Moving Beyond Simple Examples: Assessing the Incremental Value Rule within Standards*

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Abstract

This paper presents a model of patent licensing in a standard setting context when patented technologies are heterogeneous in multiple dimensions. The model allows us to assess a policy proposal put forth in the literature: that an incremental value pricing rule should define Fair, Reasonable, and Non-Discriminatory (FRAND) patent licensing within standard setting organizations as it replicates the ex ante efficient competition outcome. We find that when patented technologies must be weighed on numerous factors, and not simply one-dimensional cost-savings, there is unlikely to be a single incremental value that can be agreed upon by all relevant parties. Furthermore, ex ante competition fails to select the efficient technologies by penalizing the more versatile ones. These results cast some doubt on the usefulness of the incremental value as a precise benchmark for FRAND.

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1 Introduction

Standard Setting Organizations (SSOs) are crucial in industries where different firms have come to rely on product and service interoperability standards for their operations. Their role is to coordinate the activities of a large variety of participants so that disparate and competing firms can market products that all share a common platform or functionality. From pure technology providers to final good producers to integrated players, firms that participate in an SSO tend to have very different interests. Thus, one of the roles of SSOs is to offer a forum for constructive cooperation, where otherwise competing firms can work together to select technologies that will determine standards that can be broadly implemented in products and services. One of the common SSO rules aimed at fostering this constructive cooperation among a diverse membership is the request for firms that believe they hold patents on the technologies selected for a standard to commit to license (preferably at the time the standard is drafted) those patents to potential implementers under Fair, Reasonable, and Non-Discriminatory (FRAND) terms.

Recent competition policy cases have brought attention to these licensing commitments, which are commonly viewed as contracts between patent holding members and the SSO (Brooks and Geradin, 2011). In the continuing search to bring greater clarity and specificity to the concept of FRAND licensing within standard setting contexts, economists have proposed – and policymakers have readily latched onto – the idea of *incremental value* pricing. One early proposal to extend the idea of incremental value pricing to patent licensing is found in the influential paper by Swanson and Baumol (2005). This benchmark is based on the idea that after a technology has been selected as part of the standardization effort and it becomes "essential" for the practice of a standard (standard essential patents, or SEPs) its developer could gain market power through the standardization process, which by definition eliminates alternatives. In order to counteract this additional market power the SSO should aim to restore the ex-ante result. That is, to replicate the result of a fictitious auction among competing technologies to be selected, before standardization occurs. In that auction the licensing price would correspond to the contribution to the commercial value that the selected technology engenders over the best alternative.[1] This ex post evaluation of the different technologies is consistent with the incremental value rule used in other contexts (Farrell and Katz, 2005) and it is the one that the FTC has in mind when calling upon courts to cap reasonable royalty damages at "the incremental value of the patented invention over the next-best alternative" (FTC, 2011). It defines incremental value in relation to the price that could be commanded during the standard setting phase, assuming all R&D has been invested and patents are in hand, with these existing technologies competing during standard setting.

The question of how, exactly, to define "incremental value" is a pivotal one if the proposals to base FRAND upon it are to move beyond mere proposals. Consider the case of technologies that differ only in the cost of production. The cost differential between two technologies translates ex-ante into a technology price that can be set through an SSO auction, or any form of bargaining that takes place during standard setting, and hence is able to capture competition among technologies. With a bit of detective work, a one-dimensional cost-saving increment could also be used ex post (during a standard's commercialization), for capping reasonable royalties in any court or agency review of disputed standard essential patents bound by FRAND commitments, as recommended in the FTC (2011) IP Report. As long as the difference between two patented technologies can be reduced to a single dollar amount, either production cost savings or increased product price, this approach would provide a measure of incremental value.[2]

[1] They also argue that this price should incorporate costs like those associated with licensing or the ongoing costs of R&D.

[2] This implementation abstracts from important aspects such as the incentives for firms to invest in R&D or participate in an SSO when they anticipate that their innovation will be licensed according to its

Unfortunately, in the context of SSOs, the interpretation of technology "quality" differentials as one-dimensional dollar differences is unlikely to provide a framework rich enough to analyze how an incremental-value rule could be implemented since the same technology might mean different things to different potential licensees. The goal of this paper is to understand how heterogeneity in the technologies that innovators may provide and the different valuation that their users may have affect the equilibrium licensing agreements. Our model departs from the typical framework described above in two directions. First, we consider technology quality in a broad sense, beyond one-dimensional dollar differences as we make clear below. We evaluate the not-uncommon situation in which different technologies imply different trade-offs among their characteristics for different SSO members. Technologies differ in their stand-alone value, understood in the usual sense of raising the valuation of all consumers uniformly or reducing production costs in a constant amount, and their versatility, understood as how suitable the technology is for consumers that might use it for heterogeneous purposes. Second, we recognize that neither SSO members nor the ultimate downstream consumers purchasing products that implement standards is a monolithic group. Instead, different parties are likely to place different "incremental values" on the same technology.

Our results show that, albeit intuitive, the much advertised properties of the incremental value rule are not robust to considering innovations that are heterogeneous in multiple dimensions. We show that incremental-value pricing loses the appealing property of being just a function of technological differences. Instead, it becomes a function of specific features of the industry such as the degree of heterogeneity of the uses of the final product and the degree of competition in the final market. Furthermore, we show that the ex-ante outcome, which is used as a justification for incremental value pricing,

incremental value. Indeed, Layne-Farrar et al. (2013) show that once these effects are considered incremental value pricing is inefficient even in this simple context since it discourages firms from participating in the SSO.

is unlikely to be a good benchmark for the efficient arrangement that an SSO should aim to achieve in the first place.

The two sources of heterogeneity we describe in our model are typical of most SSOs. Interoperability standards cover complex products (computers, the internet, mobile phones) whose contributing technologies typically cannot be evaluated solely on a one-dimensional cost-savings basis. Instead, these technologies are more likely to compete on multiple dimensions, like transmission speed versus accuracy, software complexity versus hardware cost, and so forth. Furthermore, the final users of the products created by firms that make use of these technologies have heterogeneous preferences for the trade-offs that these technologies entail.

An example of these multidimensional trade-offs is the debate in the early days of the Wireless LAN standardization process, that gave rise to the current Wi-Fi technology. In the late 1990s two different standardization efforts emerged. As Negus and Petrick (2009) discuss, the OpenAir proposal emphasized interoperability between the offerings of different providers intended for a variety of uses, from high-powered office deployments to less demanding home uses. As such, this standard was highly versatile, though costly in light of the high end applications it covered. The alternative HomeRF standardization effort focused solely on the less-demanding home wireless LAN, and hence pursued low costs by sharing components with cordless phones and targeting home users that valued simplicity. Even within the SSO that pursued a versatile wireless solution capable of high end needs, there were still important trade-offs to be made. One camp wanted robust wireless that could be used indoors, meaning an emphasis on the so-called multipath problem of signals bouncing off of solid surfaces and arriving at the destination out of sync. Others within the SSO were more concerned with outdoor transmission, and hence focused on transmission speeds.

Our model captures trade-offs of these sorts by considering a setup in which innovators compete to sell their technology to downstream firms that use it to provide a good in the final market. Downstream producers face heterogeneous consumers that may choose between their products. Different technologies provide different value to the final product but may also help in making the product appealing to a wider or narrower set of consumers. We characterize the technology choice and the equilibrium royalties that emerge under ex ante competition, the benchmark that the incremental value rule is meant to replicate. As expected, when we focus on the value (or cost savings) dimension the model is analogous to that presented by Swanson and Baumol (2005) and envisioned by the FTC (2011) IP Report. When we introduce the second dimension, the versatility of the technology, we find that the notion of "incremental value" becomes considerably more complicated. Abstracting from downstream competition we analyze how the trade-offs between the characteristics that firms face change depending on the characteristics of the market they serve, making the second dimension of the incremental value (versatility/adaptability) market-specific.

Once we introduce competition, we characterize the equilibrium royalty that would emerge under ex-ante competition among different technologies. Not very surprisingly, this royalty takes into account not only the difference in stand-alone value among technologies, but also includes differences in their versatility. Interestingly, as opposed to what a standard notion of the incremental value would suggest, the equilibrium royalty price is lower for more versatile technologies, since they engender more competition in the final market, reducing the willingness to pay of downstream producers. As a result, technologies that are worse from a social point of view in both dimensions (lower value and less versatility) and under a strict application of the incremental value rule would command a lower royalty price would often be chosen.[3] The previous results are robust

[3]The "excess of inertia" concept for the adoption of *de facto* standards, introduced in the literature by Farrell and Saloner (1985) has similar implications. In that case users do not switch to a superior technology due to a lack of coordination. Here, however, firms may not adopt a better technology because they are afraid of the fiercer competition it might entail. In both cases, however, social welfare is reduced

to the existence of network effects as well as the possibility that firms adopt more than one technology.

This paper contributes to the literature that analyzes the properties of the incremental value pricing. Farrell et al. (2007) supports the Swanson and Baumol (2005) logic, proposing that a patent's "incremental value" provides an upper bound (a cap) on the licensing fees that patent owners participating in SSOs can obtain. Mariniello (2011) also takes the incremental value concept as a key element in his proposed test for determining whether actual licensing rates assessed after the standard is set meet patent holders' FRAND commitments, although he proposes that a patent's "incremental value" provides a benchmark for ex post analysis and not a strict cap on allowable licensing rates.[4] Neither Farrell et al. (2007) nor Mariniello (2011) provide a precise definition of "incremental value" in relation to patented technology, but instead both rely more generally on the notion of aggregate value added (such as cost savings in Farrell et al. (2007)).

Although less directly related, our work builds on the long literature on patent licensing. Earlier models, summarized in Kamien (1992), study the optimal contract that a monopolist may offer to various downstream competitors. More recent papers such as Muto (1993) and Hernández-Murillo and Llobet (2006) discuss the effect of the heterogeneity in the use that downstream firms can make of the innovation over the optimal contract that the innovator offers. Schmidt (2009) and Rey and Salant (2012) also allow for downstream heterogeneity and study the effect of licensing complementary patents on the number of producers and competition in the final good market.

