Inefficient Exclusion in Standard Setting Organizations*

Emanuele Tarantino†

European University Institute

August 2009

Abstract

This paper shows that vertically integrated firms have incentive to inefficiently exclude a stand-alone upstream firm from the technology licensing market. The model develops on the idea that a stand-alone upstream firm endowed of market power can hold up vertically integrated organizations through the sale of an intermediate good. The contracting environment resembles the one that characterizes standard setting organizations in several aspects, and in particular in the assumption for which parties negotiate over the royalty fees after downstream manufacturers' choice and adoption of a certain technology.

JEL codes: K21, L15, L24, L42.

Keywords: Licensing Agreements, Cross Licensing, Standards, Vertical Integration, Exclusion.

1 Introduction

Voluntary Standard Setting Organizations (SSOs) are consortia devoted to the achievement of an agreement on the rules defining the design of a final good or service by industry operators. Through their decisions, SSOs guide the path of technological adoption. For instance, among the standards certified by the SSOs in the information and communication technology sector there are the ADSL, the Wi-Fi protocol, and the DDR-SDRAM standard. The recent empirical work by Rysman and Simcoe (2008) confirms that certification consortia have a crucial role in leading to

*This paper benefited from comments by Vincenzo Denicolò, Bruno Jullien, Massimo Motta, Patrick Rey, David Salant, Bauke Visser, Andrew Updegrove and the participants at the TILEC - University of Tilburg, TSE, and EUI seminars, and the SIDE 2008 and CRESSE 2009 meetings. The usual disclaimer applies.

†Address: EUI Department of Economics, Via della Piazzuola, 43, I-50133 Firenze, email: emanuele.tarantino@eui.eu.

a bandwagon process among adopters, showing that patents disclosed in SSOs receive up to twice as many citations as other patents in the same sector.

Certification bodies tend to emphasize the consensus that would characterize their decisions, however strategic considerations among their participants can be intense. Indeed, several pieces of evidence show that strong competitive tensions influence the procedure of standard adoption, and might eventually lead to judicial disputes. These disputes mainly arise from the conflicting interests that operators with different business structure try to put forward in the process of standard certification (see Teece and Sherry (2003), DeLacey et al. (2006), Geradin (2008), Schmalensee (2008), Simcoe et al. (2009)).

In this paper, I focus on two categories of firms: vertically integrated operators and pure developers of new technologies. These firms participate to certification bodies with strikingly different objectives. Integrated organizations join SSOs because of the important economic benefits that derive from coordination among industry participants. Consequently, they have a clear interest in paying low rates for standard's technologies, while competing on the product market.[1] IPR developers raise most of their revenue from the technology licensing market. They join SSOs primarily because having a patented technology deemed essential to a new standard can help insure a long stream of licensing revenue.[2]

I propose a framework for the analysis of the incentives that vertically integrated firms have to include patented technologies into a standard, and show under which conditions they may inefficiently exclude a stand-alone firm from the upstream market. I address this issue studying how market competition and licensing decisions interact with the standard choice. Consequently, the model encompasses two markets: the technology licensing market (or upstream market); and the product market (or downstream market).

The balance of two major forces determines the exclusionary conduct. The employment of the independent upstream firm's input allows vertically integrated firms to use a more efficient technology for the production of the final good. However, it also allows the stand-alone firm to exploit its monopoly power over the patented technology (hold-up effect).

I solve for the optimal inputs' adoption choice made by integrated firms as function of two parameters: the one that measures the greater efficiency of the independent licensor's technology, and the one that captures the lower costs associated to the adoption of a unique standard.[3] In particular, as the economies generated by standardization rise, then vertically integrated firms have greater incentive to cross-license their own technologies, excluding the independent firm's technology from the bundle of inputs they employ. Instead, as the efficiency of the independent

[1] Nokia, Sony-Ericsonn, IBM belong to this class of firms.

[2] Qualcomm, Rambus, Certicom belong to this class of firms.

[3] This parameter measures the cost-savings due to standardization, like economies of scale in production, or greater final goods' compatibility.

firm's technology increases, then an equilibrium with competing standards is more likely to emerge, in which one of the vertically integrated firms uses the technology of the upstream stand-alone licensor, while the other uses its own technology, eluding the hold-up effect.[4] Finally, the joint adoption of the technology licensed by the pure upstream operator is never an equilibrium of the adoption game.

Three main assumptions are made concerning the composition and the functioning of the ideal SSO in the model. The *first assumption* is that two vertically integrated firms and one upstream firm populate the representative organization. A framework with a majority of vertically integrated firms is able to capture the conflict between integrated firms and vertically specialized technology developers. Moreover, it is able to replicate SSOs' environment in several situations, and in particular in two major antitrust cases currently under the scrutiny of antitrust authorities in the US and Europe: the FTC v. Rambus case, and the EC v. Qualcomm case. In both cases major vertically integrated firms are among the plaintiffs, and accuse upstream developers of having kept a misleading conduct during the phase of standard definition.

The *second assumption* is that it is vertically integrated firms that decide which technologies are included in the standard. This modeling choice is based on the evidence arising from the SSOs operating in the information and communications technology sector. Standardization bodies in this industry are commonly founded by manufacturers, with the intent of controlling the development of a particular technology, and avoid miscoordination among vendors.[5] Clearly, being in the pool of founding members allows these firms to play a crucial role in the phase of standard definition.

Further evidence regarding manufacturers' decision power arises from the two organizations involved in the antitrust cases mentioned above. Gandal et al. (2003) remark that in ETSI, the SSO of the Qualcomm case, the voting rule allowed even a small minority of operators to impose the adoption of their favorite standard configuration. Indeed, ETSI rules required a majority of 71 percent for standard approval, but with a voting weighting system based on European turnover: this favored European producers, and many of these are vertically integrated.[6] JEDEC, the SSO of the Rambus case, is mostly composed by vertically integrated manufacturers, which, consequently, can strongly influence the choice of the pool of technologies in a standard.[7]

[4]In the following I denote this scenario as one of disjoint adoption. Disjoint adoption arises as part of the equilibrium because I do not impose that the use of a common standard is compulsory to industry's operators. This outcome is far from being purely theoretical, as multiple standards can coexist, for instance, when users' network externalities are not particular strong. An important example is represented by the wireless telephony, where handsets based on different chips' technologies are marketed. See Cabral and Salant (2009) for a more exhaustive discussion on this issue.

[5]See Updegrove (1993) for a detailed analysis of the strategic motivations that lead manufacturers to push for the formation of standardization consortia.

[6]For example, Nokia and Ericsson are in ETSI.

[7]The evidence gathered by the FTC in the Rambus case witnesses to the large presence of integrated firms in

The *third hypothesis* consists in assuming that licensing negotiations take place after downstream manufacturers choose and adopt a specific standard, in compliance with most of the standard definition processes undertaken in technology certification bodies.[8] The main implication of this assumption is that licensing firms whose technology has been employed have full monopoly power on the determination of the royalty rate.

Licensing negotiations take place after the decision over standard composition for several reasons. However, a crucial impediment to the implementation of an ex-ante licensing policy seems to be related to the considerable uncertainty over the value of a patent before the final product that employs it is marketed. In an extension to the basic model, I relax this hypothesis and analyze the optimal technology choice using a negotiation environment that is compliant with the implementation of the FRAND agreements' reasonableness requirement. In other words, there I assume that holders of substitute patents compete for the inclusion in a standard, and set royalty rates before manufacturers commit to the adoption of a specific technology. This enriches the policy conclusions of the paper showing that early licensing decisions reduce the scope for the total exclusion of the specialized firm.

This paper analyzes how *standard composition decisions interact with licensing decisions and product market competition*. Schmidt (2008) and Schmalensee (2008) investigate the interdependence of pricing decisions between upstream innovators, downstream producers and integrated entities. Schmalensee's main interest is on the analysis of the pricing schemes that may solve the hold-up problem. Schmidt proves that, compared to a situation in which only vertically integrated firms are active, the presence of pure upstream innovators allows to decrease royalty rates, and, consequently, final output's price. This result is driven by the incentive that vertically integrated firms have to raise the cost of the inputs sold to downstream rivals (the "raising rival's cots" effect). Schmidt stresses that cross licensing between vertically integrated firms can alleviate this problem, however, he does not study the scope for upstream exclusion, but focuses on how different market configurations change pricing incentives.

The contribution of the paper to the literature on *vertical integration and exclusion* is twofold: the first consists in analyzing the extent to which vertical integrated firms can exclude an independent firm operating on the upstream market if inputs are complementary, and because of the danger of hold up. Instead, this literature has typically focused on settings with substitute intermediate goods.[9] The second consists in investigating the extent to which *exclusion on the*

JEDEC. See In the Matter of Rambus Inc., Docket No. 9302.

[8]A remarkable exemption is VITA, which switched in 2006 to a policy that requires the owners of patented technologies to disclose the maximum royalty rates, and provide binding written license declarations, at several specified points during the standard development process.

[9]See Rey and Tirole (2007) for a survey on foreclosure.

upstream market can give rise to inefficient outcomes, whilst most of the economic literature on licensing has studied the anticompetitive effects directly imparted by upstream pricing decisions on the downstream market (see Rey and Salant (2008), Lin (1996), Eswaran (1994)).[10]

The paper is also related to the literature on *patent pools' formation* (see Lerner and Tirole (2004), Lerner et a. (2007), Leveque and Ménière (2008)). In particular, Lerner and Tirole (2004) study an all-or-nothing patent pool formation problem, and develop a framework in which the degree of complementarity among a set of patents is the equilibrium outcome of a game in which independent licensing decisions are constrained either by demand forces or by strategic forces. Instead, I am interested in the analysis of the conflicts that emerge between holders of competing technologies for a given degree of complementarity, as to understand the extent to which *inefficient holdouts* may arise at equilibrium.

Finally, the model shows that *competing standards* may emerge as equilibrium outcome, like in Cabral and Salant (2009) although their analysis is based on different economic underpinnings. Cabral and Salant stress that a unique standard may give rise to a problem of free-riding, which reduces the incentives to invest in R&D with respect to a market structure with competing standards. In what follows, I show that producers' adoption of asymmetric standards is the result of the interplay between product market and licensing decisions.

The paper proceeds as follows. Section 2 presents the main model. Section 3 presents the exclusionary result under contracts with linear royalties. Section 4 analyzes the optimal technology choice when parties comply to FRAND agreements' reasonableness requirement. Section 5 concludes.

2 The Model

There are 3 firms, two of them are vertically integrated, say 1 and 2, the third is a stand-alone upstream firm. Each firm enters the game with a patented technology: two of them are substitute, say technologies τ_2 and τ_3, the third, τ_1, is perfect complement to the other two.

Moreover, only the inclusion of one between τ_2 and τ_3 increases the value of the standard, indexed $\mathcal{S}$, used for the production of the final good. Instead, if both are included, one is redundant: in this way, I limit the scope of the analysis to two competing standards, $\mathcal{S}(\tau_1, \tau_2)$ and $\mathcal{S}(\tau_1, \tau_3)$, as to make the conflict between τ_2 and τ_3 more compelling.

Finally, in order to make things more interesting, I assume that technology 3 is superior to

[10] In particular, Rey and Salant (2009) analyze the impact of alternative licensing policies by owners of essential IPRs on downstream competition. Lin (1996) shows that firms can use fixed fee licensing agreements to collude on the product market. Analogously, Eswaran (1994) proves that cross licensing constitutes a device that facilitates collusion among downstream horizontal competitors.

technology 2. More specifically, the employment of τ_3 in the standard reduces the cost borne by downstream manufacturers for the production of the final good by $e \in (0, 1)$.

[FIGURE 1 ABOUT HERE]

Upstream firms bear zero marginal cost. Downstream firms compete in quantities and use as only production inputs the two technologies in the standard. Consumers have inverse demand $P(Q)$, where Q is total industry output. Assume for simplicity that $P(Q)$ is linear, and given by $\min\{0, 1 - Q\}$. The assumption of linearity makes sure that the Cournot-Nash equilibrium of the game exists and is unique.

Downstream production requires the payment of a marginal cost $\bar{c} \in (0, 1)$, on top of the fees paid to acquire upstream inputs. However, the adoption of a unique bundle of inputs implies that manufacturers pay a smaller marginal cost, given by $c_J = \max\{0, \bar{c} - s\} < \bar{c}$.

Active licensors can choose among two pricing schemes: independent licensing or cross-licensing. Cross licensing can only take place between vertically integrated firms, because firm 3 does not operate downstream. Thus, when cross licensing agreements emerge at equilibrium, firm 3 is excluded from the upstream market.

The decision over standard composition is taken by vertically integrated firms in an non-cooperative manner. In particular, vertically integrated firms compare own profits under different standard specifications and pricing schemes.

Finally, side payments are not allowed in this model. Side payments would take the form of conditional contracts in which parties specify, before standard adoption, what type of transfers they would carry out depending on the choice of the standard. Agreements of this sort can be ruled out invoking two sorts of argument. Firstly, they would be difficult to enforce in a court: having a contingent nature, parties may be tempted to renegotiate them ex post. Secondly, rational agents may design them to collude on the product market, so that, like other forms of horizontal agreements, they are typically treated as per se unlawful by antitrust authorities.

