \psi_j$ (which implies $\Phi^R (\psi_i) > \Phi^R (\psi_j)$),[30] condition (6) (setting $\Phi = \Phi^R (\psi_j)$ in the right-hand side) boils down to $\psi_i \geq \phi^R (\psi_j)$:

$$\begin{aligned} n^R (\psi_j) \psi_j &\geq n^R (\psi_j) (\Phi^R (\psi_j) - \psi_i) \\ &\iff \psi_j \geq \Phi^R (\psi_j) - \psi_i \\ &\iff \psi_i \geq \Phi^R (\psi_j) - \psi_j = \phi^R (\psi_j) ; \end{aligned}$$

- if $\psi_i \leq \psi_j$ (and thus $\Phi^R (\psi_i) \leq \Phi^R (\psi_j)$), condition (6) amounts to (setting $\Phi = \Phi^R (\psi_i)$ in the right-hand side)

$$\hat{\Pi}^R (\psi_j) \equiv n^R (\psi_j) \psi_j \geq \Pi^R (\psi_i) \equiv n^R (\psi_i) (\Phi^R (\psi_i) - \psi_i) = n^R (\psi_i) \phi^R (\psi_i) ,$$

  where by construction the profit function $\Pi^R (\psi) = \max_\phi n^* (\psi + \phi) \phi$ decreases with ψ, whereas the profit function $\hat{\Pi}^R (\psi) = n^R (\psi) \psi$ increases with ψ.[31] Thus condition (6) requires ψ_j to be higher than some threshold $\hat{\phi}^R (\psi_i)$, which decreases as ψ_i increases. Furthermore, for $\psi_i = \phi^R (\psi_j)$ we have:

$$\hat{\Pi}^R (\psi_j) = n^* (\psi_j + \phi^R (\psi_j)) \psi_j \leq \Pi^R (\phi^R (\psi_j)) = \max_\phi n^* (\phi + \phi^R (\psi_j)) \phi,$$

  with an equality only if $\psi_j = \phi^R (\psi_i) = \phi^R (\phi^R (\psi_j))$, that is, if $\psi_i = \phi^D$; it follows that the threshold function $\hat{\phi}^R (\psi_i)$ lies above $(\phi^R)^{-1} (\psi_i)$ (and coincides with it only for $\psi_i = \psi_j = \phi^D$), as shown in Figure 2 below.

Building on these insights, we have, assuming without loss of generality that $\psi_i \leq \psi_j$ (see Figure 2):

- If $\psi_i \leq \phi^R (\psi_j)$, there is a unique, symmetric continuation equilibrium, $\Phi_1 = \Phi_2 = \psi_1 + \psi_2$; each U_i then obtains:

$$\Pi_i = n^* (\psi_1 + \psi_2) \psi_i.$$

[30] $\Phi^R (\psi) = \psi + \phi^R (\psi)$, where the slope of $\phi^R (.)$ has been shown to exceed -1.

[31] This is obvious for $\psi < \hat{\phi}$, as $n^R (\psi) = \overline{n}$ is constant in that range; and for $\psi > \hat{\phi}$, we have:

$$\hat{\Pi}^R (\psi) = n^M (f + \psi) \psi = \sqrt{\frac{t}{2 (f + \psi)}} \psi = \sqrt{\frac{t}{2} \frac{\psi}{\frac{f}{\psi} + 1}},$$

which also increases with ψ.

- If $\psi_i > \phi^R(\psi_j)$, then there is an asymmetric continuation equilibrium in which U_j charges a prohibitively high fee while U_i sells $n^R(\psi_j)$ complete licenses at a fee $\Phi^R(\psi_j)$; the two IP owners then obtain respectively:

$$U_i = \Pi^R(\psi_j), U_j = \hat{\Pi}^R(\psi_j),$$

where $\Pi^R(\psi)$ and $\hat{\Pi}^R(\psi)$ respectively decrease and increase with ψ.

- If in addition $\psi_i > \hat{\phi}^R(\psi_j)$, there is another asymmetric continuation equilibrium, in which the roles of the two IP owners are reversed.