Although our paper does not model SSOs operations directly, it is also related to the debate over the strategic behavior of firms in these organizations (Lerner and Tirole,

as a result.

[4]Epstein et al. (2012) provide a qualitative discussion of a number of practical difficulties with an incremental value cap, including the likelihood that different buyers will have different valuations for different technologies, rendering the notion of a single incremental value over the next best alternative unachievable.

2006) and how firms that contribute technology should be compensated in order to avoid potential hold-up problems (Ganglmair et al., 2011).

Finally, we note the large literature on auctions that develops scoring rules in order to express multi-dimensional attributes as single numbers. For example, Asker and Cantillon (2008) develop a model in which suppliers submit offers on all dimensions of a good – they consider price and the level of non-monetary attributes – where those offers are evaluated using a scoring rule. While multiple dimensions can be reduced to a single one using a scoring function, this reduction is only possible for attributes that can be rank ordered, such as the "non-monetary" quality "levels" that Asker and Cantillon (2008) consider. In the context of our model, however, the value that final good producers place on the different dimensions of a technology depend on how they may affect downstream competition. As a result, it might be the case that a technology that has higher quality in both dimensions, and it is therefore more efficient, is not selected by downstream producers. This feature rules out scoring functions as a criterion on which the incremental value rule could be based.

The remainder of this paper proceeds as follows. In Section 2 we present the basic model which the following sections build upon. In section 3, we develop the licensing model for patented technologies that differ on at least two dimensions, where the downstream licensee is a monopolist. The model explicitly accounts for heterogeneity in the uses of the technology and different firms face consumers with heterogeneous preferences for multiple dimensions of the product. Section 4 introduces competition in the final market. Section 5 adds network effects to better capture the cooperative standard-setting environment. Section 6 concludes with a discussion of the policy implications of our analysis.

2 The Basic Model

Consider a market where there are two upstream and two downstream firms. We denote the upstream firms as innovators 1 and 2, and the downstream firms as producers A and B. Downstream firms are competitors in a linear city of length one. Producer A is located at 0 and producer B is located at 1. These downstream firms can sell products that differ in two dimensions: the valuation that consumers assign to the good, v, and the transportation cost of delivering the product to the consumer, α. As a result, a consumer located at point x on the line facing prices p_A and p_B would obtain utility as follows:

$$U(x) = \begin{cases} v_A - \alpha_A x - p_A & \text{if buying from A,} \\ v_B - \alpha_B(1-x) - p_B & \text{if buying from B.} \end{cases}$$

We interpret v as the stand-alone "value" of the product and α as its "specificity."[5] We refer to technologies with a lower value of α as being more versatile, since this attribute is related to how broad the market for the product is. We assume that consumers are distributed according to the distribution function $\Phi(x)$. In most of the paper this distribution will be assumed to be uniform between 0 and 1.

Upstream firms possess an innovation that downstream firms can embed in their final products. For simplicity, we assume that the quality of the final good is determined exclusively by this innovation, so that if upstream firm $i = \{1, 2\}$ has an innovation with attributes (v_i, α_i), this will also be the value of the product that the downstream producer that licenses it will offer. We normalize the consumer valuation of a product when the downstream firm does not adopt any of the innovations to 0.

Upstream innovators offer their technology at a per-unit royalty r_i for $i = 1, 2$. Again for simplicity, we assume that downstream producers have no marginal cost of production aside from the royalty paid to the upstream innovator.

[5] Throughout the paper we will refer to (stand-alone) value as this vertical characteristic of the product. As it is usually the case, the results can be easily reinterpreted in terms of cost savings.

The timing of the model is as follows. In the first stage upstream innovators simultaneously choose the royalties that they offer to downstream producers. Downstream firms then choose the innovation that maximizes their profits, anticipating the outcome that will arise in the last stage of the game when they set their final prices, which is also done simultaneously.

In order to analyze this model we will proceed in two steps. In the next section we analyze the case in which there is only one downstream firm. This assumption allows us to discuss how the choice of technologies changes with the level of heterogeneity among consumers. In the following section we then discuss the equilibrium with multiple downstream firms, which allows us to assess the effects of competition. In section 5 we show that results are qualitatively unchanged once we introduced network effects.

3 Downstream Monopolistic Producer

Consider the situation in which only firm A is present in the final market. In that case, consumers will buy if their utility is positive. Let's assume that the consumer location x is distributed according to $\Phi(x) = x^{\gamma}$. The parameter $\gamma \in [0, 1]$ can be interpreted as a measure of how important heterogeneity among consumers is. In particular, if $\gamma = 0$ all consumers are homogeneous and their utility is $v - p$. As γ grows this heterogeneity becomes more important. When $\gamma = 1$ consumers are uniformly distributed along the unit line. The structure of the game is described in Figure 1.

In the second stage, if firm A obtains the technology from innovator i, demand arises from consumers located at $x \leq x^* \equiv \frac{v_i - p_A}{\alpha_i}$, so that

$$D_A(p_A) = \Phi\left(\frac{v_i - p_A}{\alpha_i}\right) = \left(\frac{v_i - p_A}{\alpha_i}\right)^{\gamma}.$$

The previous demand is decreasing in the price and increasing in the value and versatility

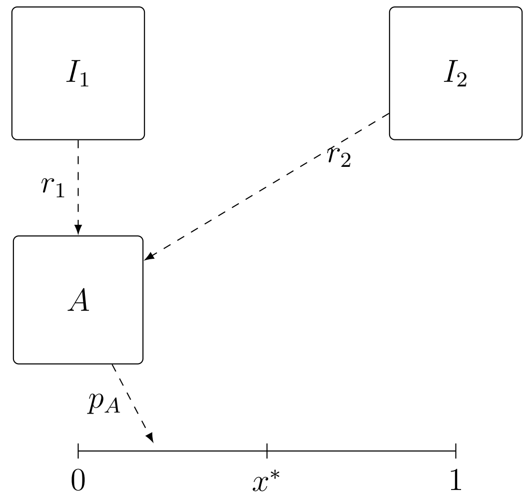

Figure 1: Structure of the game.

of the technology. This downstream producer will maximize profits according to

$$\max_{p_A} (p_A - r_i) \left(\frac{v_i - p_A}{\alpha_i} \right)^{\gamma}.$$

This expression leads to a monopoly price

$$p_A^* = p^M = \max \left\{ \frac{v_i + \gamma r_i}{\gamma + 1}, v_i - \alpha_i \right\}.$$

The first term arises in the interior solution, in which not all consumers buy. When $r_i \leq v_i - \frac{1+\gamma}{\gamma}\alpha_i$ the royalty is sufficiently low so that the market is fully covered. In order to simplify the exposition we rule out the corner solution by assuming that $v_i \leq \alpha_i$ so that in equilibrium not all consumers would buy even at a price 0. This assumption implies that the versatility dimension is sufficiently important so that consumer decisions are not driven entirely by the vertical dimension.

Under the previous assumption, profits from licensing the technology of firm i can, in turn, be written as

$$\Pi_A^M(i) = \left(\frac{\gamma}{\alpha_i} \right)^{\gamma} \left(\frac{v_i - r_i}{1 + \gamma} \right)^{1+\gamma}.$$

As expected, profits for the downstream monopolist will be increasing in the versatility of the technology (a low α_i) and the stand-alone value v_i.

In the first stage, given royalties r_1 and r_2 the downstream firm will choose the technology that leads to the highest profits. The following proposition characterizes the equilibrium royalty rates that emerge as a result of the competition among innovators.

Proposition 1. *Suppose that* $\frac{v_i}{\alpha_i^{\frac{\gamma}{1+\gamma}}} \geq \frac{v_j}{\alpha_j^{\frac{\gamma}{1+\gamma}}}$. *Then technology* i *will be adopted by the downstream firm. The equilibrium royalties will be* $r_j^* = 0$ *and*

$$r_i^* = v_i - \left(\frac{\alpha_i}{\alpha_j}\right)^{\frac{\gamma}{1+\gamma}} v_j.$$

The technology chosen is efficient. That is, it coincides with the technology chosen in the First Best.

The previous result emphasizes the fact that whether a technology is superior to the other or not depends on its combination of attributes, both play a role. If a technology is superior in both dimensions (i.e. a higher v and a lower α) that technology will be adopted by any downstream monopolist. In many realistic situations, however, we expect each technology to involve a trade-off between the two dimensions; one will have a higher value and the other will be more versatile. Proposition 1 suggests that the resolution of this trade-off, which determines the innovation that should command a positive royalty, can be obtained by redefining the measure of value as $\frac{v_i}{\alpha_i^{\frac{\gamma}{1+\gamma}}}$.

The redefined expression for value, however, is endogenous to the characteristics of the downstream buyer, through the parameter γ. An immediate consequence is that if we consider different downstream monopolists that operate in different markets and face different demands they will also have different preferences for the technologies. These differences might be such that one manufacturer prefers technology 1 while the other prefers technology 2. The reason is that differences in the parameter γ imply different weights in the trade-off between the two technologies. In particular, if γ is high the versatility becomes more important since consumers are more heterogeneous in their tastes. Thus, a downstream firm that faces a higher value of γ will tend to choose the more versatile technology.

Interestingly, that redefinition of value provides the right assessment about the technology that maximizes social welfare. So, even though market power downstream reduces social welfare through higher prices, it does not bias the technology that the firm decides to adopt. A proper benchmark for the optimal royalty should consider not only the differences in this redefined valuation but also in the characteristics of the market that licensees serve.[6] A generalization of the ex-ante auctions proposed by Swanson and Baumol (2005) using scoring auctions, for example, would implement the socially optimal allocation. Of course, the weights in this auction should be market specific.

Trivially, standardization on a unique technology occurs in the case of a downstream monopolist. In the rest of the paper we consider the situation in which there is downstream competition. In that case standardization will arise and become optimal when network effects are large. For this reason, in the next section we consider the case in which network effects are absent (or they are very weak) so that standardization might not occur. In section 5 we discuss the opposite case in which strong network effects are present resulting in standardization and a relevant role for SSOs in deciding among different technologies.