3 Linear Pricing

In this section, the main results of the analysis carried out assuming that firms set licensing agreements through linear pricing are presented.[11]

In what follows, then, w_{jk} indicates the royalty rate set by firm j on firm k, with $j, k = 1, 2$ and $j \neq k$. Instead, $w_{31} = w_{32} = w_3$ is the fee set by firm 3 on both 1 and 2: in other words, I am assuming that firm 3 cannot discriminate among downstream firms. I motivate this hypothesis

[11]The empirical evidence provided by Layne-Farrar and Lerner (2008) shows that linear royalties are used by a wide majority of patent pools' members to license out their technology.

using the non-discriminatory requirement that firms in SSOs must usually comply with when agreeing on FRAND commitments.

Firm 1 and firm 2 ignore the royalty rate set by their upstream division if their technology is in the standard. More specifically, the value of firm 1 marginal cost is:

$$c_1 = \begin{cases} w_{21} + \mathbf{I_J} \max\{0, \bar{c} - s\} + (1 - \mathbf{I_J})\bar{c} & \textit{if firm 1 adopts } \tau_1 \textit{ and } \tau_2 \\ \\ w_3 - e + \mathbf{I_J} \max\{0, \bar{c} - s\} + (1 - \mathbf{I_J})\bar{c} & \textit{if firm 1 adopts } \tau_1 \textit{ and } \tau_3 \end{cases}$$

Instead, firm 2 bears a marginal cost of the following type:

$$c_2 = \begin{cases} w_{12} + \mathbf{I_J} \max\{0, \bar{c} - s\} + (1 - \mathbf{I_J})\bar{c} & \textit{if firm 2 adopts } \tau_1 \textit{ and } \tau_2 \\ \\ w_{12} + w_3 - e + \mathbf{I_J} \max\{0, \bar{c} - s\} + (1 - \mathbf{I_J})\bar{c} & \textit{if firm 2 adopts } \tau_1 \textit{ and } \tau_3 \end{cases}$$

$\mathbf{I_J}$ is an indicator function equal to:

$$\mathbf{I_J} = \begin{cases} 1 & \textit{if joint adoption} \\ 0 & \textit{if disjoint adoption} \end{cases}$$

The timing of the game follows.

1. *Standard Choice Stage*: downstream firms choose a standard.

2. *Licensing Scheme and Royalty Setting Stage*: upstream firms whose technology is adopted downstream set the royalty rate and the licensing scheme (independent licensing/cross licensing). Consequently, each downstream firm decides whether to pay the royalty rate (and produce) or give up production.

3. *Product Market Competition Stage*: active firms set quantities.

I solve the model backwards, and the equilibrium concept I employ is the Subgame Perfect Nash Equilibrium (SPE). There are four cases to be considered. I first present the two frameworks in which vertically integrated firms jointly employ $\mathcal{S}(\tau_1, \tau_2)$ or $\mathcal{S}(\tau_1, \tau_3)$, denoted $J2$ and $J3$, respectively. Then, I discuss the scenarios that feature disjoint adoption: the one in which firm 1 adopts $\mathcal{S}(\tau_1, \tau_3)$ and firm 2 adopts $\mathcal{S}(\tau_1, \tau_2)$, which is denoted by $D32$; then the one in which firm 1 adopts $\mathcal{S}(\tau_1, \tau_2)$ and firm 2 adopts $\mathcal{S}(\tau_1, \tau_3)$, denoted by $D23$.

3.1 Joint Adoption of $\mathcal{S}(\tau_1, \tau_2)$ - "$J2$"

First I derive the optimal quantities set by firm 1 and firm 2 for given royalties, then I compute the equilibrium royalty rates. At the competition stage, each downstream firm maximizes:

$$\max_{q_j \geq 0} \Pi_j = [1 - q_j - q_k - w_{kj} - c_J]q_j + q_k w_{jk}$$

With j, k=1,2, and $j \neq k$, and $c_J = \max\{0, \bar{c} - s\}$. The equilibrium is characterized by:

$$\begin{cases} q_j^{J2}(w_{12}, w_{21}) = \frac{1-c_J-2w_{kj}+w_{jk}}{3} \\ Q^{J2}(w_{12}, w_{21}) = \frac{2(1-c_J)-(w_{jk}+w_{kj})}{3} \\ P(Q^{J2}(w_{12}, w_{21})) = \frac{1+2c_J+w_{jk}+w_{kj}}{3} \end{cases} \tag{1}$$

With $j, k = 1, 2$, $j \neq k$, and $c_J = \max\{0, \bar{c} - s\}$. At this stage, two sub-cases must be distinguished: the one in which firm 1 and firm 2 license their technologies independently (independent licensing), and the one in which licensing decisions are taken cooperatively (cross licensing).

3.1.1 Independent Licensing

At the royalty setting stage of the game with independent licensing, vertically integrated firms maximize:

$$\max_{w_{jk} \geq 0} \Pi_j^{J2} = [P(Q^{J2}(w_{12}, w_{21})) - w_{kj} - c_J]q_j^{J2}(w_{12}, w_{21}) + q_k^{J2}(w_{12}, w_{21})w_{jk}.$$

With j, k=1,2, and $j \neq k$. The first-order condition is:

$$\frac{\partial \Pi_j^{J2}}{\partial w_{jk}} = \underbrace{\underbrace{[P(Q^{J2}) - w_{kj} - c_J]\frac{\partial q_j^{J2}}{\partial w_{jk}}}_{>0\text{, raising rival's costs}} + \underbrace{\frac{\partial P(Q^{J2})}{\partial Q}\frac{\partial Q^{J2}}{\partial w_{jk}}q_j^{J2} + q_k^{J2}}_{>0}}_{>0\text{, effect on DS profits}} + \underbrace{\frac{\partial q_k^{J2}}{\partial w_{jk}}w_{jk}}_{<0\text{, effect on US profits}} = 0. \tag{2}$$

If firm j raises w_{jk} it trades off the higher revenue generated downstream (partly due to the raising rival's costs effect), with the lower upstream revenue caused by firm k's output contraction downstream. Linearity leads to:

$$w_{jk}(w_{kj}) = \frac{5(1 - c_J) - w_{kj}}{10}$$

With $j,k = 1,2$ and $j \neq k$. Using symmetry, equilibrium wholesale prices are:

$$w_{12}^{J2} = w_{21}^{J2} = 5(1 - c_J)/11.$$

Plugging this value in (1), under the joint employment of $\mathcal{S}(\tau_1, \tau_2)$ and independent licensing one has the results in Table 1. In particular, firms' profits are $\Pi_1^{J2} = \Pi_2^{J2} = 14(1 - c_J)^2/121$, and the consumer surplus is given by $CS = Q^2/2 = 8(1 - c_J)^2/121$.

[TABLE 1 ABOUT HERE]

At the licensing equilibrium of the game in which vertically integrated firms price their technologies non cooperatively, royalties are determined by two well-known effects: the *Cournot effect* and the *raising rival's costs effect*. The former is caused by the fact that the technologies in the standard are complementary: consequently, each firm does not take into account the negative externality it exerts on downstream firms when pricing its technology (Cournot (1838)). The latter is related to the incentive that the downstream competing vertically integrated firms have to increase rival's costs as to push it out of the market (see Salop and Scheffman (1983) and (1987)).

3.1.2 Cross Licensing

Cross licensing is modeled in the following way. First vertically integrated firms agree on a common rate $w = w_{12} = w_{21}$ at which they cross license their proprietary technologies; then they compete downstream. Consequently, one first needs to derive the Cournot-Nash quantities for given w, and then find the royalty that implements the monopoly outcome.

Notice that downstream equilibrium quantities are the same as in the previous section, and given by (1), however, here royalties are decided cooperatively, by setting a common value w.

Upstream maximization problem is:

$$\max_{w \geq 0} \Pi^{J2} = [P(Q^{J2}(w)) - w - c_J]q^{J2}(w) + q^{J2}(w)w = [P(Q^{J2}(w)) - c_J]q^{J2}(w).$$

Therefore, firms solve standard monopolist's first-order condition:

$$\frac{\partial \Pi^{J2}}{\partial w} = \underbrace{\frac{\partial P(Q^{J2})}{\partial Q}\frac{\partial Q^{J2}}{\partial w}q^{J2}}_{>0} + \underbrace{[P(Q^{J2}) - c_J]\frac{\partial q^{J2}}{\partial w}}_{<0} = 0.$$

In particular, using (1) with $w_{jk} = w$, the optimal royalty rate is $w^{J2} = (1 - c_J)/4$.

Cross licensing allows firms to fix the raising rival's costs and double marginalization effects, bringing royalties down to the monopoly level ($w^{J2} = (1 - c_J)/4 < w_{jk}^{J2} = 5(1 - c_J)/11$), moreover, each firm raises $\Pi^{J2} = (1 - c_J)^2/8$, splitting monopoly's profit, and the consumer surplus is given by $CS = Q^2/2 = (1 - c_J)^2/8$.

Also, comparing the results in Table 1, it emerges that the equilibrium licensing scheme when vertically integrated firms jointly adopt a standard with technology 1 and technology 2 is cross-licensing. Indeed, each firm strictly prefers the cooperative agreement to the non-cooperative one, as $\Pi_j^{J2} = 14(1 - c_J)^2/121 < (1 - c_J)^2/8 = \Pi^{J2}$.

3.2 Joint Adoption of $\mathcal{S}(\tau_1, \tau_3)$ - "$J3$"

If vertically integrated firms adopt a standard that displays technology 1 and technology 3, then both benefit of the greater efficiency of τ_3. Moreover, firms are asymmetric at the upstream level, because firm 2 does not license its technology downstream, and needs to acquire externally τ_1 and τ_3. Finally, licensing firms 1 and 3 cannot cross license their technologies, because firm 3 does not operate downstream.

At the product market competition stage, firm 1 solves:

$$\max_{q_1 \geq 0} \Pi_1 = [1 - q_1 - q_2 - w_3 + e - c_J]q_1 + q_2 w_{12}.$$

Firm 2 solves

$$\max_{q_2 \geq 0} \Pi_2 = [1 - q_1 - q_2 - w_3 - w_{12} + e - c_J]q_2.$$

With $c_J = \max\{0, \bar{c} - s\}$. The results at equilibrium are:

$$\begin{cases} q_1^{J3}(w_{12}, w_3) = \frac{1-(w_3-e)+w_{12}-c_J}{3} \\ q_2^{J3}(w_{12}, w_3) = \frac{1-(w_3-e)-2w_{12}-c_J}{3} \\ Q^{J3}(w_{12}, w_3) = \frac{2(1-c_J)-[2(w_3-e)+w_{12}]}{3} \\ P(Q^{J3}(w_{12}, w_3)) = \frac{(1-e)+2c_J+2w_3+w_{12}}{3} \end{cases} \quad (3)$$

At the royalty setting stage, firm 1 solves the following problem:

$$\max_{w_{12} \geq 0} \Pi_1^{J3} = [P(Q^{J3}(w_{12}, w_3)) - (w_3 - e) - c_J]q_1^{J3}(w_{12}, w_3) + q_2^{J3}(w_{12}, w_3)w_{12}.$$

And resulting first-order condition is

$$\frac{\partial \Pi_1^{J3}}{\partial w_{12}} = [P(Q^{J3}) - (w_3 - e) - c_J]\frac{\partial q_1^{J3}}{\partial w_{12}} + \frac{\partial P(Q^{J3})}{\partial Q}\frac{\partial Q^{J3}}{\partial w_{12}}q_1^{J3} + q_2^{J3} + \frac{\partial q_2^{J3}}{\partial w_{12}}w_{12} = 0.$$

The optimal value of w_{12} is determined by the tradeoff generated by the effect of an higher royalty on downstream and upstream revenues. In particular, the first term is related to the raising rival's costs effect: it is positive and, in this case, acts only at the expenses of firm 2.

Invoking linearity, firm 1 upstream reaction function is equal to:

$$w_{12}(w_3) = \frac{1-(w_3-e)-c_J}{2}. \tag{4}$$

Firm 3 solves the following problem:

$$\max_{w_3 \geq e} \Pi_3 = Q^{J3}(w_{12}, w_3)w_3.$$

Resulting first-order condition is:

$$\frac{\partial \Pi^{J3}}{\partial w_3} = \frac{\partial Q^{J3}}{\partial w_3} w_3 + Q^{J3} = 0.$$

Clearly, the raising rival's costs effect does not play any role for firm 3, because it does not operate downstream. Using linearity, one finds that the reaction function of firm 3 is given by:

$$w_3(w_{12}) = \frac{2(1+e-c_J)-w_{12}}{4}. \tag{5}$$

Solving for w_{12} and w_3 from (4) and (5), one can derive the following equilibrium conditions:

$$\text{if} \quad e \leq \bar{e}^{J3} \equiv 3(1-c_J)/4: \quad \begin{cases} w_{12}^{J3} = \frac{2(1-c_J+e)}{7} \\ w_3^{J3} = \frac{3(1-c_J+e)}{7} \end{cases} \tag{6}$$

$$\text{if} \quad e > \bar{e}^{J3} \equiv 3(1-c_J)/4: \quad \begin{cases} w_{12}^{J3} = \frac{1-c_J}{2} \\ w_3^{J3} = e \end{cases} \tag{7}$$

Royalty rate w_3 cannot exceed the value of the parameter that measures the marginal contribution of τ_3 to lowering producers' marginal cost, e. Consequently, two sub cases must be considered. For values of e below $\bar{e}^{J3} = 3(1-c_J)/4$, the equilibrium conditions in (6) must be employed in (3) to compute firms' payoffs. Otherwise, one must use the conditions in (7). Table 2 summarizes the results of this section. In particular, if $e \leq \bar{e}^{J3}$, $\Pi_3^{J3} = 6(1-c_J+e)^2/49 > \Pi_1^{J3} = 4(1-c_J+e)^2/49 > \Pi_2^{J3} = 0$, and $CS = Q^2/2 = 2(1-c_J+e)^2/49$. Instead, if if $e > \bar{e}^{J3}$, $\Pi_3^{J3} = e(1-c_J)/2$, $\Pi_1^{J3} = (1-c_J)^2/4 > \Pi_2^{J3} = 0$, and $CS = (1-c_J)^2/8$.