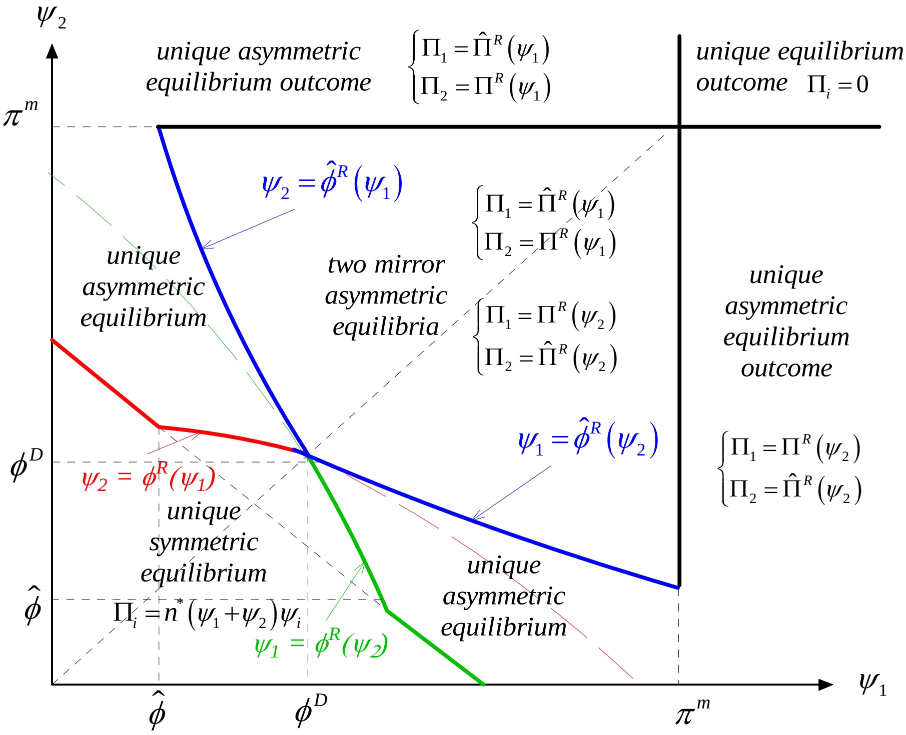

Figure 2: Competition for complete licenses

B.2 First stage of IP interaction

We now turn to the first stage and start with the scenario where the two IP owners jointly determine a reciprocal upstream fee $\psi_1 = \psi_2 = \psi$. By setting this fee to:

$$\psi^\Pi \equiv \frac{\pi^*(n^\Pi)}{2},$$

they can ensure that the second stage leads to $\Phi_1 = \Phi_2 = \pi^*(n^\Pi)$ and thus to the entry of n^Π downstream firms, and share equally the profit that an integrated IP owner could generate. In the light of the above analysis, it suffices to note that $n^D < n^\Pi$ implies $\phi^D = \pi^*\left(n^D\right)/2 > \psi^\Pi = \pi^*\left(n^\Pi\right)/2$, which in turn implies $\psi^\Pi < \phi^R\left(\psi^\Pi\right)$.

Finally, consider the alternative scenario where the two IP owners set their upstream fees simultaneously and independently. It is easy to check that (see Figure 2):

- There is no equilibrium in which $\psi_1 < \phi^R(\psi_2)$ and $\psi_2 < \phi^R(\psi_1)$: in the unique continuation equilibrium, each U_i would obtain a profit $\Pi_i = n^*(\psi_1 + \psi_2)\psi_i$ and would thus deviate and increase its fee.

- There is no equilibrium in which $\phi^R\left(\psi_j\right) \le \psi_i < \hat{\phi}^R\left(\psi_j\right)$: in the unique continuation equilibrium, U_j would then obtain a profit $\Pi_j = n^R\left(\psi_j\right)\psi_j$, which increases with ψ_j, and would thus deviate and increase its fee.

- There is no equilibrium in which $\psi_i > \pi^m > \psi_j$: in the unique continuation equilibrium, U_j would then obtain a profit $\Pi_j = n^R\left(\psi_j\right)\psi_j$, which increases with ψ_j, and would thus deviate and increase its fee.