4 Downstream Competition

With the foundation laid in the simple downstream monopoly case, we now turn to the case in which two producers, A and B, located at the two extremes of a linear city compete in the final market. As in the previous case we will assume that innovator

[6]Of course, if both technologies have the same versatility the one with the highest value will be adopted. The resulting royalty for the "winning" firm will be $r_i^* = v_i - v_j$, independent of the characteristics of the market. In other words, as the standard interpretation of the *incremental value theory* indicates, if innovations differ only in the stand-alone value in equilibrium its creator will (and should in this model) charge a royalty equal to the technology's incremental value over the next best alternative.

$i = \{1, 2\}$ has a technology with components (v_i, α_i). To simplify the algebra, we assume that consumers are uniformly distributed; that is, in the specification of the previous section we set $\gamma = 1$.[7] This structure is described in Figure 2.

As usual, we solve the game by backwards induction, starting with the final pricing stage. We compute the optimal decisions of downstream firms as a function of their initial licensing decisions. We denote as $(\tilde{v}_j, \tilde{\alpha}_j)$ the characteristic of the technology that firm $j = \{A, B\}$ has licensed in the previous stage. If downstream firm j licenses from innovator $i \in \{1, 2\}$ it will use the technology $(\tilde{v}_j, \tilde{\alpha}_j) = (v_i, \alpha_i)$ and pay a royalty rate $\tilde{r}_j = r_i$. Each firm can license a technology from one upstream innovator. This turns out to be an innocuous simplification since, as Appendix A shows, in equilibrium it is never optimal for a downstream firm to sell at the same time two products that embed different technologies.

Given prices p_A and p_B and assuming that all consumers prefer to buy (that is, the market is *covered*), the consumer indifferent between buying from either of the firms, x^*, will be defined by

$$\tilde{v}_A - \tilde{\alpha}_A x^* - p_A = \tilde{v}_B - \tilde{\alpha}_B(1 - x^*) - p_B.$$

Downstream firms simultaneously choose prices to maximize profits. Standard calculations lead to equilibrium prices

$$\begin{aligned} p_A^* &= \frac{\tilde{v}_A - \tilde{v}_B + 2\tilde{\alpha}_B + \tilde{\alpha}_A + 2\tilde{r}_A + \tilde{r}_B}{3}, \\ p_B^* &= \frac{\tilde{v}_B - \tilde{v}_A + 2\tilde{\alpha}_A + \tilde{\alpha}_B + 2\tilde{r}_B + \tilde{r}_A}{3}. \end{aligned}$$

In an interior equilibrium, the indifferent consumer will be located at

$$x^* = \frac{\tilde{v}_A - \tilde{v}_B + 2\tilde{\alpha}_B + \tilde{\alpha}_A + \tilde{r}_B - \tilde{r}_A}{3(\tilde{\alpha}_A + \tilde{\alpha}_B)}.$$

[7] If $\gamma = 0$ all consumers are homogeneous. In that case, the versatility of the technology will not play a role downstream and the winning technology will be determined only according to the stand-alone value. If $v_i > v_j$ the equilibrium royalty will correspond to the quality premium, $r_i^* = v_i - v_j$.

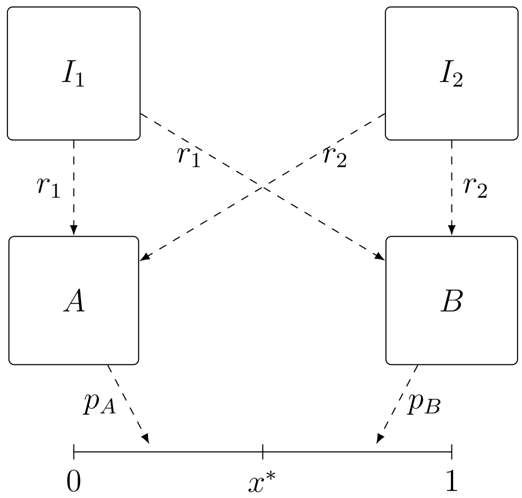

Figure 2: Structure of the game.

Equilibrium profits are obtained as

$$\Pi_A^* = (p_A^* - \tilde{r}_A)x^* = \frac{(\tilde{v}_A - \tilde{v}_B + 2\tilde{\alpha}_B + \tilde{\alpha}_A + \tilde{r}_B - \tilde{r}_A)^2}{9(\tilde{\alpha}_A + \tilde{\alpha}_B)}, \tag{1}$$

$$\Pi_B^* = (p_B^* - \tilde{r}_B)(1 - x^*) = \frac{(\tilde{v}_B - \tilde{v}_A + 2\tilde{\alpha}_A + \tilde{\alpha}_B + \tilde{r}_A - \tilde{r}_B)^2}{9(\tilde{\alpha}_B + \tilde{\alpha}_A)}. \tag{2}$$

We can now turn to the first stage, where we will consider the case in which innovators compete to have their innovation adopted by one or more downstream competitors and the case of an SSO that decides to standardize a unique technology. We will restrict ourselves to the case in which an innovator offers the same royalty to the two downstream firms. Furthermore, in order to reduce the number of cases that may emerge we will assume that the second firm produces a (completely) *versatile* technology. That is, we assume that the technology firm 2 owns generates the same value to all final consumers regardless of x, which implies that $\alpha_2 = 0$. As a result, when at least one downstream firm adopts the technology of firm 2 the market will be covered, as postulated above.

An important difference between this case and the one we discussed in the previous section is that the willingness to pay of a downstream producer now will depend not only on the technology that it licenses but also on the technology licensed by the competitor in the final market. In particular, when downstream producers choose their technology independently we need to consider three cases depending on the technology adopted by the competitor. Specifically, both firms could license the (versatile) technology from innovator 2, both firms could license a (specific) technology from innovator 1 or, finally, each firm could license a different technology. In this last case, without loss of generality, we assume that firm B licenses the (versatile) technology of firm 2.

4.1 The Pricing Equilibrium

If both firms license the technology from innovator 2 they will both produce a good that consumers regard as homogeneous due to the zero transportation cost ($\alpha_2 = 0$). Thus, equilibrium prices of the final good converge to marginal cost, $p_A^* = p_B^* = r_2$, and, consequently, downstream producers make zero profits, $\Pi_A^* = \Pi_B^* = 0$. Similarly, if both downstream producers license the technology of firm 1, their profits, according to (1) and (2), correspond to

$$\Pi_A^* = \Pi_B^* = \frac{\alpha_1}{2}.$$

Finally, the third and last case is the equilibrium in which downstream producer A licenses from innovator 1 and producer B licenses from innovator 2. From (1) and (2) we can write the profits of downstream firms as

$$\Pi_A^* = \frac{(v_1 - v_2 + \alpha_1 + r_2 - r_1)^2}{9\alpha_1},$$
$$\Pi_B^* = \frac{(v_2 - v_1 + 2\alpha_1 + r_1 - r_2)^2}{9\alpha_1}.$$

The previous expression requires firm demands to be well-defined so that

$$x^* = \frac{v_1 - v_2 + \alpha_1 + r_2 - r_1}{3\alpha_1} \in [0, 1]. \tag{3}$$

This condition will be satisfied if

$$v_1 - v_2 + \alpha_1 \geq r_1 - r_2 \geq v_1 - v_2 - 2\alpha_1. \tag{4}$$

4.2 Technology Choice

The profits that downstream producers anticipate in the last stage of the game determine their simultaneous choice of technology. The following payoff matrix describes these profits according to the calculations in the previous section.

		B: 1	B: 2
A	1	$\left(\frac{\alpha_1}{2}, \frac{\alpha_1}{2}\right)$	$\left(\frac{(v_1-v_2+\alpha_1+r_2-r_1)^2}{9\alpha_1}, \frac{(v_2-v_1+2\alpha_1+r_1-r_2)^2}{9\alpha_1}\right)$
	2	$\left(\frac{(v_2-v_1+2\alpha_1+r_1-r_2)^2}{9\alpha_1}, \frac{(v_1-v_2+\alpha_1+r_2-r_1)^2}{9\alpha_1}\right)$	$(0, 0)$

As is obvious from the previous discussion, royalties will only affect profits when firms choose different technologies, determining the equilibrium that emerges. Furthermore, the previous expressions for profits presume that both firms have a positive market share. That is, condition (4) is satisfied. Otherwise, firms would make zero profits. Following the previous convention, when both producers choose different technologies we assume that producer A licenses from innovator 1 and producer B from innovator 2.

The next proposition summarizes the conditions that royalty rates must satisfy for each combination of technology choices to emerge as part of an equilibrium.

Proposition 2. *Given r_1 and r_2 in the equilibrium of the second stage of the game, both firms will choose technology 1 if $r_1 - r_2 < v_1 - v_2 + \left(\frac{3}{\sqrt{2}} - 2\right)\alpha_1$. Firms choose different technologies if $v_1 - v_2 + \left(\frac{3}{\sqrt{2}} - 2\right)\alpha_1 \leq r_1 - r_2 < v_1 - v_2 + \alpha_1$. Both firms choose technology 2 if $r_1 - r_2 \geq v_1 - v_2 + \alpha_1$.*

An important conclusion of the previous proposition is that no *generic* multiplicity of equilibria can arise in the second stage of the game. In particular, as mentioned before, the only multiplicity we may observe is in the choice of each technology when downstream producers opt for different technologies.[8]

[8]Notice that we assume as a tie-breaking rule that whenever firms are indifferent they will choose technology 2. This assumption has no significant implications for the results of the paper.

This proposition also sheds some light on the characteristics of the technology that facilitates the licensing to downstream producers. It is easy to observe that, as opposed to the case of a downstream monopolist, there might be situations in which technology 2 is preferable for society because it provides a higher dollar value and greater versatility than technology 1 and yet in equilibrium it is not adopted. In particular, if the value difference is small, $v_1 < v_2 < v_1 + \alpha_1$, downstream competitors will not be willing to adopt the technology 2 even if it is offered at the same royalty rate as technology 1. The reason is that the use of the versatile technology implies fiercer competition with the other downstream producer, which leads to lower prices for the final product. As a result, the royalty that innovator 1 can charge is decreasing in the versatility of technology 1 (i.e, decreasing in α_1); the more versatile is technology 1 the less sheltered downstream firms are from competition if they switch to that technology, and the lower must be r_1.