[TABLE 2 ABOUT HERE]

It has to be remarked that the equilibrium of the game in which firm 1 and firm 3 price their technologies non cooperatively features a monopoly of firm 1 downstream. This is because, with respect to the case of joint adoption of $\mathcal{S}(\tau_1, \tau_2)$, firm 2 looses a device to face firm 1 competition on the product market (namely, the possibility to price an input of firm 1). Finally, since firm 3 sets the royalty rate after its technology has been adopted, it can *hold firm 1 up*, as to appropriate part of its profits.

3.3 Disjoint Adoption: Firm 1 uses $\mathcal{S}(\tau_1, \tau_3)$, Firm 2 uses $\mathcal{S}(\tau_1, \tau_2)$ - "$D32$"

At the product market competition stage, firm 1 solves:

$$\max_{q_1 \geq 0} \Pi_1 = [1 - q_1 - q_2 - (w_3 - e) - \bar{c}]q_1 + q_2 w_{12},$$

Firm 2 solves

$$\max_{q_2 \geq 0} \Pi_2 = [1 - q_1 - q_2 - w_{12} - \bar{c}]q_2.$$

Parameter e affects the maximization problem of firm 1, because firm 2 employs its own technology instead of 3's. The reduced form equilibrium results associated to the maximization problems above follow.

$$\begin{cases} q_1^{D32}(w_{12}, w_3) = \frac{(1-\bar{c})-2(w_3-e)+w_{12}}{3} \\ q_2^{D32}(w_{12}, w_3) = \frac{(1-\bar{c})+(w_3-e)-2w_{12}}{3} \\ Q^{D32}(w_{12}, w_3) = \frac{2(1-\bar{c})-[(w_3-e)+w_{12}]}{3} \\ P(Q^{D32}(w_{12}, w_3)) = \frac{(1-e)+2\bar{c}+w_3+w_{12}}{3} \end{cases} \tag{8}$$

At the royalty setting stage, firm 1 solves:

$$\max_{w_{12} \geq 0} \Pi_1^{D32} = [1 - Q^{D32}(w_{12}, w_3) - (w_3 - e) - \bar{c}]q_1^{D32}(w_{12}, w_3) + q_2^{D32}(w_{12}, w_3)w_{12}$$

Resulting first-order condition is:

$$\frac{\partial \Pi_1^{D32}}{\partial w_{12}} = [1 - Q^{D32} - (w_3 - e) - \bar{c}]\frac{\partial q_1^{D32}}{\partial w_{12}} - \frac{\partial Q^{D32}}{\partial w_{12}} q_1^{D32} + q_2^{D32} + \frac{\partial q_2^{D32}}{\partial w_{12}} w_{12} = 0$$

Again, firm 1 acts as monopolist, and takes into account the fact that raising the value of w_{12} it can exert a negative externality on firm 2, reducing rival's downstream market share. Using linearity, firm 1 upstream reaction function is equal to:

$$w_{12}(w_3) = \frac{5(1-\bar{c}) - (w_3 - e)}{10}. \tag{9}$$

Firm 3 solves the following problem:

$$\max_{w_3 \geq 0} \Pi_3^{D32} = q_1^{D32}(w_{12}, w_3)w_3.$$

And the first-order condition is:

$$\frac{\partial \Pi^{D32}}{\partial w_3} = \frac{\partial q_1^{D32}}{\partial w_3} w_3 + q_1^{D32} = 0.$$

In this case, firm 3 can exert its monopoly power only at expenses of firm 1, because firm 2 employs its own technology. Using linearity, one finds that the reaction function of firm 3 is equal to:

$$w_3(w_{12}) = \frac{(1-\bar{c}) + w_{12} + 2e}{4}. \tag{10}$$

Solving for w_{12} and w_3 from (9) and (10), one can derive the following equilibrium conditions:

$$\text{if} \quad e \leq \bar{e}^{D32} \equiv 3(1-\bar{c})/4 : \begin{cases} w_{12}^{D32} = \frac{19(1-\bar{c})+2e}{41} \\ w_3^{D32} = \frac{3[5(1-\bar{c})+7e]}{41} \end{cases} \tag{11}$$

$$\text{if} \quad e > \bar{e}^{D32} \equiv 3(1-\bar{c})/4 : \begin{cases} w_{12}^{D32} = \frac{1-\bar{c}}{2} \\ w_3^{D32} = e \end{cases} \tag{12}$$

$\bar{e}^{D32} = 3(1-\bar{c})/4$ determines the threshold above which w_3 is equal to e. For values of e below $\bar{e}^{D32}$, the equilibrium conditions in (11) must be employed in (8) to compute firms' payoffs. Otherwise, one must use the conditions in (12). The results of this section are in table 3 .

[TABLE 3 ABOUT HERE]

Remarkably, if $e \leq \bar{e}^{D32}$, firm 2 produces a positive amount on the market for the final good. This occurs because firm 2 decides to use its own technology instead of the one licensed by firm 3. Consequently, it is only firm 1 to be held-up by firm 3, and firm 2 is not stifled by the raising rival's costs effect. Comparing the equilibrium conditions in (3) and (8), the main difference lies in the way the use of τ_3 affects optimal outputs $\{q_1, q_2\}$. Indeed, w_3 negatively impacts on q_2 in (3), while the same effect is positive in (8). Conversely, the marginal negative impact of w_3 on q_1 increases from (3) to (8).

3.4 Disjoint Adoption: Firm 1 uses $\mathcal{S}(\tau_1, \tau_2)$, Firm 2 uses $\mathcal{S}(\tau_1, \tau_3)$ - "$D23$"

At the product market competition stage, firm 1 solves:

$$\max_{q_1 \geq 0} \Pi_1 = [1 - q_1 - q_2 - w_{21} - \bar{c}]q_1 + q_2 w_{12},$$

While firm 2 solves

$$\max_{q_2 \geq 0} \Pi_2 = [1 - q_1 - q_2 - (w_3 - e) - w_{12} - \bar{c}]q_2 + q_1 w_{21}.$$

The reduced form equilibrium results of the maximization problems above follow:

$$\begin{cases} q_1^{D23}(w_{12}, w_{21}, w_3) = \frac{(1-\bar{c})+(w_3-e)-2w_{21}+w_{12}}{3} \\ q_2^{D23}(w_{12}, w_{21}, w_3) = \frac{(1-\bar{c})-2(w_3-e)-2w_{12}+w_{21}}{3} \\ Q^{D23}(w_{12}, w_{21}, w_3) = \frac{2(1-\bar{c})-(w_3-e+w_{12}+w_{21})}{3} \\ P(Q^{D23}(w_{12}, w_{21}, w_3)) = \frac{(1-e)+2\bar{c}+w_{12}+w_{21}+w_3}{3} \end{cases} \tag{13}$$

At the royalty setting stage, firm 1 solves:

$$\max_{w_{12} \geq 0} \Pi_1^{D23} = [1 - Q^{D23}(w_{12}, w_{21}, w_3) - w_{21} - \bar{c}]q_1^{D23}(w_{12}, w_{21}, w_3) + q_2^{D23}(w_{12}, w_{21}, w_3)w_{12}$$

Resulting first-order condition is:

$$\frac{\partial \Pi_1^{D23}}{\partial w_{12}} = [1 - Q^{D23} - w_{21} - \bar{c}]\frac{\partial q_1^{D23}}{\partial w_{12}} - \frac{\partial Q^{D23}}{\partial w_{12}} q_1^{D23} + q_2^{D23} + \frac{\partial q_2^{D23}}{\partial w_{12}} w_{12} = 0$$

Using linearity, firm 1 upstream reaction function is equal to:

$$w_{12}(w_21, w_3) = \frac{5(1-\bar{c}) - 4(w_3 - e) - w_{21}}{10}. \quad (14)$$

Unlike case D32, studied in Section 3.3, here firm 2 licenses τ_2 to firm 1. In particular, firm 2 solves the following problem:

$$\max_{w_{21}\geq 0} \Pi_2^{D23} = [1 - Q^{D23}(w_{12}, w_{21}, w_3) - w_{12} - (w_3 - e) - \bar{c}]q_2^{D23}(w_{12}, w_{21}, w_3) + q_1^{D23}(w_{12}, w_{21}, w_3)w_{21}$$

And resulting first-order condition is:

$$\frac{\partial \Pi_2^{D23}}{\partial w_{21}} = [1 - Q^{D23} - w_{12} - (w_3 - e) - \bar{c}]\frac{\partial q_2^{D23}}{\partial w_{21}} - \frac{\partial Q^{D23}}{\partial w_{21}}q_2^{D23} + q_1^{D23} + \frac{\partial q_1^{D23}}{\partial w_{21}}w_{21} = 0$$

Notice that in this case the royalty rates of firm 1 and firm 2 are influenced by the raising rival's costs effect. The reaction function of firm 2 is given by:

$$w_{21}(w_{12}, w_{21}, w_3) = \frac{5(1-\bar{c}) - (w_3 - e) - w_{12}}{10}. \quad (15)$$

Finally, firm 3 solves:

$$\max_{w_3\geq 0} \Pi_3^{D23} = q_2^{D23}(w_{12}, w_{21}, w_3)w_3.$$

And the first-order condition is:

$$\frac{\partial \Pi^{D23}}{\partial w_3} = \frac{\partial q_2^{D23}}{\partial w_3}w_3 + q_2^{D23} = 0.$$

In this case, firm 3 exerts its monopoly power at expenses of firm 2, because firm 1 employs the technology licensed by 2. The reaction function of firm 3 is equal to:

$$w_3(w_{12}, w_{21}, w_3) = \frac{(1-\bar{c}) - 2w_{12} + 2e + w_{21}}{4}. \quad (16)$$

Solving for w_{12}, w_{21}, and w_3 from (14), (15) and (16), one can derive the following equilibrium conditions:

$$\text{if} \quad e \leq \bar{e}^{D23} \equiv 3(1-\bar{c})/11 \quad \begin{cases} w_{12}^{D23} = \frac{231(1-\bar{c})+143e}{594} \\ w_{21}^{D23} = \frac{132(1-\bar{c})+11e}{297} \\ w_3^{D32} = \frac{3(1-\bar{c})+7e}{18} \end{cases} \quad (17)$$

$$
\text{if} \quad e > \bar{e}^{D23} \equiv 3(1-\bar{c})/11 \quad \begin{cases} w_{12}^{D23} = \frac{5(1-\bar{c})}{11} \\ w_{12}^{D23} = \frac{5(1-\bar{c})}{11} \\ w_{3}^{D23} = e \end{cases} \tag{18}
$$

Where $\bar{e}^{D23} = 3(1-\bar{c})/11$ determines the threshold above which w_3 is equal to e. For values of e below $\bar{e}^{D23}$, the equilibrium conditions in (17) must be employed in (13) to compute firms' payoffs. Otherwise, one must use the conditions in (18). Table 4 summarizes the results of this section.

[TABLE 4 ABOUT HERE]

3.5 Standard Choice and Welfare Analysis with Linear Pricing

3.5.1 Standard Choice

In the first stage of the game, vertically integrated firms choose the bundle of inputs they employ for the production of the final good in a non-cooperative manner. In the following, I use the three thresholds of e that have been derived so far to distinguish between four cases: *case A*, with $e \in (0, \bar{e}^{D23}]$; *case B*, with $e \in (\bar{e}^{D23}, \bar{e}^{D32}]$; *case C*, with $e \in (\bar{e}^{D32}, \bar{e}^{J3}]$; and *case D*, with $e \in (\bar{e}^{J3}, 1)$.

Lemma 1.
Assume that side payments are not allowed; if the choice of the standard is taken by vertically integrated firms, then standard choice at equilibrium is given by:

i. If $e \in (0, \bar{e}^{D32}]$, (CASES A-B):
- *The joint adoption of $\mathcal{S}(\tau_1, \tau_2)$, if $e \leq e^{NE}(c_J)$.*
- *The adoption of $\mathcal{S}(\tau_1, \tau_3)$ by firm 1 and $\mathcal{S}(\tau_1, \tau_2)$ by firm 2, if $e > e^{NE}(c_J)$.*

i. If $e \in (\bar{e}^{D32}, 1)$, (CASES C-D):
- *The joint adoption of $\mathcal{S}(\tau_1, \tau_2)$, if $\bar{c} \geq \bar{c}^{NE}(c_J)$.*
- *The adoption of $\mathcal{S}(\tau_1, \tau_3)$ by firm 1 and $\mathcal{S}(\tau_1, \tau_2)$ by firm 2, if $\bar{c} < \bar{c}^{NE}(c_J)$.*

Proof. See Appendix A.