- There is no equilibrium in which $\psi_i > \pi^m$ and $\psi_j \ge \pi^m$: in the unique continuation equilibrium, U_i would then obtain zero profit, whereas setting e.g. ψ_i to $\left(\hat{\phi}^R\right)^{-1}\left(\psi_j\right)$ would yield instead $\Pi^R(\psi_i)\psi_i > 0$.

Let us now focus on candidate equilibria where $\psi_1 \ge \hat{\phi}^R(\psi_2)$, $\psi_2 \ge \hat{\phi}^R(\psi_1)$, and $\psi_1, \psi_2 \le \pi^m$. In this region, there are two continuation equilibria, one (E_i) in which U_i sells at $\Phi^R\left(\psi_j\right)$ and earns $\Pi^R\left(\psi_j\right)$ whereas U_j earns $\hat{\Pi}^R\left(\psi_j\right)$, and another one (E_j) in which the roles are reversed. Suppose without loss of generality that $\psi_i \ge \psi_j$ (which, in this region, implies $\psi_i \ge \phi^D$); then:

- There is no equilibrium in which $\psi_k > \phi^D$ and the continuation equilibrium is E_h, where $h \ne k \in \{1,2\}$: U_h, which then obtains $\Pi^R(\psi_k)$ (where $k \ne h \in \{1,2\}$), could profitably deviate by choosing instead $\tilde{\psi}_h = \phi^R(\psi_k)\left(< \hat{\phi}^R(\psi_k)\right)$, as it would then earn

$$\hat{\Pi}^R\left(\tilde{\psi}_h\right) = n^R\left(\tilde{\psi}_h\right)\tilde{\psi}_h = n^R\left(\phi^R(\psi_k)\right)\phi^R(\psi_k) > \Pi^R(\psi_k) = n^R(\psi_k)\phi^R(\psi_k),$$

where the inequality stems from the fact that $\psi_k > \phi^D$ implies $\psi_k > \phi^R(\psi_k)$ and thus $n^R\left(\phi^R(\psi_k)\right) < n^R(\psi_k)$.

- The above argument rules out any equilibrium configuration such that $\psi_i \geq \psi_j > \phi^D$; furthermore, when instead $\psi_i \geq \phi^D \geq \psi_j$, the only possible continuation equilibrium is E_i, in which U_i obtains $\Pi^R(\psi_j)$ and U_j obtains $\hat{\Pi}^R(\psi_j)$. Conversely, this indeed constitutes an equilibrium, assuming that any deviation by U_h, for $h = 1, 2$, is followed by the continuation equilibrium E_h whenever it exists. Indeed, in that case:

  - Deviating gives U_i either the same profit $\Pi^R(\psi_j)$ if $\psi_i \geq \phi^R(\psi_j)$, or a lower profit $n^*(\psi_i + \psi_j)\psi_i$ if $\psi_i < \phi^R(\psi_j)$.
  - Reducing the upstream fee ψ_i does not allow U_j to alter its profit, whereas raising it triggers a switch to the other continuation equilibrium E_j, giving U_j a (weakly) lower profit:

$$\Pi^R(\psi_i) = n^R(\psi_i)\phi^R(\psi_i) \leq \hat{\Pi}^R(\psi_j) = n^R(\psi_j)\psi_j,$$

    where the inequality stems from $\psi_i \geq \psi_j > \hat{\phi}^R(\psi_i)\left(\geq \phi^R(\psi_i)\right)$ implies $n^R(\psi_i) \leq n^R(\psi_j)$ and $\psi_j \geq \phi^R(\psi_i)$.

- The equilibrium that generates the greater joint profit, $n^R(\psi_i)\left(\psi_j + \phi^R(\psi_i)\right) = n^R(\psi_i)\Phi^R(\psi_i)$ is the one for which ψ_j is the lowest, and thus for which ψ_i is maximal: $\psi_i = \pi^m$ and ψ_j such that $n^R(\psi_j)\phi^R(\psi_j) = \underline{n}\pi^m$. This equilibrium gives IP owners a larger total profit than the "double marginalization" outcome but only one IP owner benefits from it: $\psi_j < \phi^D$ indeed implies:

$$\Pi_i = \Pi^R(\psi_j) > \Pi^D = \Pi^R(\phi^D) = \hat{\Pi}^R(\phi^D) > \Pi_j = \hat{\Pi}^R(\psi_j).$$