The previous proposition allows us to compute the sales of products embedding each technology. For innovator 1, downstream demand for its technology, denoted as $D_1(r_1, r_2)$ can be written as

$$D_1(r_1, r_2) = \begin{cases} 0 & \text{if } r_1 > v_1 - v_2 + \alpha_1 + r_2, \\ \frac{v_1 - v_2 + 2\alpha_1 + r_2 - r_1}{3\alpha_1} \in (0,1) & \text{if } v_1 - v_2 + \left(\frac{3}{\sqrt{2}} - 2\right)\alpha_1 + r_2 \leq r_1 < v_1 - v_2 + \alpha_1 + r_2, \\ 1 & \text{otherwise.} \end{cases}$$

whereas the demand for innovator 2, $D_2(r_2, r_1)$, can be derived as

$$D_2(r_2, r_1) = \begin{cases} 0 & \text{if } r_2 > v_2 - v_1 - \left(\frac{3}{\sqrt{2}} - 2\right)\alpha_1 + r_1, \\ \frac{v_2 - v_1 + 2\alpha_1 + r_1 - r_2}{3\alpha_1} \in (0,1) & \text{if } v_2 - v_1 - \left(\frac{3}{\sqrt{2}} - 2\right)\alpha_1 + r_1 \leq r_2 < v_2 - v_1 - \alpha_1 + r_1, \\ 1 & \text{otherwise.} \end{cases}$$

This demand is induced by the number of downstream firms that choose each technology and their pricing behavior. Licensing the technology to downstream producers is just instrumental to reach final consumers. As a result, the induced demand functions turn out to be discontinuous. In particular, consider a situation in which each downstream producer licenses the technology from a different innovator. As developer 2 raises r_2 its licensee raises the price, reducing sales and profits. However, at the point in which the royalty is such that the licensee is indifferent between obtaining a license from firm 1 or 2, characterized by

$$r_2 = v_2 - v_1 - \left(\frac{3}{\sqrt{2}} - 2\right)\alpha_1 + r_1, \tag{5}$$

it is still selling a positive quantity that leads to profits $\frac{\alpha_1}{2}$. Thus, a slightly higher royalty means that the innovator 2 goes from selling a strictly positive amount to 0 and innovator 1 from selling to part of the market, x^*, to the whole market. Hence the discontinuity.[9]

4.3 Equilibrium Royalties

Upstream innovators choose the royalty that maximizes their expected profits,

$$r_i \in \arg\max_{r_i} \; r_i D_i(r_i, r_j) \quad \text{for } i = 1, 2 \text{ and } j \neq i. \tag{6}$$

Once we replace the expression for the demand we see that the equilibrium in the first stage when firms share the market can take two forms. Depending on parameter values there is an interior solution in which firms sell to a share of the market or a situation in which the discontinuity of the demand plays a role. The next lemma states the necessary conditions for those two equilibria to exist.

Lemma 1. *In an equilibrium in which downstream firm A licenses from innovator* 1 *and downstream firm B licenses from innovator* 2 *the resulting royalties are*

$$\begin{aligned} r_1^* =& \frac{v_1 - v_2 + 4\alpha_1}{3}, \\ r_2^* =& \frac{v_2 - v_1 + 5\alpha_1}{3}, \end{aligned}$$

if $-4\alpha_1 \leq v_1 - v_2 \leq -\left(\frac{9}{2^{1/4}} - 5\right)\alpha_1$ *and*

$$\begin{aligned} r_1^* =& 3\left(1 - 2^{-\frac{1}{4}}\right)\alpha_1, \\ r_2^* =& v_2 - v_1 + (5 - 3 \times 2^{\frac{3}{4}})\alpha_1, \end{aligned}$$

[9] Notice that this discontinuity does not occur when r_2 is low in order to license to both downstream producers. The reason is that the value of r_2 for which both downstream producers want to license from developer 2 is one in which they make zero profits from using the other technology, which occurs if under that technology they already obtain 0 sales.

if $-\left(\frac{9}{2^{1/4}}-5\right)\alpha_1 \leq v_1 - v_2 < (5 - 3 \times 2^{\frac{3}{4}})\alpha_1$.

This lemma shows that the two technologies can be used in equilibrium in two different royalty-rate configurations. First, if the stand-alone value of technology 2 is sufficiently high, compared to technology 1, both upstream producers will choose the royalty that results from the interior solution to (6). No firm will benefit from undercutting its competitor. Second, if the difference in stand-alone value $v_1 - v_2$ is sufficiently high the interior solution will not be the equilibrium royalties. At those royalty rates innovator 1 will be interested in undercutting innovator 2 in order to attract downstream firm B and as a result serve the whole market. This occurs because demand for both firms is discontinuous. Innovator 2 can prevent innovator 1 from serving the whole market by lowering the royalty r_2. The second part of the previous lemma describes the equilibrium in which innovator 2 chooses the highest value of r_2 which does not trigger a royalty by innovator 1 that steals all the market. The royalty r_1 is obtained as the best response to that r_2, using (6).[10]

When the stand-alone value of one of the technologies is notably higher than the one of the competitor that firm grabs the whole market in equilibrium. The royalty rate that emerges in that case is the result of limit pricing: the highest possible royalty that does not allow the competitor to lower its royalty and attract at least one of the downstream producers. The next proposition characterizes the equilibrium in the first stage.

Proposition 3 (Equilibrium Royalties)**.** *Assume that* $\alpha_1 \leq \frac{2v_2}{3\sqrt{2}-1}$ *so that the market is always covered in equilibrium. When downstream producers choose their technology independently, four possible equilibria may exist depending on the difference* $v_1 - v_2$.

1. *If* $v_1 - v_2 \leq -4\alpha_1$, *only upstream producer* 2 *licenses its technology. The equilibrium*

[10]Innovator 2 will never find it optimal to undercut innovator 1 in order to lure downstream producer A. The reason is that, as pointed out before, this producer anticipates that if both downstream firms use the same (homogeneous) technology profits will be 0.

royalties correspond to

$$
\begin{aligned}
r_1^* =& 0, \\
r_2^* =& v_2 - v_1 - \alpha_1.
\end{aligned}
$$

2. *If* $-4\alpha_1 \leq v_1 - v_2 \leq -\left(\frac{9}{2^{1/4}} - 5\right)\alpha_1$ *each innovator sells to only one downstream firm and sets royalties*

$$
\begin{aligned}
r_1^* =& \frac{v_1 - v_2 + 4\alpha_1}{3}, \\
r_2^* =& \frac{v_2 - v_1 + 5\alpha_1}{3}.
\end{aligned}
$$

3. *If* $-\left(\frac{9}{2^{1/4}} - 5\right)\alpha_1 \leq v_1 - v_2 \leq (5 - 3 \times 2^{\frac{3}{4}})\alpha_1$ *each innovator sells to only one downstream firm and sets royalties*

$$
\begin{aligned}
r_1^* =& 3\left(1 - 2^{-\frac{1}{4}}\right)\alpha_1, \\
r_2^* =& v_2 - v_1 + (5 - 3 \times 2^{\frac{3}{4}})\alpha_1.
\end{aligned}
$$

4. *If* $v_1 - v_2 > (5 - 3 \times 2^{\frac{3}{4}})\alpha_1$ *only upstream producer* 1 *licenses its technology. The equilibrium royalties correspond to*

$$
\begin{aligned}
r_1^* =& v_1 - v_2 + \left[\frac{3}{\sqrt{2}} - 2\right]\alpha_1, \\
r_2^* =& 0.
\end{aligned}
$$

The characteristics of the equilibrium royalty rate in Proposition 3 can be better explained using Figure 3. This figure represents the equilibrium royalty that both upstream firms charge as a function of the difference in the stand-alone value of both innovations. As expected, the royalty that each innovator can charge is, for the most part, increasing in its stand-alone value advantage with respect to the competitor.

The proposition shows that when one of the technologies has a much higher stand-alone value that technology will be the only one used in equilibrium. This result arises

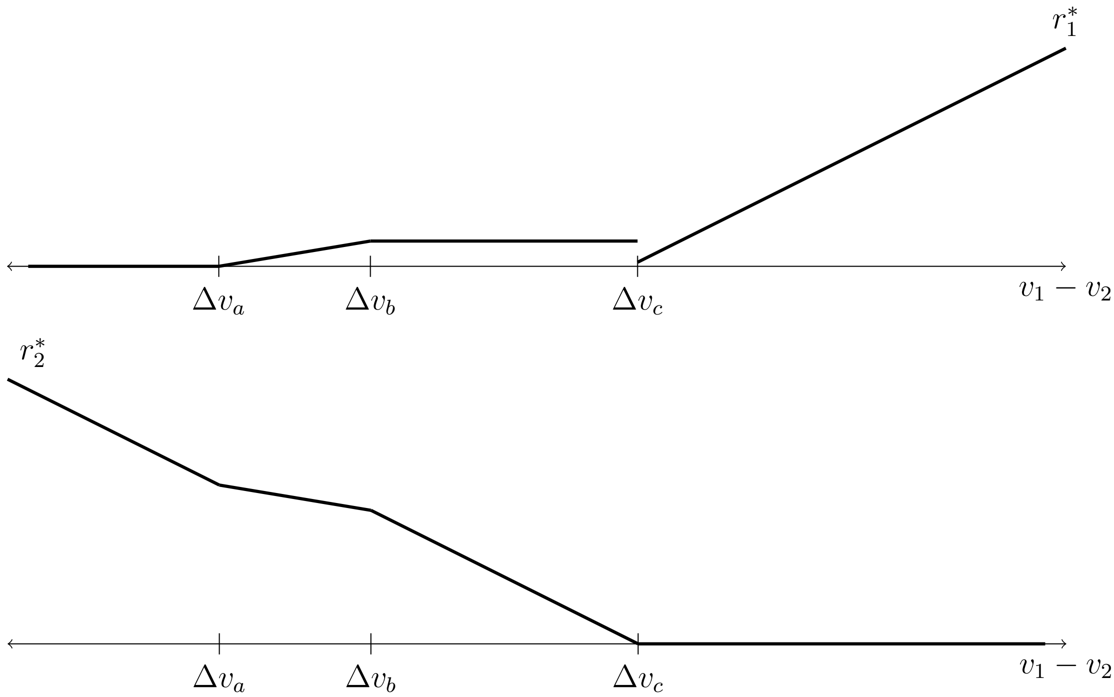

Figure 3: Equilibrium royalty charged by innovator 1 and 2 as a function of $v_1 - v_2$. We have defined $\Delta v_a \equiv -4\alpha_1$, $\Delta v_b \equiv -\left(\frac{9}{2^{1/4}} - 5\right)\alpha_1$, and $\Delta v_c \equiv (5 - 3 \times 2^{\frac{3}{4}})\alpha_1$.