Figure 2 illustrates the results of Lemma 1. Figure 1.a and 1.b represent cases A-B, or, equivalently, the Nash Equilibria if $e \in (0, \bar{e}^{D32}]$. Figure 1.c depicts cases C-D, in which e lies into the interval $(\bar{e}^{D32}, 1)$.

[FIGURE 2 ABOUT HERE]

The outcome of the adoption game is determined by the interaction between the raising rival's costs effect and the hold-up effect. Indeed, on the one side, firm 2 prefers to employ its own technology instead of the one licensed by firm 3, because in this way it eludes the hold-up effect exerted by firm 3, and it limits the impact of the raising rival's costs effect exerted by firm 1. Consequently, the joint adoption of $\mathcal{S}(\tau_1, \tau_3)$ is never a Nash Equilibrium of the adoption game.

On the other side, firm 1 prefers to employ technology τ_3 if the value of the cost savings associated to joint adoption, s, is low enough. In particular, at $s = 0$, the Nash Equilibrium features disjoint adoption, with firm 1 that squeezes as much as it can firm 2's downstream rent through the licensing of its technology. However, unless e is big enough,[12] the raising rival's costs effect is not fully successful, and firm 2 is active on the downstream market. Hence, the Nash Equilibria with disjoint adoption in Figure 1.a and 1.b feature firm 2 producing a positive amount, instead, the Nash Equilibria with disjoint adoption in Figure 1.c feature a monopoly of firm 1 downstream.

3.5.2 Welfare Analysis

Lemma 2.
Total welfare maximizing standard adoption choices follow:

1. *If* $e \in (0, \bar{e}^{D32}]$*, (CASES A-B):*
   - *i. The joint adoption of* $\mathcal{S}(\tau_1, \tau_2)$ *if* $e \in (0, \hat{e}^{J2J3}] \setminus (\hat{e}^{J2D32}(c_J), \hat{e}^{J2J3}]$*;*
   - *ii. The joint adoption of* $\mathcal{S}(\tau_1, \tau_3)$ *if* $e \in [\hat{e}^{J2J3}, \bar{e}^{D32}) \setminus [\hat{e}^{J2J3}, \hat{e}^{J3D32}(c_J))$*;*
   - *iii. The adoption of* $\mathcal{S}(\tau_1, \tau_3)$ *by firm 1 and* $\mathcal{S}(\tau_1, \tau_2)$ *by firm 2 if* $e \in [\hat{e}^{J2D32}(c_J), \hat{e}^{J3D32}(c_J)]$.

2. *If* $e \in (\bar{e}^{D32}, \bar{e}^{J3}]$*, (CASE C):*
   - *i. The joint adoption of* $\mathcal{S}(\tau_1, \tau_2)$ *if* $\bar{c} \geq \bar{c}^W(c_J)$*;*
   - *ii. The joint adoption of* $\mathcal{S}(\tau_1, \tau_3)$ *if* $\bar{c} < \bar{c}^W(c_J)$.

3. *If* $e \in (\bar{e}^{J3}, 1)$*, (CASE D):*
   - *i. The joint adoption of* $\mathcal{S}(\tau_1, \tau_3)$.

Proof. See Appendix B.

[FIGURES 3 and 4 ABOUT HERE]

[12] More specifically, bigger than $\bar{e}^{J32} = 3(1 - \bar{c})/4$.

Figure 3 and 4 illustrate the results of Lemma 2 for cases A-B and C, respectively.

In Figure 3 there are three relevant areas: the joint adoption of $\mathcal{S}(\tau_1, \tau_2)$ maximizes total welfare for low enough values of e, and the joint employment of $\mathcal{S}(\tau_1, \tau_3)$ maximizes total welfare for high values of e. Finally, the area in which the adoption of $\mathcal{S}(\tau_1, \tau_2)$ by firm 2, and $\mathcal{S}(\tau_1, \tau_3)$ by firm 1 maximizes total welfare gets larger if $\bar{c}$ goes to zero: in other words, as the cost-savings due to standardization become negligible, disjoint adoption is more efficient.

In Figure 4 there are two relevant areas. More specifically, the joint adoption of $\mathcal{S}(\tau_1, \tau_2)$ maximizes total welfare for high enough values of $\bar{c}$, otherwise, it is the joint adoption of $\mathcal{S}(\tau_1, \tau_3)$ that maximizes total welfare. In case D total welfare is at its maximum if $\mathcal{S}(\tau_1, \tau_3)$ is employed by both manufacturers, independently from the value of $\bar{c}$.

Using the results of Lemma 1 and Lemma 2, one can derive the following result.

Proposition 1.
Vertically integrated firms can have incentive to totally and inefficiently exclude firm 3 from the upstream market.

Proof. See Appendix C.

Proposition 1 presents the main result of the paper, and it is illustrated in Figure 5.

[FIGURE 5 ABOUT HERE]

In particular, the areas marked by (E) in each of the four axes are the areas of total and inefficient exclusion. To begin with, for given values of $\bar{c}$ and s, the areas of inefficient exclusion get larger as e increases. Intuitively, as the efficiency of the pure licensor rises, also the area in which its joint adoption would be optimal from a social point of view increases in size. Moreover, comparing Figure 5.a and 5.b, it emerges that the size of area (E) increases with $\bar{c}$. Indeed, as production gets more expensive, the incidence of the cost-savings generated by standardization rises: consequently, the joint employment of the superior technology becomes more efficient.

4 Commitment to Ex-ante Competitive Conditions

In the model of Section 2, I assume that firms set licensing prices after being included into the standard: this choice grants monopoly power in the negotiations' phase to licensors whose technology is adopted by manufacturers. In this section, I study what happens if the royalty rate stage precedes standard choice and adoption, and let firm 2 and firm 3 compete for the inclusion of their technologies into the standard. The timing of the new game follows.

1. *Licensing Scheme and Royalty Setting Stage*: upstream firms set the royalty rate and the licensing scheme (independent licensing/cross licensing).

2. *Standard Choice Stage*: downstream firms choose the standard.

3. *Product Market Competition Stage*: active firms set quantities.

This timeline allows to reproduce the results of an auction carried out between the technologies of firms 2 and 3 at the competitive conditions prevailing before standard adoption. In other words, in this framework I can analyze what consequences would have the adoption of a policy of early licensing commitments on the definition of the standard, as to replicate the effects of FRAND agreements' reasonableness requirement.[13]

Solving the game backwards, the equilibrium values at the product market competition stage when integrated firms choose $\mathcal{S}(\tau_1, \tau_2)$ are the same as in (1), those in case of joint adoption of $\mathcal{S}(\tau_1, \tau_3)$ are given in (3), and those related to the cases of disjoint adoption are in (8) and (13).

At the royalty setting stage, firm 1 sets a rate equal to the monopoly price, and given by $w_{12} = 1/2$. Instead, firms 2 and 3 compete for the inclusion in the standard. In particular, firm 2, when τ_2 is adopted by firm 1, can offer to firm 1 to cross-license their technologies, and share the monopoly profit. Otherwise, the best deal it can propose would consist in licensing on an independent basis at a nil royalty. Indeed, perfect competition between 2 and 3 leads to an equilibrium with $w_3 = e$, and $w_{21} = 0$.

At this equilibrium, one has that firm 2 is active only if 1 accepts to cross-license. Indeed, in case of joint adoption of $\mathcal{S}(\tau_1, \tau_2)$ and cross licensing, firm 1 and firm 2 would get $(1 - c_J)^2/8$ each, while firm 3 would be left at zero. Finally, in the cases of disjoint adoption, firm 1 obtains profits equal to $(1 - \bar{c})^2/4$, firm 3 earns $e(1 - \bar{c})/2$, and firm 2 gets nothing.

[TABLE 5 ABOUT HERE]

From Table 5, it is clear that the employment of $\mathcal{S}(\tau_1, \tau_2)$ is a weakly dominant strategy to firm 2. Hence, the Nash Equilibrium of the adoption game depends on firm 1, and is determined by the following condition:

$$\frac{(1 - c_J)^2}{8} \geq \frac{(1 - \bar{c})^2}{4} \iff c_J \leq 1 - \sqrt{2}(1 - \bar{c})$$

[13] Reasonableness requires that licensing decisions taken before standard decision must be consistent with those decided after standard employment by manufacturers, as to avoid royalties that are higher only because of the lack of competitive alternatives. As remarked above, this policy has been adopted by a small number of SSOs.

Solving it for $\bar{c}$, I obtain:

$$\bar{c} = \bar{c}^{NE}(c_J) \equiv \begin{cases} 1 - \frac{1}{\sqrt{2}} = .29 & \textit{If } c_J = 0 \\ \\ 1 - (1+\sqrt{2})s & \textit{If } c_J > 0 \end{cases}$$

This is the same function that determines the adoption equilibria in cases C-D of the main model, that is, if e is big enough. In this extension, it determines the Nash Equilibria independently from the value taken by e. Moreover, in the main model with ex-post licensing decisions total exclusion can arise even for values of $\bar{c}$ smaller than .29, if e is low enough (cases A-B); instead, in this extension it never arises if $\bar{c}$ is smaller than $\bar{c}^{NE}(0) = .29$.

In other words, reversing the timing of the licensing decisions implies that vertically integrated firms may still want to totally exclude firm 3, but in a smaller range of values of $\bar{c}$.

Proposition 2.
A policy of early licensing decisions reduces the scope for total exclusion of the independent licensor by vertically integrated manufacturers.

5 Conclusions and Future Research

In this paper I have looked at the incentives that vertically integrated firms have to include patents into a technology standard. The main result I deliver is that if vertically integrated firms decide, then they may inefficiently exclude a superior technology provided by a stand-alone upstream firm from the inputs they employ to carry out downstream production.

The model develops on the idea that a stand-alone upstream firm endowed of market power can hold up vertically integrated firms through the sale of an intermediate good. Integrated organizations can choose between competing inputs, among which the one provided by the specialized firm is superior: in this way, I can study if integrated operators may want to exclude the stand-alone firm, and circumvent the hold-up problem, or buy from it, and enjoy the greater efficiency of its technology.

The contracting environment I employ resembles the one that characterizes standard setting organizations in several aspects, and in particular in the assumption for which parties negotiate over the royalty fees after downstream manufacturers' choice and adoption of a certain technology. This timing gives a strong bargaining power to upstream suppliers whose technology is employed for the production of the final good, and generates the hold-up effect.

Future work will go along two main directions. The first concerns the analysis of the robustness of the mechanism through which a pure upstream firm can put in difficulty a vertically integrated organization. The second regards the analysis of model's results under different specifications of the framework, as to study the working of SSOs in different, and policy relevant, environments.

For instance, one may use my model to understand how the standard choice changes if it is the pure upstream firm to hold the complementary technology. Also, one can develop an extension of the main model in which a pure downstream manufacturer competes on the product market with the integrated firms. In both cases, the model would provide guidance on issues that are currently debated in the antitrust law and economics literature.

A Proof of Lemma 1

There are three relevant thresholds, $\{\bar{e}^{D23}, \bar{e}^{D32}, \bar{e}^{J3}\}$, with $1 > \bar{e}^{J3} > \bar{e}^{D32} > \bar{e}^{D23} > 0$, and four cases, *case A*, with $e \in (0, \bar{e}^{D23}]$; *case B*, with $e \in (\bar{e}^{D23}, \bar{e}^{D32}]$; *case C*, with $e \in (\bar{e}^{D32}, \bar{e}^{J3}]$; and *case D*, with $e \in (\bar{e}^{J3}, 1)$.

First of all, the analysis can be greatly simplified realizing that, in all four cases, the adoption of $\mathcal{S}(\tau_1, \tau_2)$ is a dominant strategy for firm 2. Let me start by looking at case A.

Case A: $e \in (0, \bar{e}^{D23}]$. If firm 1 adopts $\mathcal{S}(\tau_1, \tau_3)$, firm 2 raises $\Pi_2^{D32} = 4[\frac{3(1-\bar{c})-4e}{41}]^2 > 0$ if it uses $\mathcal{S}(\tau_1, \tau_2)$, while its payoff is $\Pi_2^{J3} = 0$ if it uses $\mathcal{S}(\tau_1, \tau_3)$.

If firm 1 adopts $\mathcal{S}(\tau_1, \tau_2)$, firm 2 raises $\Pi_2^{J2} = (1-c_J)^2/8$ if it uses $\mathcal{S}(\tau_1, \tau_2)$, while its payoff is equal to $\Pi_2^{D23} = \frac{9(1-\bar{c})^2+5e^2}{81}$ if it uses $\mathcal{S}(\tau_1, \tau_3)$. After some simple algebra, one can establish that:

$$\frac{(1-c_J)^2}{8} > \frac{9(1-\bar{c})^2+5e^2}{81} \quad \forall \quad e \in (0, \bar{e}^{D23}], \quad \bar{e}^{D23} = 3(1-\bar{c})/11, \quad c_J = \max\{0, \bar{c}-s\} < \bar{c} \in (0,1).$$

Therefore, the employment of $\mathcal{S}(\tau_1, \tau_2)$ is a *strictly dominant* strategy for firm 2 in case A.