from the fact that a large difference in stand-alone value — in particular, $v_2 - v_1 > 4\alpha_1 \equiv -\Delta v_a$ or $v_1 - v_2 > (5 - 3 \times 2^{\frac{3}{4}})\alpha_1 \equiv \Delta v_c$ — translates into a large royalty that the innovator can charge and, for this reason, a high interest in covering the whole market. More specifically, if technology 2 has a substantially higher stand-alone value compared to technology 1, firm 1 will need to lower the royalty in order to attract one of the downstream producers. In situations in which in equilibrium both producers license from firm 2, firm 1 will charge in equilibrium a royalty of 0. Firm 2 will charge a royalty that makes producers indifferent between licensing from either firm. Interestingly, though, the royalty that innovator 2 can charge in that case is not consistent with any generalization of the Incremental Value rule. Although r_2^* is increasing in $v_2 - v_1$, it is decreasing in α_1, meaning that the less versatile is technology 1 the lower is the royalty that innovator 2 may charge.

Similarly, if technology 1 is substantially better than technology 2, firm 2 will charge in equilibrium a royalty of 0. Innovator 1 will charge a royalty that will be decreasing in its versatility, again in contradiction with incremental value considerations. Furthermore, notice that the fact that an innovator can win a privately negotiated bidding war against a competing technology provider, so as to define a standard does not mean it is profitable to do so. The reason is that when the difference between the two technologies is not very large, even if the competitor charges a royalty of 0 when using its technology an innovator might prefer to charge a higher royalty and focus only on part of the market. This is precisely the reason for the discontinuity in the royalty rate for innovator 1 around Δv_c.

In the intermediate region defined by $\Delta v_a \leq v_1 - v_2 \leq \Delta v_c$ both technologies are very similar. In that case, without coordination there will be no standard and the upstream innovators will share the market. As Lemma 1 describes, the market can be shared under two different equilibrium configurations. If $v_1 - v_2$ is relatively low (in the region Δv_a to Δv_b in the figure) both innovators compete when choosing their royalty rate, to obtain a large market share downstream, under the assumption that each innovator sells to one downstream firm. When $v_1 - v_2$ lays between Δv_a and Δv_b the stand alone value of firm 1 is sufficiently high that, under the previous royalty rate, undercutting would be profitable. For this reason, innovator 2 chooses a lower royalty. When $v_1 - v_2 = \Delta v_c$, $r_2 = 0$ and innovator 1 chooses a lower r_1 in order to serve the whole market.

Interestingly, since $\Delta v_c < 0$ there might be situations in which, in the equilibrium, even though innovator 1 produces a good that consumers consider worse in both dimensions, it has a lower value and a lower versatility, its technology will be adopted in equilibrium by both downstream producers. This is in contrast with the case in which there is no downstream competition. As we argued earlier, in that case, the optimal technology would always be adopted by any downstream producer. By characterizing the First Best, the next proposition allows us to analyze the inefficiencies that emerge when downstream firms compete.

Proposition 4 (First Best). *Assume* $\alpha_1 \leq \frac{2v_2}{3\sqrt{2}-1}$. *In the First Best the market is covered. Both producers adopt technology* 2 *if and only if* $v_2 - v_1 \geq 0$. *Each producer adopts a different technology if* $\left(1 - \frac{1}{\sqrt{2}}\right)\alpha_1 < v_2 - v_1 < 0$. *Otherwise, both producers choose technology* 1.

Notice that as opposed to the equilibrium solution, technology 2 is always uniquely adopted when it is superior in both dimensions to technology 1, indicating that downstream competition biases the decisions towards technology 1 if that allow firms to set higher downstream prices. Furthermore, in contrast with the equilibrium outcome, in the First Best technology 2 is sometimes used by one of the firms even if its stand-alone value is lower.

Finally, we can compare the previous two technology adoption benchmarks with what would occur if downstream producers, together, chose which technologies to adopt. This behavior assumes that firms coordinate only in the technology that will be sponsored while allowing producers to compete in the sale of the final product.[11] In particular, we assume that an SSO maximizes the profits of its members, in this case the downstream producers.[12] As the next proposition shows, technology 1 is preferred by the both downstream producers for a large region of parameters. This region includes not only the case in which under independent negotiation both firms select different technologies but also some values for which both firms choose technology 2.

Proposition 5. *If* $v_1 \geq v_2 - \alpha_1$ *an SSO that maximizes producer profits will always adopt technology* 1 *for all its members. The equilibrium royalties would be* $r_2^* = 0$ *and*

$$r_1^* = \begin{cases} v_1 - \frac{3}{2}\alpha_1 & \text{if } v_2 \geq \frac{5}{2}\alpha_1, \\ v_1 - v_2 - \frac{11}{4}\alpha_1 + \frac{3}{4}\sqrt{8\alpha_1 v_2 + 5\alpha_1^2} & \text{otherwise.} \end{cases}$$

[11]Notice that since network effects are absent in this section it may not necessarily lead to an agreement around a unique technology.

[12]In the model, to the extent that an SSO maximized the profits of all upstream and downstream producers it will lead to the first best allocation, since market power in the linear city does not generate a dead-weight loss through higher than optimal prices. Nevertheless, in many informal fora and SSOs, downstream producers (the implementers) comprise a higher proportion of the membership.

Notice that the previous result implies a standardization around technology 1 in spite of the fact that consumer utility does not depend on the technology that defines the products other consumers purchase. Instead, the reason for the previous result is that under joint technological negotiation the power of innovator 1 is reinforced, since there is no threat that potential licensees unilaterally deviate and license technology 2 when v_2 is sufficiently high. The SSO might be willing to accept a higher royalty if its members can pass through the increase in the marginal cost in the form of higher product prices, without affecting sales much (as is the case in the linear city model for which quantity stays constant when valuation is high). The alternative of switching to technology 2 is less appealing due to the fiercer competition it engenders.

5 Network Effects

One of the reasons why SSOs emerge is the need to standardize the technologies underlying the products that firms sell in order to benefit from the network effects that enhance the valuation consumers place on the product. The model in the previous section did not include those effects, and for this reason, downstream firms had little incentive to coordinate their technology adoption decisions. The lack of network effects led to a region in which both technologies could coexist if they had similar stand-alone values.

In this section we take the opposite extreme view and assume that network effects are so large that the product is valuable to consumers if and only if all of them purchase a product that embeds the same technology. In particular, we assume that a consumer located at a distance x from the downstream firm obtains a utility $v_i - \alpha_i - x - p_i$ when buying from producer i for $i = A, B$ if all consumers buy a product that uses the same technology, and 0 otherwise. Notice that this implies that technologies 1 and 2 are incompatible.

Previous calculations indicate that in the second stage, after royalties have been set, downstream firms anticipate that if both firms choose technology 2 their profits will be 0. The extreme network effects that we assume here also imply that profits will be 0 if downstream producers choose different technologies.[13]

To the extent that innovator 1 chooses a royalty that guarantees positive profits to downstream producers, it will be their (weakly) dominant strategy to adopt technology 1. In our previous calculations, when both downstream producers chose technology 1 their profits were equal to $\Pi_i = \frac{\alpha_1}{2}$. These profits, as it is common in the linear city model, were obtained by assuming that the indifferent consumer obtained a strictly positive utility from buying. In other words, we assumed that v_1 was sufficiently large for the market to be covered. Under the network effects assumed in this section, technology 1 is relevant to the extent that even the consumer furthest away from each of the downstream producers — that is, the consumer located at $x = \frac{1}{2}$ — enjoys positive utility at a price of 0, or $v_1 \geq \frac{\alpha_1}{2}$. In that case we denote the technology as *viable*. The next proposition shows that whenever technology 1 is viable it will be chosen in equilibrium.

Proposition 6. *With extreme network effects technology* 1 *is chosen if and only if it is viable,* $v_1 \geq \frac{\alpha_1}{2}$. *In that case equilibrium royalties will be* $r_1^* = v_1 - \frac{\alpha_1}{2}$ *and* $r_2^* \geq 0$.

Some comments about the previous proposition are in order. Developer 1 finds it optimal to raise the royalty rate r_1 up to the point in which the indifferent consumer in the final market obtains 0 utility. Interestingly, this also implies that downstream producers choose a price $p_i^* = r_1^*$ and obtain 0 profits. The reason is that if they raised the price, some consumers would obtain negative utility from buying, resulting in the loss of the network effects and no equilibrium sales. This result is a consequence of the complementarity that the network effects introduce in the purchasing decision of all final

[13]Results would be essentially unchanged if we assumed that network effects arose from the technology adoption of firms. Instead, if network effects only operated by increasing the utility that consumers enjoyed (depending on how many other consumers bought a product with the same technology), profits from choosing different technologies could still be positive and regions in which both technologies coexist in equilibrium might still be possible, just as in the benchmark model.

consumers.

It is also important to point out that in equilibrium the royalty that firms will charge will be independent of the value of the technology that developer 2 brings to the table. Downstream competition also implies that any positive royalty rate for innovator 2 will be inconsequential to the equilibrium, since in no circumstances its technology will be chosen. Furthermore, if downstream developers could cooperatively choose a unique technology, while still competing in the final market, the result would be unchanged.

Corollary 1. *If downstream producers choose the technology cooperatively and compete in the final market the results are identical as if firms chose technology independently.*

In contrast, the First Best will factor in the characteristics of the technologies in both dimensions and balance them optimally. Thus, technology 1 should only be chosen to the extent that its stand-alone value is sufficiently higher to compensate its lower versatility compared to technology 2.

Proposition 7. *Under extreme network effects it is socially optimal that both firms adopt technology* 1 *as opposed to technology* 2 *if and only if* $v_1 \geq v_2 + \frac{\alpha_1}{2}$.

Comparing this case to the one in the previous section we observe that competition operates in the same way, reducing the range of values under which the versatile technology 2 will emerge in equilibrium. Under network effects, the bias is stronger, because adoption of technology 2 by one of the producers implies Bertrand competition, since the competitor has to adopt the same technology, and this hinders the adoption of this technology in the first place.

6 Policy Implications for the Incremental Value Rule

The literature on FRAND licensing has focused thus far on appropriate benchmarks for determining whether or not a particular licensing offer made by the holder of a standard essential patent satisfies the FRAND commitment to an SSO. It is in this context that the traditional pricing theory of "incremental value" has been proposed. The policy motivation for the proposal is clear: making FRAND assessments more precise so that ex post licensing terms and conditions are appropriately tied to the value the patented technology provides to the standard and do not include any element of holdup derived from market power gained through the standard setting process. But in the quest for more transparent rules for FRAND licensing, we must keep in mind the real world complexities that such rules must operate within. The model we develop above addresses one such complexity: the common incidence that technologies considered for inclusion in a standard must be evaluated on multiple dimensions, at least some of which cannot be easily reduced to an ordinal measure. We find that multi-dimension technologies involving either-or trade-offs introduce a number of difficulties for implementing an incremental value rule for FRAND licensing.

Multiple dimensions are not problematic in themselves, as a large literature demonstrates how scoring functions can be employed to express those dimensions within a single, easily compared index (Asker and Cantillon, 2008). And in the simplest version of our model, presented in section 3 we show that a scoring function could work to aggregate multiple dimensions of a technology when the firms licensing that technology do not face any downstream competition. Specifically, in section 3 we find that while a downstream monopoly restricts the quantity sold in the final market it does not alter the choice of technologies upstream, which depend on a score of the different dimensions. This score can be understood as a generalization of the incremental value rule, which would account not only for the traditional value enhancement or "cost savings" aspect typically used in discussions of applying the rule to patent licensing, but also for more complex aspects of the technology that affect the characteristics of the final products, such as the ability of downstream implementers to adapt the technology so as to target their products to narrow market niches. Even here, however, the scoring function is not straightforward, though, as the scoring function contains an endogenous variable, γ.[14]

Downstream competition, however, changes things radically. Whereas more versatile (non-specific) technologies tend to benefit a larger proportion of consumers, the fiercer competition that such technologies induce for licensees reduces the technologies' appeal to firms that sell in the final market. The example in which no network effects are present in the market, developed in section 4, illustrates the strategic side of technology choices made in cooperative standard setting. The mismatch in incentives surrounding technology choice is apparent from a comparison of Proposition 3 which defines the profit maximizing choices downstream firms will make depending on the relative comparison of the value enhancement aspect of the two technologies and Proposition 4, which defines the First Best technology choice from a social perspective. This last proposition shows that to achieve the social optimum, the versatile technology 2 should be used whenever it is (at least) as good in terms of the stand-alone value dimension as the differentiated technology 1. In the equilibrium solution, however, it is clear that firms are reluctant to adopt technology 2 unless it yields an increase in value sufficiently large to "overcome" the competitive disadvantage motivated by its higher versatility.

The presence of network effects, considered in section 5, makes implementing firms' strategic choices even more apparent. In the limit case we consider, the versatile technology 2 is never used as long as the differentiable technology 1 is viable. As some degree of network effects are a likely explanation for emergence of cooperative interoperability standards, the results in section 4 likely understate the extent to which strategic competitive concerns affect technology choices within SSOs.

These results suggest that in the presence of competition, imposing any sort of rule

[14]The other difficulty that emerges is how, exactly, to measure the "cost savings" or "price enhancing" aspect of a given technology, regardless of the presence of any other dimensions that must be compared as well in order to determine an "increment".

based on some sort of score of the value dimension of a given technology is unlikely to reach an efficient outcome. In fact, the imposition of an incremental value rule for FRAND licensing is likely to tilt technology adoption towards those that soften downstream competition. In our benchmark example, a rule that rewarded technology 2 for its higher versatility would lead to a lower adoption of that technology as compared to ex ante equilibrium technology choices: the equilibrium in which both firms adopt the versatile technology 2 – when $v_1 - v_2 \leq -4\alpha_1$ in Proposition 3 – provides a royalty r_2^* that is lower than $v_2 - v_1$ and that is actually increasing, rather than decreasing, in the versatility of the other technology.

Under the circumstances we study in this paper, there is little room for a competition agency to improve on outcomes. Consider first the case of downstream monopolies. Absent the concern about intensified competition in the downstream market that comes from the more versatile technology, downstream monopolists freely choose to license the more versatile technology as long as the difference in the stand-alone value dimension for the narrower technology is not too large; this outcome matches the First Best (see Proposition 1). Hence there is nothing for an agency to improve upon in this case. However, when downstream markets are competitive (which is often the goal and the realization for cooperative standard setting), agencies would be faced with the task of recreating not only the rank ordering of the technologies considered during the development of a standard in terms of any measurable value enhancements or "cost savings" (the v dimensions), but also in terms of any strategic dimensions of the competing technologies (the α dimensions). SSO meeting minutes and other documentation may contain contemporaneous comparisons of competing technological solutions on observable measures (e.g., transmission speed or bit error rates), but those records are unlikely to contain any information on the strategic elements of product differentiation.

Moreover, even for technologies that compete solely on definable characteristics, those characteristics may often involve trade-offs that pit one member's preference set against another's. For example, reliability versus cost is a common trade-off across many technology fields – technology A may involve "cost savings" as compared to technology B, but B is viewed as considerably more "reliable" than A. Looking solely at the "cost savings" dimension would be misleading for any "incremental value" calculation. But since "cost savings" move inversely with "reliability" under this trade-off, combining both dimensions in a scoring function is unlikely to be helpful either: such an index would simply suggest the midpoint compromise, with moderate cost and moderate reliability, whereas product markets may be more likely to dictate a solution closer to one or the other extreme. Firms implementing the same standard but in different end products are likely to view trade-offs of this sort quite differently. An SSO vote is likely to accurately reflect the majority view of these trade-offs, but recreating that complex comparison ex post, say with a constructed scoring function, is likely to be difficult at best. Such information should of course be collected when feasible, as it could nonetheless inform FRAND assessments, but the hope for a formulaic incremental value calculation strikes us as unrealistic.

When private concerns, such as end product differentiation and market competition, are included in the calculus as well, we could even find that one firm's "benefit" is another firm's "detriment." In this case, an ex post scoring function would be entirely unworkable. Nor are we likely to uncover information of this sort in any forensic dig through SSO documents, though individual firm records may be informative nonetheless. We might think that private benefits should be excluded, in the interest of social good, from any "incremental value" calculation for a FRAND assessment, but if the task is to determine what licensing fees are reasonable for a particular implementer to pay for access to a FRAND-encumbered patent, then private value is very much relevant.[15]

[15] Private value is embedded in the Georgia-Pacific factors that guide reasonable royalty assessments in patent infringement cases in US courts.

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Appendix

A The Licensing of Multiple Technologies

Consider an extension of our basic model in which final good producers can license the technology from both upstream developers if they choose to do so and sell one product with each of them. Assume that the timing of the model remains unchanged: Initially developers set their royalty rates. Downstream producers first simultaneously choose which products to sell and later they simultaneously set their prices.

Suppose that in the final period a firm, say firm A, has licensed the innovations both of firm 1 and 2. It is easy to see that in order for the products that embed each of the innovations to be sold at the same time consumers located close to producer A (at a low value of x) should buy the product that embeds innovation 1 and consumers further away from the location of firm A should buy the other product. That is, if we denote as p_A^i the price of the product that embeds innovation $i = 1, 2$, then the indifferent consumer will be characterized by

$$v_1 - \alpha_1 x_A - p_A^1 = v_2 - p_A^2, \tag{7}$$

so that consumers at $x < x_A$ prefer the product that embeds innovation 1.

We now solve for the different combinations of products that can emerge in the final stage. Our first result shows that in equilibrium it will never be the case that at least one downstream firm sells the two products and both firms offer the product that embeds the innovation developed by upstream firm 2.

Lemma 2. *When downstream producers can sell more than one product, if in equilibrium one firm sells both products, the competitor will sell only product* 1.

Thus, the previous result suggests that the only case in which firms might sell multiple products in equilibrium corresponds to the situation in which one of the firms sells two products, say firm A, and the other (firm B) sells only the product that embeds the technology of firm 1. If the three products are sold in equilibrium, following the previous arguments, we will have that consumers between 0 and x_A (as defined in equation (7)) buy product 1 from firm A. Consumers between x_A and x_B buy product 2 from firm A and consumers between x_B and 1 buy from firm B, where x_B is defined as

$$v_1 - \alpha_1(1 - x_B) - p_B^1 = v_2 - p_A^2. \tag{8}$$

Firm A chooses p_A^1 and p_A^2 to maximize

$$\max_{p_A^1,p_A^2} (p_A^1 - r_1)x_A + (p_A^2 - r_2)(x_B - x_A)$$

whereas firm B chooses p_B^1 to maximize

$$\max_{p_B^1} (p_B^1 - r_1)(1 - x_B).$$

For given r_1 and r_2 the equilibrium prices become

$$\begin{aligned}
p_A^{1*} =& \frac{v_1 - v_2 + r_2 + 5r_1 + 4\alpha_1}{6}, \\
p_A^{2*} =& \frac{v_2 - v_1 + 2r_2 + r_1 + 2\alpha_1}{3}, \\
p_B^{1*} =& \frac{v_1 - v_2 + r_2 + 2r_1 + \alpha_1}{3}.
\end{aligned}$$

Replacing in the profit function of both downstream producers we obtain

$$\pi_A^M(r_1, r_2) = \frac{(v_1 - v_2 + r_2 - r_1)^2}{4\alpha_1} + \frac{(v_2 - v_1 + 2\alpha_1 + r_1 - r_2)^2}{9\alpha_1}, \tag{9}$$

$$\pi_B^M(r_1, r_2) = \frac{(v_1 - v_2 - r_1 + r_2 + \alpha_1)^2}{9\alpha_1}. \tag{10}$$

We can now move to the previous stage in which, given r_1 and r_2, firms A and B choose which technologies to license. From the previous lemma we know that the only deviations that may arise in equilibrium correspond to the case in which firm A decides to license either only 1 or only 2. That is, the deviation implies that both firms sell only one product. Thus, in the initial stage, innovators 1 and 2 maximize profits subject to granting firm A at least the same level of profits as if it were buying only the product from the competitor. In particular,

$$\max_{r_1} r_1 \left[1 - (x_B - x_A)\right] \tag{11}$$

$$\text{s.t. } \pi_A^M(r_1, r_2) \geq \frac{(v_2 - v_1 + 2\alpha_1 + r_1 - r_2)^2}{9\alpha_1}, \tag{12}$$

where the last term in the constraint corresponds to the profits in the subgame in which firm A licenses innovation 2 when the competitor licenses only innovation 1. Obviously, from equation (10), the constraint will never be binding.