Case B: $e \in (\bar{e}^{D23}, \bar{e}^{D32}]$**.** If firm 1 adopts $\mathcal{S}(\tau_1, \tau_3)$, firm 2 raises $\Pi_2^{D32} = 4[\frac{3(1-\bar{c})-4e}{41}]^2 > 0$ if it uses $\mathcal{S}(\tau_1, \tau_2)$, while its payoff is $\Pi_2^{J3} = 0$ if it uses $\mathcal{S}(\tau_1, \tau_3)$.

If firm 1 adopts $\mathcal{S}(\tau_1, \tau_2)$, firm 2 raises $\Pi_2^{J2} = (1-c_J)^2/8$ if it uses $\mathcal{S}(\tau_1, \tau_2)$, while its payoff is equal to $\Pi_2^{D23} = \frac{14(1-\bar{c})^2}{121}$ if it uses $\mathcal{S}(\tau_1, \tau_3)$, with:

$$\frac{(1-c_J)^2}{8} > \frac{14(1-\bar{c})^2}{121} \quad \forall \quad c_J = \max\{0, \bar{c}-s\} < \bar{c} \in (0,1).$$

Therefore, the employment of $\mathcal{S}(\tau_1, \tau_2)$ is a *strictly dominant* strategy for firm 2 in case B.

Cases C-D: $e \in (\bar{e}^{D32}, 1)$**.** If firm 1 adopts $\mathcal{S}(\tau_1, \tau_3)$, firm 2's payoff is nil independently from whether it employs $\mathcal{S}(\tau_1, \tau_2)$ or $\mathcal{S}(\tau_1, \tau_3)$.

If firm 1 adopts $\mathcal{S}(\tau_1, \tau_2)$, firm 2 raises $\Pi_2^{J2} = (1 - c_J)^2/8$ if it uses $\mathcal{S}(\tau_1, \tau_2)$, instead its payoff is equal to $\Pi_2^{D23} = \frac{14(1-\bar{c})^2}{121}$ if it uses $\mathcal{S}(\tau_1, \tau_3)$.

Hence, analogously to *case B*, $\Pi_2^{J2} > \Pi_2^{D23}$, and the employment of $\mathcal{S}(\tau_1, \tau_2)$ is a *weakly dominant* strategy for firm 2 in cases C and D.

From the analysis of the four cases above, I can conclude that the Nash-Equilibrium of the adoption game features firm 2 using $\mathcal{S}(\tau_1, \tau_2)$, and ultimately depends by the choice of firm 1 in each case.

Cases A-B: $e \in (0, \bar{e}^{D32}]$. Firm 1 gets $\Pi_1^{J2} = (1 - c_J)^2/8$ if it employs $\mathcal{S}(\tau_1, \tau_2)$, while it gets $\Pi_1^{D32} = 2\frac{107(1-\bar{c})^2+10e[9e+7(1-\bar{c})]}{1681}$ if it employs $\mathcal{S}(\tau_1, \tau_3)$. In this case, the equilibrium is determined by the following second order equation in e:

$$\frac{(1 - c_J)^2}{8} = 2\frac{107(1 - \bar{c})^2 + 10e[9e + 7(1 - \bar{c})]}{1681}.$$

Using the standard quadratic formula, one can compute the roots of this equation, out of which I take the positive one, given by:

$$e = \frac{41\sqrt{10}\sqrt{9 - 8(1 - \bar{c})^2 - 9(2 - c_J)c_J}}{360} - \frac{7(1 - \bar{c})}{18}.$$

Consequently, the Nash Equilibrium of the adoption game is determined by:

$$e = e^{NE}(c_J) \equiv \begin{cases} \frac{41\sqrt{10}\sqrt{9-8(1-\bar{c})^2-9(2-\bar{c}+s)(\bar{c}-s)}}{360} - \frac{7(1-\bar{c})}{18} & \textit{if } c_J > 0 \iff s < \bar{c} \\ \\ \frac{41\sqrt{10}\sqrt{9-8(1-\bar{c})^2}}{360} - \frac{7(1-\bar{c})}{18} & \textit{if } c_J = 0 \iff s \geq \bar{c} \end{cases}$$

$e^{NE}(c_J)$ exhibits a (first-order) discontinuity at $s = \bar{c}$, or $c_J = 0$, it is increasing in s if $c_J = \max\{0, \bar{c} - s\} > 0$, otherwise its value is constant in $(0, 1)$.

Concluding, the Nash Equilibria in cases A and B feature:

- The joint adoption of $\mathcal{S}(\tau_1, \tau_2)$ if $e \leq e^{NE}(c_J)$.

- The adoption of $\mathcal{S}(\tau_1, \tau_3)$ by firm 1, and $\mathcal{S}(\tau_1, \tau_2)$ by firm 2 if $e > e^{NE}(c_J)$.

Cases C-D: $e \in (\bar{e}^{D32}, 1)$**.** The payoffs of firm 1 are not affected by parameter e, because the fee set by firm 3 is equal to the marginal contribution of its technology to the decrease of manufacturer's marginal cost. Consequently, it is only parameter s that shapes firm 1 decisions.

More specifically, firm 1 gets $\Pi_1^{J2} = (1-c_J)^2/8$ if it employs $\mathcal{S}(\tau_1,\tau_2)$, while it gets $\Pi_1^{D32} = \frac{(1-\bar{c})^2}{4}$ if it employs $\mathcal{S}(\tau_1,\tau_3)$. Thus, the relevant condition is:

$$\frac{(1-c_J)^2}{8} \geq \frac{(1-\bar{c})^2}{4} \iff c_J \leq 1-\sqrt{2}(1-\bar{c})$$

So that the function determining the Nash Equilibria of cases C-D is:

$$\bar{c} = \bar{c}^{NE}(c_J) \equiv \begin{cases} 1-\frac{1}{\sqrt{2}} = .29 & \textit{If } c_J = 0 \\ \\ 1-(1+\sqrt{2})s & \textit{If } c_J > 0 \end{cases}$$

Concluding, the Nash Equilibria in cases C and D feature::

- The joint adoption of $\mathcal{S}(\tau_1,\tau_2)$, if $\bar{c} \geq \bar{c}^{NE}(c_J)$.
- The adoption of $\mathcal{S}(\tau_1,\tau_3)$ by firm 1 and $\mathcal{S}(\tau_1,\tau_2)$ by firm 2, if $\bar{c} < \bar{c}^{NE}(c_J)$.

■

B Proof of Lemma 2

The welfare analysis boils down to solving a set of second order equations whose roots determine the thresholds of the areas of maximum efficiency.

Case A: $e \in (0, \bar{e}^{D23}]$. Comparing total surplus in the cases of joint adoption, $J2$ and $J3$, one has the following condition:

$$TS^{J2} = \frac{3(1-c_J)^2}{8} \geq TS^{J3} = \frac{12(1-c_J+e)^2}{49}$$

Using the standard quadratic formula for e, and taking the positive root, above inequality is satisfied if:

$$0 < e \leq (1-c_J)\Big[\frac{7}{4\sqrt{2}}-1\Big] \equiv \hat{e}^{J2J3}(c_J)$$

And,

$$\hat{e}^{J2J3}(c_J) = \begin{cases} \frac{7}{4\sqrt{2}}-1 = .237 & \textit{if } c_J = 0 \\ \\ (1-\bar{c}+s)\Big[\frac{7}{4\sqrt{2}}-1\Big] & \textit{if } c_J > 0 \end{cases}$$

First of all, I have to check whether the cases of disjoint adoption, $D23$ and $D32$, deliver a bigger total surplus than $J2$ below $e = \hat{e}^{J2J3}(c_J)$. In particular, $D23$, analyzed in Section 3.4, is more efficient than $J2$ if:

$$TS^{J2} = \frac{3(1-c_J)^2}{8} \leq TS^{D23} = \frac{45(1-\bar{c})^2 + e[30(1-\bar{c}) + 41e]}{162}$$

Using the fact that TS^{D23} is increasing in e, I evaluate whether this inequality is satisfied at $e = \hat{e}^{J2J3}(c_J)$. Indeed, if it does not hold at $e = \hat{e}^{J2J3}(c_J)$, $J2$ is more efficient than $D23$ below $\hat{e}^{J2J3}(c_J)$.

In particular, if $c_J = 0$, and $e = .237$:

$$TS^{J2} = .375 > .2778(1-\bar{c})^2 + .0439(1-\bar{c}) + .0142 = TS^{D23} \quad \forall \bar{c} \in (0,1).$$

If $c_J > 0$, and $e = (1-c_J)\left[\frac{7}{4\sqrt{2}} - 1\right] = .237(1-c_J)$:

$$TS^{J2} = .375(1-c_J)^2, \quad TS^{D23} = .0061[45(1-\bar{c})^2 + 7.11(1-\bar{c})(1-c_J) + 2.3029(1-c_J)^2].$$

Using $c_J < \bar{c}$, it follows that:

$$\begin{aligned} .0061[45(1-\bar{c})^2 + 7.11(1-\bar{c})(1-c_J) + 2.3029(1-c_J)^2] &< .0061(1-c_J)^2(45 + 7.11 + 2.3029) = \\ = 0.3319(1-c_J)^2 &< .375(1-c_J)^2. \end{aligned}$$

Consequently, $TS^{J2} > TS^{D23}$ if $0 < e \leq \hat{e}^{J2J3}$.

$D32$, analyzed in Section 3.2, is more efficient than $J2$ if:

$$TS^{J2} = \frac{3(1-c_J)^2}{8} \leq TS^{D32} = 4\frac{132(1-\bar{c})^2 + e[139e + 140(1-\bar{c})]}{1681}$$

Using the quadratic formula for e, and taking the positive root, above inequality is satisfied if:

$$1 > e \geq \frac{41\sqrt{2}\sqrt{417[1-(2-c_J)c_J] - 256(1-\bar{c})^2}}{1112} - \frac{70(1-\bar{c})}{139} \equiv \hat{e}^{J2D32}(c_J)$$

And,

$$\hat{e}^{J2D32}(c_J) = \begin{cases} \frac{41\sqrt{2}\sqrt{417-256(1-\bar{c})^2}}{1112} - \frac{70(1-\bar{c})}{139} & \textit{if } c_J = 0 \\ \\ \frac{41\sqrt{2}\sqrt{417[1-(2-\bar{c}+s)(\bar{c}-s)]-256(1-\bar{c})^2}}{1112} - \frac{70(1-\bar{c})}{139} & \textit{if } c_J > 0 \end{cases}$$

$\hat{e}^{J2D32}(c_J)$ is increasing in s if $c_J > 0$, and $\hat{e}^{J2D32}(0) > \hat{e}^{J2D32}(c_J)$ for all $\bar{c} \in (0,1)$, so that the minimum of $\hat{e}^{J2D32}(c_J)$ is at $s = 0$.

$\hat{e}^{J2D32}(c_J)$ lies partly below $\hat{e}^{J2J3}(c_J)$, meaning that there is a set of values of e in which $D32$ is more efficient than $J2$. More precisely, the branches of $\hat{e}^{J2D32}(c_J)|_{c_J>0}$ and $\hat{e}^{J2J3}(c_J)|_{c_J>0}$ cross each other in the locus given by:

$$s = 0.056(1-\bar{c}) \quad \forall \bar{c} > 0.053,$$

At $\bar{c} = 0.053$,

$$\hat{e}^{J2D32}(0) = \hat{e}^{J2J3}(0),$$

And, if $\bar{c} < 0.053$, $\hat{e}^{J2D32}(c_J)$ lies strictly below $\hat{e}^{J2J3}(c_J)$.

Consequently,

$$\forall \quad e \in (\hat{e}^{J2D32}(c_J), \hat{e}^{J2J3}(c_J)] \quad \Rightarrow TS^{J2} < TS^{D32}.$$

I now turn to the analysis of maximum efficiency above $e = \hat{e}^{J2J3}(c_J)$. First of all, notice that $D23$ is less efficient than $J3$ above $\hat{e}^{J2J3}(c_J)$. Indeed, the area in which $D23$ is more efficient than $J3$ lies below $\hat{e}^{J2J3}(c_J)$.

As for case $D32$, this is more efficient than $J3$ if:

$$TS^{J3} = \frac{12(1-c_J+e)^2}{49} \leq TS^{D32} = 4\frac{132(1-\bar{c})^2 + e[139e + 140(1-\bar{c})]}{1681}$$

Using the quadratic formula for e, and taking the root whose value is below 1, above inequality is satisfied if:

$$0 < e \leq \frac{1613 + 3430\bar{c} - 5043c_J - 287\sqrt{1 + 4(103+\bar{c})\bar{c} - 6c_J(69+70\bar{c}) - 417c_J^2}}{1768} \equiv \hat{e}^{J3D32}(c_J)$$

And,

$$\hat{e}^{J3D32}(c_J) = \begin{cases} \frac{1613+3430\bar{c}-287\sqrt{1+4(103+\bar{c})\bar{c}}}{1768} & \textit{if } c_J = 0 \\ \\ \frac{1613+3430\bar{c}-5043(\bar{c}-s)-287\sqrt{1+4(103+\bar{c})\bar{c}-6(\bar{c}-s)(69+70\bar{c})-417(\bar{c}-s)^2}}{1768} & \textit{if } c_J > 0 \end{cases}$$

With $\hat{e}^{J3D32}(c_J)$ decreasing in s if $c_J > 0$.