Regarding developer 2, we can obtain profits from

$$\max_{r_2} r_2(x_B - x_A) \tag{13}$$

$$\text{s.t. } \pi_A^M(r_1, r_2) \geq \frac{\alpha_1}{2}, \tag{14}$$

where the last term in the constraint corresponds to the profits in the subgame in which firm A decides to license only innovation 1.

The next proposition shows that there is no combination of the royalties that satisfies the previous condition while, at the same time, it guarantees a positive market share for all products.

Lemma 3. *There is no equilibrium in which one firm licenses both technologies and the competitor licenses only technology* 1 *and all products have a positive market share.*

An immediate consequence, that we summarize in the following proposition, is that even when firms can create products that embed innovations from both firms they will choose not to do it.

Proposition 8. *In equilibrium each downstream firm will sell a unique product even if there are no costs of adopting more than one.*

The reason is that by adopting a second product (typically from innovator 2) they make competition fiercer not only with the other firm but also with the other product that they might be selling. Of course, this result could change if by selling an additional product, downstream firms not only stole sales from other products in the market but they also attracted new consumers to the market.

B Proofs

In this section we include the proof of the results of this paper.

Proof of Proposition 1: The downstream producer will prefer the technology of innovator i over innovator j if $\pi_A^M(i) \geq \pi_A^M(j)$. This condition is satisfied if

$$\frac{v_i}{\alpha_i^{\frac{\gamma}{1+\gamma}}} - \frac{r_i}{\alpha_i^{\frac{\gamma}{1+\gamma}}} \geq \frac{v_i}{\alpha_j^{\frac{\gamma}{1+\gamma}}} - \frac{r_j}{\alpha_j^{\frac{\gamma}{1+\gamma}}}.$$

Bertrand competition among technology producers implies that in equilibrium one of the firms, say firm j, will set a royalty equal to 0. In that case firm i will optimally set a positive royalty if and only if

$$\frac{v_i}{\alpha_i^{\frac{\gamma}{1+\gamma}}} \geq \frac{v_j}{\alpha_j^{\frac{\gamma}{1+\gamma}}}.$$

Using the previous expressions and replacing $r_j^* = 0$ we obtain the maximum royalty that firm i can charge and, therefore, the optimal one as

$$r_i^* = v_i - \left(\frac{\alpha_i}{\alpha_j}\right)^{\frac{\gamma}{1+\gamma}} v_j.$$

In the First Best, social welfare arising from the choice of technology i can be computed as

$$W = \int_0^{\frac{v_i}{\alpha_i}} (v_i - \alpha_i x)\gamma x^{\gamma-1} dx = \frac{v_i^{\gamma+1}}{\alpha_i^{\gamma}} \frac{1}{1+\gamma},$$

and the result is immediate. □

Proof of Proposition 2: For an equilibrium in which both downstream firms license technology 1 it has to be that the deviation, choose technology 2, leads to lower profits. Comparing profits in the different alternatives, it is immediate that lower profits arise when $r_1 - r_2 < v_1 - v_2 + \left(\frac{3}{\sqrt{2}} - 2\right)\alpha_1$. Similarly, for an equilibrium in which both downstream producers choose technology 2 it has to be the case that by choosing technology 1 they obtain no demand. This condition implies that $r_1 - r_2 \geq v_1 - v_2 + \alpha_1$. These two conditions are mutually exclusive meaning that the two equilibria cannot coexist. If neither condition is satisfied the equilibrium in which firms choose different technologies arises. □

Proof of Lemma 1: The first order condition that determines the solution to the problem of both upstream producers in the text (equation (6)) leads to reaction functions

$$r_1^R(r_2) = \frac{v_1 - v_2 + r_2 + \alpha_1}{2},$$
$$r_2^R(r_1) = \frac{v_2 - v_1 + r_1 + 2\alpha_1}{2}.$$

The intersection of both reaction functions determines the interior solution for the equilibrium royalty $r_1^* = \frac{v_1 - v_2 + 4\alpha_1}{3}$ and $r_2^* = \frac{v_2 - v_1 + 5\alpha_1}{3}$. Notice, however, that this result requires that $4\alpha_1 \geq v_2 - v_1 \geq -5\alpha_1$. These are the same conditions that guarantee that the indifferent consumer, x^*, lies between 0 and 1.

We now analyze the incentives for an innovator to undercut the competitor. In particular, consider a given r_2. Profits for innovator 1 when the market is shared correspond to

$$\Pi_1^*(r_2) = \max_{r_1} \; r_1 x^* = \frac{(v_1 - v_2 + \alpha_1 + r_2)^2}{12\alpha_1},$$

whereas if it undercuts innovator 2 by the lowest possible amount, as reflected in (5), profits become

$$\hat{\Pi}_1(r_2) = v_1 - v_2 + \left[\frac{3}{\sqrt{2}} - 2\right] \alpha_1 + r_2.$$

Under the previous equilibrium royalties undercutting will not occur if $\Pi_1^*(r_2^*) \geq \hat{\Pi}_1(r_2^*)$ and that inequality will hold if $v_1 - v_2 > \left(5 - \frac{9}{2^{1/4}}\right) \alpha_1$. If the opposite is true, innovator 2 will find optimal to choose a royalty $r_2 < r_2^*$. In particular, notice that

$$\begin{aligned}\frac{\partial}{\partial r_2}\left(\hat{\Pi}_1(r_2) - \Pi_1^*(r_2)\right) =& 1 - \frac{v_1 - v_2 + \alpha_1 + r_2}{6\alpha_1} \geq 1 - \frac{v_1 - v_2 + \alpha_1 + r_2^*}{6\alpha_1} = \\ =& \frac{5\alpha_1 - v_1 + v_2}{9\alpha_1} > 0,\end{aligned}$$

since $v_1 - v_2 \leq 5\alpha_1$. Thus, to prevent undercutting and maximize profits innovator 2 will choose the royalty $\tilde{r}_2$ that equates both profits, $\Pi_1^*(\tilde{r}_2) = \hat{\Pi}_1(\tilde{r}_2)$, or

$$\tilde{r}_2 = v_2 - v_1 + \left(5 - 3 \times 2^{\frac{3}{4}}\right) \alpha_1,$$

and the best response of innovator 1 corresponds to $\tilde{r}_1^* = r_1^R(\tilde{r}_2) = 3\left(1 - 2^{-\frac{1}{4}}\right) \alpha_1$. □

Proof of Proposition 3: Using a Bertrand competition argument, if both producers choose technology 2, in equilibrium $r_1^* = 0$ and the highest royalty that firm 2 can charge is $r_2^* = v_2 - v_1 - \alpha_1$. Innovator 1 makes 0 profits whereas innovator 2 makes profits $\Pi_2 = r_2^*$. This equilibrium requires $v_1 - v_2 < -\alpha_1$. Lemma 1, however, shows that when $v_1 - v_2 = -4\alpha_1$ in an equilibrium in which both downstream firms choose different technologies $r_1^* = 0$. Thus, for $-4\alpha_1 < v_1 - v_2 < -\alpha_1$ the best response of innovator 2 involves sharing the market, generating higher profits.

Similarly, if both downstream producers choose technology 1, innovator 2 will charge in equilibrium a royalty $r_2^* = 0$. From proposition 2 we know that the highest royalty that firm 1 can charge in that case is $r_1^* = v_1 - v_2 + \left(\frac{3}{\sqrt{2}} - 2\right) \alpha_1$ and a sufficient condition for this equilibrium to exist is that $v_1 - v_2 > -\left(\frac{3}{\sqrt{2}} - 2\right) \alpha_1$. Notice that for $v_1 - v_2 = (5 - 3 \times 2^{\frac{3}{4}})\alpha_1$, using again Lemma 1, in an equilibrium in which both firms share the market $r_2^* = 0$. The lemma shows that the best response of innovator 1 is interior, meaning that it is not serving the whole market. Thus, in the region $(5 - 3 \times 2^{\frac{3}{4}})\alpha_1 \geq v_1 - v_2 > -\left(\frac{3}{\sqrt{2}} - 2\right) \alpha_1$ in equilibrium both innovators license to one downstream producer. The equilibrium royalties in the intermediate region arise from Lemma 1. □

Proof of Proposition 4: We start by computing welfare under different technologies arrangements. When only technology 2 is adopted welfare becomes $W_2 = v_2$, where given the assumption of $\alpha_2 = 0$ the result does not change regardless of whether one firm or both adopt it.

When both firms adopt different technologies – for example, firm A adopts technology 1 and firm B technology 2 – the market is always covered. Product A is assigned to those consumers located at x such that $v_1 - \alpha_1 x > v_2$. Welfare in this case can be computed as

$$W_{12} = \int_0^{\frac{v_1 - v_2}{\alpha_1}} (v_1 - \alpha_1 x)dx + v_2 \left(1 - \frac{v_1 - v_2}{\alpha_1}\right) = v_2 + \frac{(v_1 - v_2)^2}{2\alpha_1},$$

with $v_1 > v_2 > v_1 - \alpha_1$.