$\hat{e}^{J3D32}(c_J)$ lies partly above $\hat{e}^{J2J3}(c_J)$. More specifically, the branches of $\hat{e}^{J3D32}(c_J)|_{c_J>0}$ and $\hat{e}^{J2J3}(c_J)|_{c_J>0}$ cross each other in the locus given by:

$$s = 0.056(1-\bar{c}) \quad \forall \bar{c} > 0.053,$$

At $\bar{c} = 0.053$,

$$\hat{e}^{J3D32}(0) = \hat{e}^{J2J3}(0),$$

And, if $\bar{c} < 0.053$, $\hat{e}^{J3D32}(c_J)$ lies strictly above $\hat{e}^{J2J3}(c_J)$.

Hence,

$$\forall \quad e \in (\hat{e}^{J2J3}(c_J), \hat{e}^{J3D32}(c_J)] \quad \Rightarrow TS^{J3} < TS^{D32}.$$

Case B: $e \in (\bar{e}^{D23}, \bar{e}^{D32}]$**.** Case B differs from case A for the results of case $D23$. However, the total surplus associated to $D23$ in case B is smaller than the one of case A. In particular,

$$TS^{D23}_{CaseA} = \frac{45(1-\bar{c})^2 + e[30(1-\bar{c}) + 41e]}{162} \quad \geq \quad 2(1-\bar{c})\frac{18(1-\bar{c}) + 11e}{121} = TS^{D23}_{CaseB} \iff$$

$$.2531e^2 + 0.0033(1-\bar{c})e - 0,0197(1-\bar{c})^2 \quad \geq \quad 0.$$

The last inequality is increasing in e, therefore, if it holds for $e = \bar{e}^{D23} = \frac{3(1-\bar{c})}{11}$, it also holds for every $e \in (\bar{e}^{D23}, \bar{e}^{D32}]$. Substituting for $e = \bar{e}^{D23}$, one has that:

$$.0188 + 0.0009 - 0.0197 = 0.$$

Which proves that the welfare analysis in case B delivers the same conclusions as in case A.

Overall, if $0 < e \leq \bar{e}^{D32} = 3(1-\bar{c})/4$ (CASES A-B):

i. The joint adoption of $\mathcal{S}(\tau_1, \tau_2)$, case $J2$, maximizes total welfare if

$$e \in (0, \hat{e}^{J2J3}] \smallsetminus (\hat{e}^{J2D32}(c), \hat{e}^{J2J3});$$

ii. The joint adoption of $\mathcal{S}(\tau_1, \tau_3)$, case $J3$, maximizes total welfare if

$$e \in (\hat{e}^{J2J3}, \bar{e}^{D32}] \setminus [\hat{e}^{J2J3}, \hat{e}^{J3D32}(c));$$

iii. The adoption of $\mathcal{S}(\tau_1, \tau_3)$ by firm 1 and $\mathcal{S}(\tau_1, \tau_2)$ by firm 2, case $D32$, maximizes total welfare if

$$e \in [\hat{e}^{J2D32}(c), \hat{e}^{J3D32}(c)].$$

Case C: $e \in (\bar{e}^{D32}, \bar{e}^{J3}]$**.** Case C differs from case B for the total surplus generated by $D32$.

First, I need to check whether $D32$ delivers a bigger total surplus than $J2$ below $e = \hat{e}^{J2J3}(c_J)$.[14] More specifically, $D32$ is more efficient than $J2$ if:

$$TS^{J2} = \frac{3(1-c_J)^2}{8} \leq TS^{D32} = (1-\bar{c})\frac{3(1-\bar{c})+4e}{8} \iff 1 > e \geq \frac{3(\bar{c}-c_J)(2-\bar{c}-c_J)}{4(1-\bar{c})} \equiv \hat{\hat{e}}^{J2D32}(c_J)$$

And,

$$\hat{\hat{e}}^{J2D32}(c_J) = \begin{cases} \frac{3\bar{c}(2-\bar{c})}{4(1-\bar{c})} & \textit{if } c_J = 0 \\ \\ \frac{3s[2(1-\bar{c})+s]}{4(1-\bar{c})} & \textit{if } c_J > 0 \end{cases}$$

With $\hat{\hat{e}}^{J2D32}(c_J)$ increasing in s if $c_J > 0$.

I now prove that the values of e in which $D32$ is more efficient than the joint adoption of $\mathcal{S}(\tau_1, \tau_2)$ are always below $(\bar{e}^{D32}, \bar{e}^{J3}]$. In other words, $\bar{e}^{D32} = 3(1-\bar{c})/4$ lies above the values of e in the interval $(\hat{\hat{e}}^{J2D32}(c_J), \hat{e}^{J2J3}(c_J)]$, where $TS^{J2} < TS^{D32}$.

I first provide the locus of points in which $\hat{\hat{e}}^{J2D32}(c_J)|_{c_J>0}$ crosses $\hat{e}^{J2J3}(c_J)|_{c_J>0}$. This is:

$$s = 0.171(1-\bar{c}) \quad \forall \bar{c} > 0.146, \tag{19}$$

With $\hat{\hat{e}}^{J2D32}(0) = \hat{e}^{J2J3}(0)$, at $\bar{c} = 0.146$. Equation (19) establishes a monotonic and decreasing relationship between s and $\bar{c}$ along which $\hat{\hat{e}}^{J2D32}(c_J) = \hat{e}^{J2J3}(c_J)$ in the interval of $\bar{c}$ equal to $(.146, 1)$. Now, I take the limits of $\hat{\hat{e}}^{J2D32}$ and $\bar{e}^{D32}$ at the superior and inferior of such interval.[15]

[14]Indeed, $TS^{J2} > TS^{D23}$ if $0 < e \leq \hat{e}^{J2J3}(c_J)$, because $\hat{e}^{J2D23}(c_J) > \hat{e}^{J2J3}(c_J)$ for all $c_J \in [0, 1)$. Analogously, $TS^{J3} > TS^{D23}$ above $\hat{e}^{J2J3}(c_J)$.

[15]I do this because $\hat{\hat{e}}^{J2D32}(c_J)$ lies below $\bar{e}^{D32}$ below $\bar{c} = 0.146$.

In particular, as $\bar{c}$ tends to 0.146 I have that $\hat{\hat{e}}^{J2D32}(c_J)$ lies below $\bar{e}^{D32}$:

$$\lim_{\bar{c}\to 0.146} \hat{\hat{e}}^{J2D32}(c_J) = \lim_{\bar{c}\to 0.146} \hat{e}^{J2J3}(c_J) = 0.237 < 0.641 = \lim_{\bar{c}\to 0.146} \bar{e}^{D32}.$$

However, this wedge gets narrowing if $\bar{c}$ grows, tending to zero as $\bar{c}$ approaches 1. Indeed, taking the limit of $\bar{e}^{D32}$ and $\hat{\hat{e}}^{J2D32}(c_J)$ as $\bar{c}$ goes to 1, one has that:

$$\lim_{\bar{c}\to 1} \bar{e}^{D32} = \lim_{\bar{c}\to 1} \hat{\hat{e}}^{J2D32} = 0$$

Therefore I can conclude that in the range of parameters that are relevant for case C, $(\bar{e}^{D32}, \bar{e}^{J3}]$, the joint adoption of $\mathcal{S}(\tau_1, \tau_2)$ maximizes total welfare below $\hat{e}^{J2J3}(c_J)$.

Case $D32$ is more efficient than $J3$ if:

$$\begin{array}{c} TS^{J3} = \frac{12(1-c_J+e)^2}{49} < TS^{D32} = (1-\bar{c})\frac{3(1-\bar{c})+4e}{8} \iff \\ 0 < e < \frac{1-49\bar{c}+48c_J+7\sqrt{(1-\bar{c})(25-121\bar{c}+96c_J)}}{48} \equiv \hat{\hat{e}}^{J3D32}(c_J) \end{array}$$

And,

$$\hat{\hat{e}}^{J3D32}(c_J) = \begin{cases} \frac{1-49\bar{c}+7\sqrt{(1-\bar{c})(25-121\bar{c})}}{48} & \textit{if } c_J = 0 \\ \\ \frac{1-49\bar{c}+48(\bar{c}-s)+7\sqrt{(1-\bar{c})(25-121\bar{c}+96(\bar{c}-s))}}{48} & \textit{if } c_J > 0 \end{cases}$$

$\hat{\hat{e}}^{J3D32}(c_J)$ is decreasing in s if $c_J > 0$. Also in this case, the values of e in which disjoint adoption is more efficient than the joint adoption of $\mathcal{S}(\tau_1, \tau_3)$ are always below the relevant values of e. In other words, $\bar{e}^{D32}$ lies above the values of e in which $TS^{J3} < TS^{D32}$, that is the set $(\hat{e}^{J2J3}, \hat{\hat{e}}^{J3D32}]$. In order to show this, one can take the value of $\bar{e}^{D32}$ and $\hat{\hat{e}}^{J3D32}(c_J)$ as s goes to 0, at which $\hat{\hat{e}}^{J3D32}(c_J)$ reaches its maximum, and see that:

$$\hat{\hat{e}}^{J3D32}(c_J)|_{s=0} = 3(1-\bar{c})/4 = \bar{e}^{D32}.$$

Consequently, in the range of parameters that characterize case C, $(\bar{e}^{D32}, \bar{e}^{J3}]$, the joint adoption of $\mathcal{S}(\tau_1, \tau_3)$ maximizes total welfare above $\hat{e}^{J2J3}(c_J)$.

Summarizing the results of the welfare analysis carried out in case C, one can can conclude that it is only $\hat{e}^{J2J3}(c_J)$ that determines the regions of maximum welfare, which are two: the one in which the joint adoption of $\mathcal{S}(\tau_1, \tau_2)$ maximizes total welfare, and the one in which the joint adoption of $\mathcal{S}(\tau_1, \tau_3)$ maximizes total welfare.

In particular, a joint adoption of $\mathcal{S}(\tau_1, \tau_2)$ maximizes total welfare for the values of e that are below $\hat{e}^{J2J3}(c_J)$ and above $\bar{e}^{D32}$. Hence, as to derive a relationship between $\bar{c}$ and s that can be represented in the $\{s, \bar{c}\}$ axes, and illustrate the area of maximum efficiency associated to $J2$, one has to solve the following equation:

$$\hat{e}^{J2J3}(c_J) = (1 - c_J)\Big[\frac{7}{4\sqrt{2}} - 1\Big] \;\; \geq \;\; \frac{3(1-\bar{c})}{4} = \bar{e}^{D32} \iff \bar{c} \geq \frac{14 - 7\sqrt{2}(1-c_J) - 8c_J}{6}.$$

From such condition I obtain $\bar{c}^W(c_J)$:

$$\bar{c}^W(c_J) = \begin{cases} \frac{7(2-\sqrt{2})}{6} & \text{if } c_J = 0 \\ \\ \frac{7+s(1-3\sqrt{2})}{7} & \text{if } c_J > 0 \end{cases}$$

Above $\bar{c}^W(c_J)$ it is the joint adoption of $\mathcal{S}(\tau_1, \tau_2)$ that maximizes total surplus, while below $\bar{c}^W(c_J)$ it is the joint adoption of $\mathcal{S}(\tau_1, \tau_3)$ that maximizes total surplus.

Case D: $e \in (\bar{e}^{J3}, 1)$**.** Case D differs from case C for the total welfare associated to $J3$.

In this case, $J3$ is always more efficient than $J2$. Indeed,

$$TS^{J2} = \frac{3(1-c_J)^2}{8} < TS^{J3} = (1-c_J)\frac{3(1-c_J)+4e}{8} \quad \forall \quad e \in (0,1), \quad c_J \in [0,1).$$

As for the cases of disjoint adoption, $D23$ and $D32$, these are more efficient than $J3$ if, respectively:

$$TS^{J3} = (1-c_J)\tfrac{3(1-c_J)+4e}{8} < TS^{D23} = 2(1-\bar{c})\tfrac{18(1-\bar{c})+11e}{121} \iff$$
$$e < \tfrac{-75-288(2-\bar{c})+363(2-c_J)c_J}{44(7+4c-11c_J)} < 0 \quad \forall \quad \bar{c} \in (0,1), \quad c_J \in [0,1).$$

And

$$TS^{J3} = (1-c_J)\tfrac{3(1-c_J)+4e}{8} < TS^{D32} = (1-\bar{c})\tfrac{3(1-\bar{c})+4e}{8} \iff$$
$$e < \tfrac{3(c+c_J-2)}{4} < 0 \quad \forall \bar{c} \in (0,1), \quad c_J \in [0,1).$$

Therefore, the joint adoption of $\mathcal{S}(\tau_1, \tau_3)$ maximizes total welfare in case D. ■

C Proof of Proposition 1

Let me start analyzing case D. In Lemma 2 I show that in case D it is the joint adoption of $\mathcal{S}(\tau_1, \tau_3)$ that maximizes total welfare, however, in Lemma 1 I prove that the Nash Equilibrium of the adoption game features either the joint adoption of $\mathcal{S}(\tau_1, \tau_2)$, or disjoint adoption, $D32$.