Finally, if both downstream firms adopt technology 1 the market will be covered if and only if $v_1 > \frac{\alpha_1}{2}$. As a result, social welfare can be computed as

$$W_1 = \begin{cases} \frac{v_1^2}{\alpha_1} & \text{if } v_1 \leq \frac{\alpha_1}{2}, \\ v_1 - \frac{\alpha_1}{4} & \text{otherwise.} \end{cases}$$

Obviously, if $v_2 \geq v_1$ the unique adoption of technology 2 is optimal. It is immediate that $W_2 \geq W_{12}$ and that $W_2 > W_1$ if $v_1 > \frac{\alpha_1}{2}$. When $v_1 < \frac{\alpha_1}{2}$, notice that since $\alpha_1 \leq \frac{2}{3\sqrt{2}-1} v_2$ we have that

$$W_2 = v_2 \geq \frac{3\sqrt{2}-1}{2}\alpha_1 > \frac{\alpha_1}{4} \geq W_1.$$

If $v_2 < v_1$ we have that $W_{12} > W_2$. Furthermore, $v_1 > v_2 \geq \frac{3\sqrt{2}-1}{2}\alpha_1$ implies that $W_1 = v_1 - \frac{\alpha_1}{4}$. It is immediate that $W_{12} > W_1$ if and only if $v_2 > v_1 - \left(1 - \frac{1}{\sqrt{2}}\right)\alpha_1$. □

Proof of Proposition 5: First notice that, from the point of view of both downstream producers, choosing technology 2 by firms will never be optimal since it would lead to aggregate profits of 0. If both firms chose different technologies their joint profits would be

$$\Pi_A^1 + \Pi_B^2 = \frac{(v_1 + 2\alpha_1 + r_2 - r_1)^2}{9\alpha_1} + \frac{(v_2 - v_1 + \alpha_1 + r_1 - r_2)^2}{9\alpha_1},$$

where $v_1 - v_2 - 2\alpha - 1 \leq r_1 - r_2 \leq v_1 - v_2 + \alpha_1$ for both firms to have positive sales under this technology configuration. It is easy to see that the previous function is a parabola, with a minimum at $v_1 - v_2 - \frac{\alpha_1}{2}$. Both extremes constitute the maximum and are equal and imply profits of α_1.

If both firms choose technology 1 and v_1 is sufficiently high so that the indifferent consumer always obtains positive utility, the equilibrium price will be $p_i = \alpha_1 + r_i^*$ for $i = A, B$. The indifferent consumer, located at 1/2, will obtain utility

$$U\left(\frac{1}{2}\right) = v_1 - \frac{\alpha_1}{2} - (\alpha_1 + r_1^*).$$

If $r_1^* \leq v_1 - \frac{3}{2}\alpha_1$ both downstream firms make profits of $\Pi_i^1 = \frac{\alpha_1}{2}$ so that total profits are α_1, dominating the case in which firms choose different technologies. For royalty rates $r_1 \in \left(v_1 - \frac{3}{2}\alpha_1, v_1 + \alpha_1\right)$ joint profits of downstream firms correspond to $v_1 - \frac{\alpha_1}{2} - r_1$ which decrease at a rate of 1 with r_1 and the market is still covered in equilibrium.

We now show that in equilibrium both firms license technology 1 as long as $v_1 - v_2 + \alpha_1 > 0$. First suppose that $v_2 \geq \frac{5}{2}\alpha_1$ so that $v_1 - \frac{3}{2}\alpha_1 \geq v_1 - v_2 + \alpha_1$. In that case, $r_1^* = v_1 - v_2 + \alpha_1$ and $r_2^* = 0$. A higher r_1 will lead to an equilibrium with two technologies where the market share of the licensee of technology 1 would be 0.

If $v_2 < \frac{5}{2}\alpha_1$ so that $v_1 - \frac{3}{2}\alpha_1 < v_1 - v_2 + \alpha_1$, innovator 1 can raise r_1 and still induce higher profits for the licensee than what they could obtain by relying on two technologies. Equating both expressions for profits we obtain that such a move is profitable as long as

$$r_1 \leq v_1 - v_2 - \frac{11}{4}\alpha_1 + \frac{3}{4}\sqrt{8\alpha_1 v_2 + 5\alpha_1^2},$$

which leads to the equilibrium stated in the text. □

Proof of Proposition 6: If both downstream producers choose technology 1 and face a royalty r_1 their profits will be defined, for $i = A, B$, as

$$\Pi_i = \max_{p_i} (p_i - r_1)\frac{v_1 - p_i}{\alpha_1},$$

if all consumers buy,

$$\frac{v_1 - p_A}{\alpha_1} + \frac{v_1 - p_B}{\alpha_1} = 1$$

and 0 otherwise. If the constraint is not binding, we obtain that in equilibrium $p_A^* = p_B^* = p^* = r_1 + \alpha_1$. If $v_1 - \frac{\alpha_1}{2} - p^* < 0$ firms must lower their price in order to guarantee a positive utility to the consumer located at $\frac{1}{2}$. The highest possible royalty that developer 1 could charge while the market remains covered is $r_1^* = v_1 - \frac{\alpha_1}{2}$. In this case, each producer is indifferent between setting $p_i = r_1^*$ and covering the market or deviating to another price.

As mentioned in the text, to the extent that downstream developers obtain positive profits by choosing technology 1 it is a weakly dominant strategy for both downstream producers to choose that technology. □

Proof of Proposition 7: The expression for social welfare when both producers adopt technology 1, W_1, and both producers adopt technology 2, W_2, are derived in

Proposition 4 as

$$W_2 = v_2$$
$$W_1 = v_1 - \frac{\alpha_1}{4}.$$

where, given the network effects, in the case of technology 1 it is always optimal that the market is covered. The direct comparison of these expressions leads to the result in the proposition. $\square$

Proof of Lemma 2: In order to prove the previous result we will show that an allocation in which each firm sells both products or one in which one firm sells both products and the other sells only product 2 will not arise in equilibrium.

Regarding the latter, suppose first that one firm, say firm A sells both products and firm B sells only the product that embeds the technology from firm 2. From equation (7), firm B will only sell if the price for its product p_B^2 is lower or equal than p_A^2. Since firm B only sells product 2 it is a dominant strategy to undercut firm A as long as $p_A^2 > r_2$. Thus, in equilibrium firm A will either sell only the product that embeds the technology of firm 1 or will choose $p_A^2 = p_B^2 = r_2$. Notice that the first case is equivalent to firm A not offering product 2 at all. Thus, for the candidate equilibrium to exist it has to be that $p_A^2 = r_2$. In the previous stage, when firms choose which products to sell, firm A compares offering both products with, among other options, offering only product 1. Clearly, the second option is preferred since otherwise first firm A meets more competition for product 1, while not benefiting from the sale of product 2. Thus, this candidate equilibrium cannot arise.

Suppose now that both firms license the technology from both upstream producers in order for each firm to sell both products. According to equation (7), it has to be the case that consumers located at $x \leq x_A$ buy product 1 from downstream producer A. We can define x_B in a symmetric way. As a result, we conclude that consumers at $x \geq x_B \geq x_A$ buy product 1 from producer B. Consumers at $x \in (x_A, x_B)$ buy product 2. Thus, at any price greater than r_2 one of the firms will have incentives to undercut the competitor for the product embedding innovation 2, since it will sell to all consumers between x_A and x_B and have a negligible impact on the indifferent consumers themselves. Thus, the standard Bertrand competition argument will lead to $p_A^2 = p_B^2 = r_2$.

From the previous argument, the indifferent consumer between buying product 1 from firm A and buying product 2, x_A^*, corresponds to

$$v_1 - \alpha_1 x_A^* - p_A^1 = v_2 - r.$$

Thus, the price for product 1 that maximizes profits for firm A can be obtained from

$$\max_{p_A^1} (p_A^1 - r_1)\frac{v_1 - v_2 - p_A^1 + r_2}{\alpha_1},$$

or $p_A^{1*} = \frac{v_1 - v_2 + r_2 + r_1}{2}$ and lead to profits of $\pi_A^{12} = \frac{(v_1 - v_2 + r_2 - r_1)^2}{4\alpha_1}$. Notice that for this equilibrium to exist $x_A^* = x_B^* \leq \frac{1}{2}$ implying that $v_1 - v_2 + r_2 - r_1 \leq \alpha_1$.

Moving to the previous stage, suppose now that A has adopted both innovations and B is considering whether to adopt only innovation 1 or adopting 1 and 2. If firm B adopts only 1, profits are identical to those of equation (10). The comparison with the profits when both firms sell both products show that the selling of both products leads to higher profits if

$$v_1 - v_2 + r_2 - r_1 \geq 2\alpha_1,$$

which is a contradiction with $x_A^* = x_B^* \leq \frac{1}{2}$. □

Proof of Lemma 3: The constraint in the problem of developer 2, equation (14), implies that either

$$r_2 - r_1 \leq v_2 - v_1 + \frac{8 - 3\sqrt{10}}{13}\alpha_1$$

or

$$r_2 - r_1 \geq v_2 - v_1 + \frac{8 + 3\sqrt{10}}{13}\alpha_1.$$

For the solution to lead to positive market share it has to be that $0 < x_A < x_B < 1$. In particular

$$\begin{aligned}
x_A = \frac{v_1 - v_2 + r_2 - r_1}{2\alpha_1} > 0 &\Longrightarrow r_2 - r_1 > v_2 - v_1, \\
x_B = \frac{v_2 - v_1 - r_2 + r_1 + 2\alpha_1}{3\alpha_1} < 1 &\Longrightarrow r_2 - r_1 > v_2 - v_1 - \alpha_1, \\
x_A > x_B &\Longrightarrow r_2 - r_1 < v_2 - v_1 + \frac{4}{5}\alpha_1.
\end{aligned}$$

Since the second condition is implied by the first, we have that for all products to have a positive market share it has to be that $v_2 - v_1 < r_2 - r_1 < v_2 - v_1 + \frac{4}{5}\alpha_1$, and this is incompatible with the two conditions above, since $\frac{8-3\sqrt{10}}{13} < 0$ and $\frac{8+3\sqrt{10}}{13} > \frac{4}{5}$. □

Proof of Proposition 8: Immediate from Lemma 2 and 3. □