In case C, $\bar{c}^W(c_J)$ determines the areas of maximum welfare, while $\bar{c}^{NE}(c_J)$ determines the Nash Equilibria of the adoption game: in particular, above $\bar{c}^{NE}(c_J)$ it is the joint adoption of $\mathcal{S}(\tau_1, \tau_2)$ to maximize total surplus, while below $\bar{c}^W(c_J)$ it is the joint adoption of $\mathcal{S}(\tau_1, \tau_3)$ that delivers maximum surplus. Hence, if $\bar{c}^W(c_J)$ lies above $\bar{c}^{NE}(c_J)$ then total and inefficient exclusion arises. In particular, if $c_J = 0$,

$$\bar{c}^{NE}(0) = 1 - \frac{1}{\sqrt{2}} = .29 < .68 = \frac{7(2-\sqrt{2})}{6} = \bar{c}^W(0).$$

And, if $c_J > 0$:

$$\bar{c}^{NE}(c_J) = 1 - (1+\sqrt{2})s < \frac{7 + s(1-3\sqrt{2})}{7} = \bar{c}^W(c_J), \quad \forall s \in (0,1).$$

Finally, in cases A-B, if $e \leq e^{NE}(c_J)$, then firms jointly adopt $\mathcal{S}(\tau_1, \tau_2)$. Moreover, $e \leq e^{NE}(c_J)$ crosses $\hat{e}^{J2J3}(c_J)$ along the locus given by:

$$s = 0.121(1-\bar{c}), \quad \forall \bar{c} > 0.108.$$

At $\bar{c} = 0.108$, $e^{NE}(0) = \hat{e}^{J2J3}(0)$. Instead, if $0 < \bar{c} < 0.108$, then $e^{NE}(c_J) < \hat{e}^{J2J3}(c_J)$. Therefore, total and inefficient exclusion arises if $1 > \bar{c} > 0.108$, because there $e^{NE}(c_J)$ lies above $\hat{e}^{J2J3}(c_J)$, in the area in which $J3$ maximizes total welfare. ■

References

[1] Cabral, L., Salant, D., 2009, "Evolving Technologies and Standards Regulation", mimeo.

[2] Cournot, A. A., 1838, *Researches into the mathematical principles of the theory of wealth*, English edition of *Researches sur les principles mathematiques de la theorie des richesses*. New York: Kelley.

[3] Delacey, B. J., Herman, K., Kiron, D. J., Lerner, J., 2006, "Strategic Behavior in Standard-Setting Organizations", Harvard NOM Working Paper No. 903214.

[4] Eswaran, M., 1994, "Cross-Licensing of Competing Patents as a Facilitating Device", *The Canadian Journal of Economics*, Vol. 27, No. 3, pp. 689-708.

[5] Gandal, N., Salant, D., Waverman, L., 2003, "Standards in wireless telephone networks", *Telecommunications Policy*, Vol. 27, pp. 325-332.

[6] Geradin, D., 2008, "What's Wrong with Royalties in High Technology Industries?", TILEC Discussion Paper Series.

[7] Layne-Farrar, A., Lerner, J., 2008, "To Join or not to Join: Examining Patent Pool Participation and Rent Sharing Rules," mimeo, Harvard University.

[8] Lerner, J., Tirole, J., 2004, "Efficient Patent Pools", *The American Economic Review*, Vol. 94, No. 3, pp. 691-711.

[9] Lerner, J., Strojwas, M., Tirole, J., 2007, "The Design of Patent Pools: The Determinants of Licensing Rules", *The RAND Journal of Economics*, Vol. 38, No. 3, pp. 610-625.

[10] Leveque, F., Ménière, Y., 2008, "Early Commitments Help Patent Pool Formation", mimeo.

[11] Lin, P., 1996, "Fixed-Fee Licensing of Innovations and Collusion", *The Journal of Industrial Economics*, Vol. 44, No. 4, pp. 443-449.

[12] Rey, P., Salant, D., 2009, "Abuse of Dominance and Licensing of Intellectual Property", mimeo.

[13] Rey, P., Tirole, J., 2007, "A Primer on Foreclosure", in: Armstrong, M., and R. H. Porter (eds.), *Handbook of Industrial Organization*, Vol. 3, North-Holland, pp. 2145-2220.

[14] Rysman, M., Simcoe, T., 2008, "Patents and the Performance of Voluntary Standard Setting Organizations", *Management Science*, Vol. 54, No. 11, pp. 1920-1934.

[15] Salop, S. C., Scheffman, D. T., 1983, "Raising Rivals Costs", *American Economic Review, Papers and Proceedings*, Vol. 73, pp. 267-271.

[16] Salop, S. C., Scheffman, D. T., 1987, "Cost-Raising Strategies", *The Journal of Industrial Economics*, Vol. 36, pp. 19-34.

[17] Schmalensee, R., 2008, "Standard-Setting, Innovation Specialists, and Competition Policy", mimeo.

[18] Schmidt, K. M., 2008, "Complementary Patents and Market Structure", CEPR Discussion Paper No. DP7005.

[19] Sherry, E. F., Teece, D. J., 2003, "Standard Setting and Antitrust", *Minnesota Law Review*, Vol. 87, No. 6, pp. 1913-1994.

[20] Simcoe, T., Graham, S. J. H., Feldman, M. P., forthcoming, "Competing on Standards? Entrepreneurship, Intellectual Property and Platform technologies", *The Journal of Economics and Management Strategy.*

[21] Updegrove, A., 1993, "Forming, Funding and Operating Standard-Setting Consortia", *IEEE Micro*, Vol. 13, No. 6, pp. 52 - 61.

Table 1: Results under joint adoption of standard $\mathcal{S}(\tau_1, \tau_2)$.

	Independent Licensing	**Cross Licensing**
w_{jk}^{J2}	$5(1-c_J)/11$	$(1-c_J)/4$
q_j^{J2}	$2(1-c_J)/11$	$(1-c_J)/4$
$Q^{J2}, P(Q^{J2})$	$4(1-c_J)/11, (7+4c_J)/11$	$(1-c_J)/2, (1+c_J)/2$
CS^{J2}	$8(1-c_J)^2/121$	$(1-c_J)^2/8$
$\Pi_1^{J2}, \Pi_2^{J2}, \Pi_3^{J2}$	$14(1-c_J)^2/121, 14(1-c_J)^2/121, 0$	$(1-c_J)^2/8,\ (1-c_J)^2/8,\ 0$
$Total\ Welfare,\ TS^{J2}$	$36(1-c_J)^2/121$	$3(1-c_J)^2/8$

Table 2: Results under joint adoption of $\mathcal{S}(\tau_1, \tau_3)$.

	$e \leq 3(1-c_J)/4$	$e > 3(1-c_J)/4$
w_{12}^{J3}, w_3^{J3}	$2(1-c_J+e)/7, 3(1-c_J+e)/7$	$(1-c_J)/2, e$
q_1^{J3}, q_2^{J3}	$2(1-c_J+e)/7, 0$	$(1-c_J)/2, 0$
$Q^{J3}, P(Q^{J3})$	$2(1-c_J+e)/7, (5+2c_J-2e)/7$	$(1-c_J)/2, (1+c_J)/2$
CS^{J3}	$2(1-c_J+e)^2/49$	$(1-c_J)^2/8$
$\Pi_1^{J3}, \Pi_2^{J3}, \Pi_3^{J3}$	$4(1-c_J+e)^2/49, 0, 6(1-c_J+e)^2/49$	$(1-c_J)^2/4, 0, e(1-c_J)/2$
$Total\ Welfare,\ TS^{J3}$	$12(1-c_J+e)^2/49$	$(1-c_J)\frac{3(1-c_J)+4e}{8}$

Table 3: Results under disjoint adoption of $\mathcal{S}(\tau_1, \tau_3)$ by firm 1 and $\mathcal{S}(\tau_1, \tau_2)$ by firm 2.

	$e \leq 3(1-\bar{c})/4$	$e > 3(1-\bar{c})/4$
w_{12}^{D32}, w_3^{D32}	$\frac{19(1-\bar{c})+2e}{41}, \frac{3[5(1-\bar{c})+7e]}{41}$	$(1-\bar{c})/2, 0$
q_1^{D32}, q_2^{D32}	$\frac{2[5(1-\bar{c})+7e]}{41}, \frac{2[3(1-\bar{c})-4e]}{41}$	$(1-\bar{c})/2, 0$
$Q^{D32}, P(Q^{D32})$	$2\frac{8(1-\bar{c})+3e}{41}, \frac{25+16c-6e}{41}$	$(1-\bar{c})/2, (1+c)/2$
CS^{D32}	$2[\frac{8(1-\bar{c})+3e}{41}]^2$	$(1-\bar{c})^2/2$
$\Pi_1^{D32}, \Pi_2^{D32}, \Pi_3^{D32}$	$2\frac{107(1-\bar{c})^2+10e[9e+7(1-\bar{c})]}{1681}, 4[\frac{3(1-\bar{c})-4e}{41}]^2, 6[\frac{5(1-\bar{c})+7e}{41}]^2$	$(1-\bar{c})^2/4, 0, e(1-\bar{c})/2$
$Total\ Welfare,\ TS^{D32}$	$4\frac{132(1-\bar{c})^2+e[139e+140(1-\bar{c})]}{1681}$	$(1-\bar{c})\frac{3(1-\bar{c})+4e}{8}$

Table 4: Results under disjoint adoption of $\mathcal{S}(\tau_1, \tau_2)$ by firm 1 and $\mathcal{S}(\tau_1, \tau_3)$ by firm 2.

	$e \leq 3(1-\bar{c})/11$	$e > 3(1-\bar{c})/11$
$w_{12}^{D23}, w_{21}^{D23}, w_3^{D23}$	$\frac{231(1-\bar{c})+143e}{594}, \frac{132(1-\bar{c})+11e}{297}, \frac{3(1-\bar{c})+7e}{18}$	$\frac{5(1-\bar{c})}{11}, \frac{5(1-\bar{c})}{11}, e$
q_1^{D23}, q_2^{D23}	$\frac{2[3(1-\bar{c})-2e]}{27}, \frac{3(1-\bar{c})+7e}{27}$	$\frac{2(1-\bar{c})}{11}, \frac{2(1-\bar{c})}{11}$
$Q^{D23}, P(Q^{D23})$	$\frac{3(1-\bar{c})+e}{9}, \frac{6+3c-e}{9}$	$\frac{4(1-\bar{c})}{11}, \frac{7+4c}{11}$
CS^{D23}	$\frac{[3(1-\bar{c})+e]^2}{162}$	$\frac{8(1-\bar{c})^2}{121}$
$\Pi_1^{D23}, \Pi_2^{D23}, \Pi_3^{D23}$	$\frac{45(1-\bar{c})^2+e[30(1-\bar{c})+41e]}{486}, \frac{9(1-\bar{c})^2+5e^2}{81}, \frac{[3(1-\bar{c})+7e]^2}{486}$	$\frac{14(1-\bar{c})^2}{121}, \frac{14(1-\bar{c})^2}{121}, \frac{2e(1-\bar{c})}{11}$
$Total\ Welfare,\ TS^{D23}$	$\frac{45(1-\bar{c})^2+e[30(1-\bar{c})+41e]}{162}$	$2(1-\bar{c})\frac{18(1-\bar{c})+11e}{121}$

Table 5: Adoption game and FRAND reasonableness requirement

		Firm 2	
		$\mathcal{S}(\tau_1, \tau_2)$	$\mathcal{S}(\tau_1, \tau_3)$
Firm 1	$\mathcal{S}(\tau_1, \tau_2)$	$(1-c_J)^2/8, (1-c_J)^2/8$	$(1-\bar{c})^2/4, 0$
	$\mathcal{S}(\tau_1, \tau_3)$	$(1-\bar{c})^2/4, 0$	$(1-c_J)^2/4, 0$

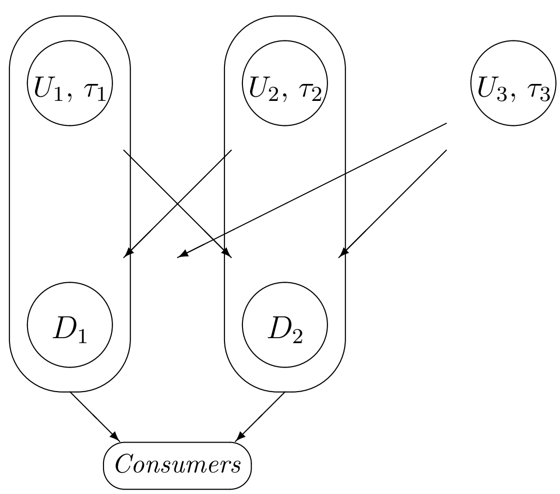
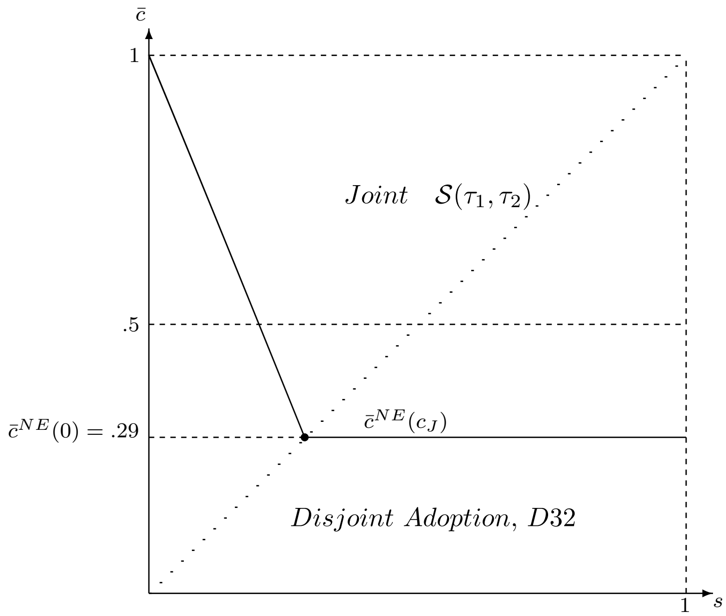
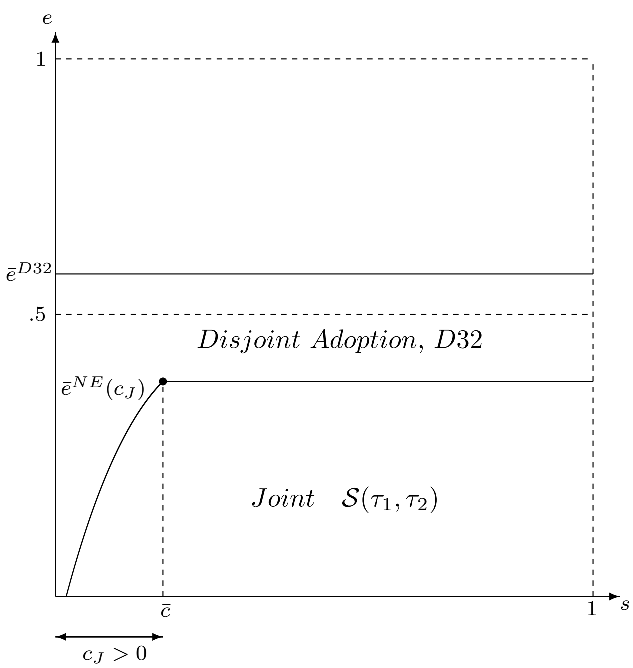


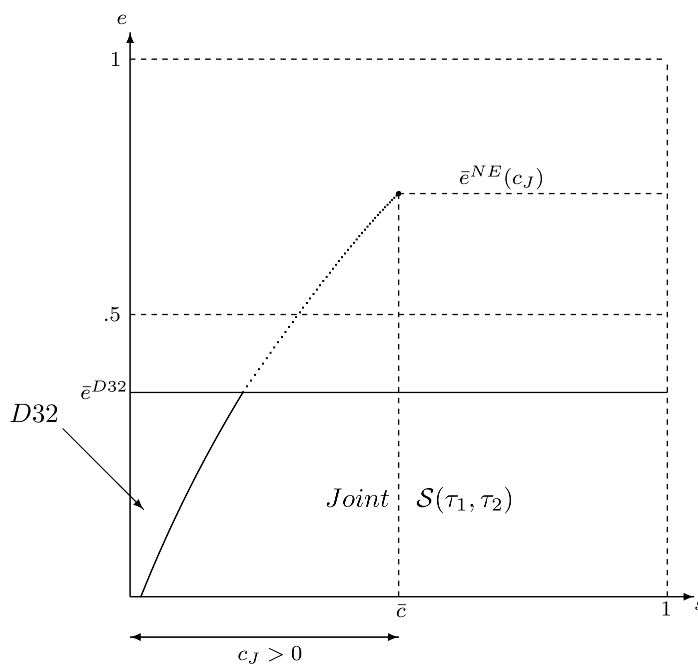
Figure 1: Framework.



(c) *CASES C − D*



(a) *CASES A − B*, $\bar{c} = .2$



(b) *CASES A − B*, $\bar{c} = .5$

Figure 2: Adoption Game - Equilibrium Analysis

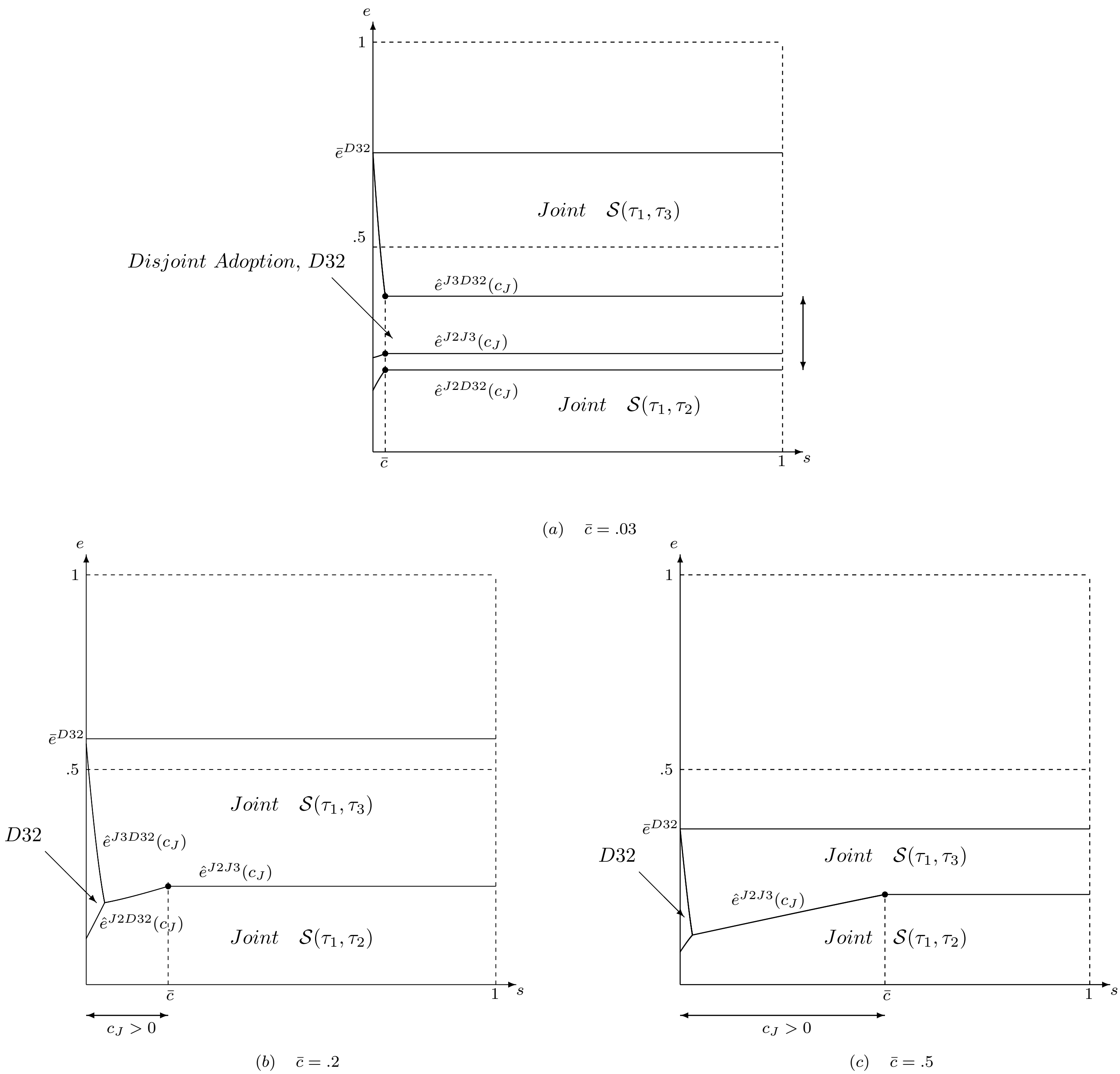


Figure 3: Welfare Analysis - Cases A-B

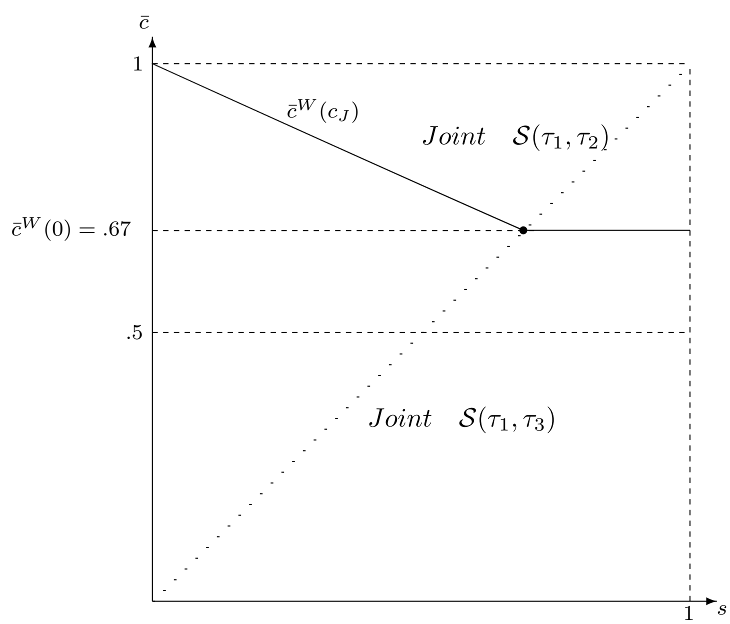
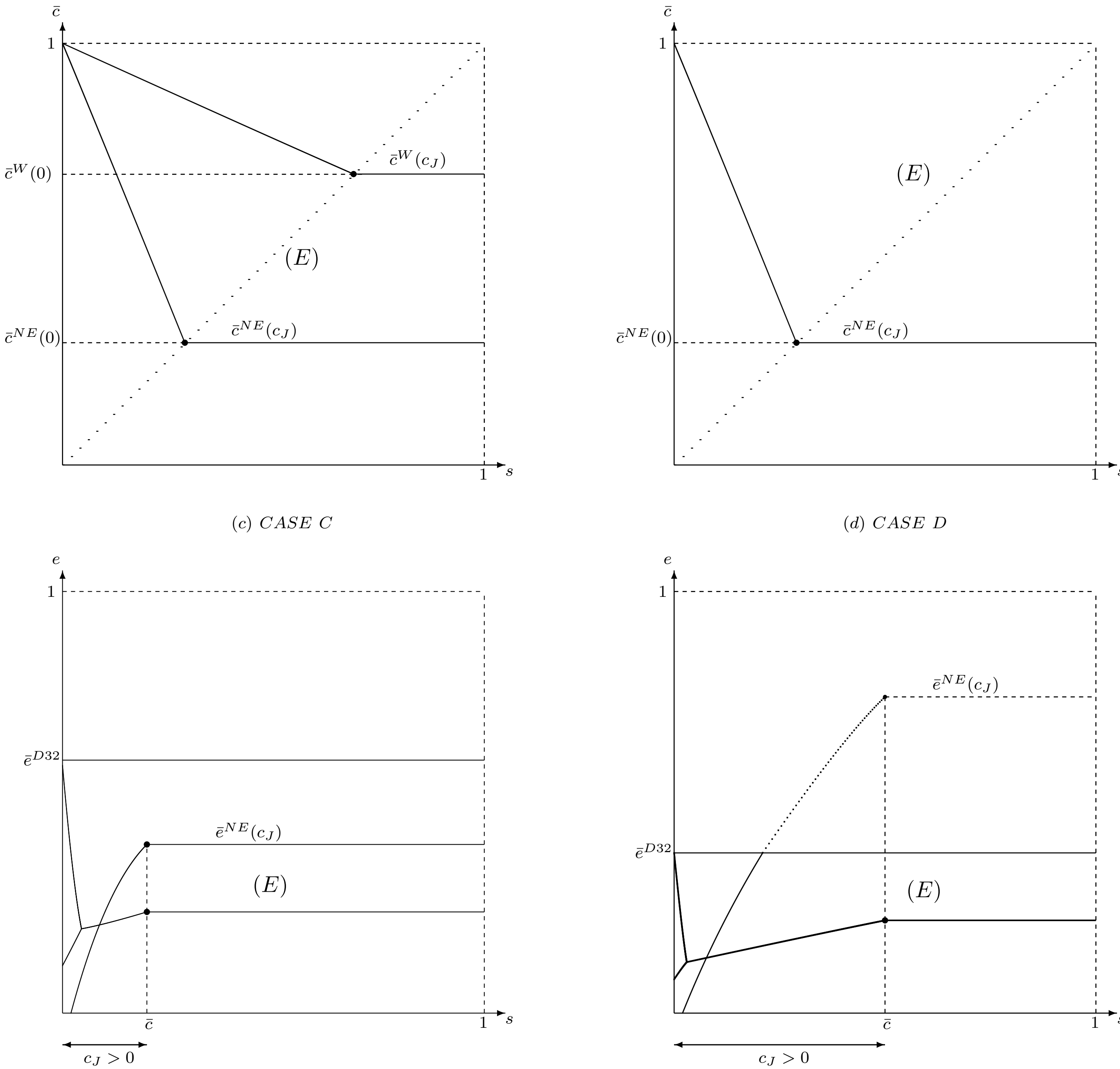


Figure 4: Welfare Analysis - Case C



(c) *CASE C*

(d) *CASE D*

(a) *CASES* $A - B$, $\bar{c} = .2$

(b) *CASES* $A - B$, $\bar{c} = .5$

Figure 5: Adoption Equilibria and Efficiency