**Innovation and *Ex Ante* Consideration of Licensing
Terms in Standard Setting**

by

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Abstract

In an effort to produce interoperable products, firms frequently participate in Standard Setting Organizations (SSOs) to collaboratively set technical standards for products used by networks of consumers. Some SSO members say they suffer from a type of holdup: after they sink technology-specific investments in developing and implementing a standard using a particular patented technology the patent owner can set licensing terms that exploit those investments. These members have called on SSOs to enhance competition between patent owners by soliciting and considering licensing terms for competing technologies *ex ante*, before anointing one as "the standard." However, more competitive licensing terms may dampen incentives to innovate. This paper analyzes the balance between the welfare benefits of the added competition and the welfare costs of reduced innovation. The model of R&D investment and standard setting predicts that both total welfare and consumer welfare are higher when an SSO considered licensing terms *ex ante* as long as the cost of innovation is not "high." The model also predicts that the welfare benefits of *ex ante* consideration of licensing terms grow as the costs of innovation falls. However, when the cost of innovation is "high" the negative welfare effects are always small.

1 Introduction

Technical standards add tremendous value by enabling products to interoperate. A cell phone is valuable because it is compatible with a network of other phones. Computer software is valuable, in part, because it allows us to create documents that can be viewed by others. The technological standards that are the foundation of such networks are commonly established through three mechanisms: 1) market competition, where firms produce incompatible products until one firm's technology becomes the *de facto* standard; 2) collaboration between rival producers who agree to use the same (or compatible) technology; and 3) government intervention.[1]

There are many examples of each route to standardization. The triumph of VHS technology over Betamax and the rise of Microsoft Windows are classic examples of the first route. The second route was used to collaboratively develop interpretability standards for the World Wide Web and Wireless Local Area Networks (WLAN).[2] Similar standards for mobile broadband technology are currently being developed by an industry group called the WiMAX Forum. The third route was used when the quasi-governmental International Telecommunications Union (ITU) established the standard protocols for FAX machines. The ITU also cut short a standards war between competing protocols for 56K modems when it promoted one protocol as the industry standard. More recently, the US Federal Geographic Data Committee (FGDC) has led an effort to develop compatibility among Geographic Information Systems (GIS) software, and the Federal Communications Commission (FCC) has designated a standard for high definition television (HDTV). See (Augereau *et al.* , 2004).

To ensure that their products are compatible, and thus more valuable, firms frequently collaborate in Standard Setting Organizations (SSOs) to choose a particular technology as the industry standard.[3] Traditionally, SSOs have been

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[1] Economic theories of networks and standards have primarily focused on the competition between firms to become the *de facto* industry standard. A 1992 Journal of Industrial Economics symposium on network industries (Gilbert, 1992), (Katz & Shapiro, 1986b), and (Katz & Shapiro, 1986c) provided a theoretical foundation for an extensive literature on competition in network industries and the implications of networks for investment and antitrust. Most models that have considered *de jure* standard setting (standard setting within collaborative standard setting organizations) have focused on the strategic issues surrounding coordination. Firms might disagree over which technology the SSO should choose and some firms must decide between participating in collaboration or trying to establish their own *de facto* standard. These issues are discussed by Joseph Farrell and various coauthors in (Farrell, 1996), (Farrell & Saloner, 1988), and (Besen & Farrell, 1994). Two excellent summaries of the literature are (Quelin *et al.* , 2001) and (David & Greenstein, 1990). (Tassey, 2000) provides useful general background on technological standards.

[2] The World Wide Web Consortium (3WC) has developed numerous protocols that support the transfer of data, photos, video, and audio across the internet. Until recently, the 3WC required that all proprietary technology incorporated in its standards be licensed "royalty free." The Institute of Electrical and Electronics Engineers (IEEE) has also developed standard protocols for wireless data transmission from computers to nearby internet connections.

[3] SSOs are also used to develop quality standards that enable adherents to commit to a certain level of quality. Examples of such standards are board certification for medical professionals and product safety standards.

populated by engineers who consider the technical merits of available alternative technologies and select the "best" technology as the industry standard without regard to what the licensing terms for any patented technologies might be. In selecting one technology as the standard, the SSO members effectively eliminate their ability to substitute between the available technologies. When the selected technology is under a patent, the intellectual property (IP) owner effectively becomes a monopolist.

Recently, some SSO members have complained that IP owners exploit their positions as monopolists and set unfair or excessive licensing terms for technologies that the SSOs have adopted as industry standards.[4] Dissatisfaction with the *status quo* system has prompted calls for SSOs to consider the licensing terms, as well as the technical merits, of the available technologies before "anointing" one as the standard because the current safeguards requiring "reasonable and non-discriminatory" (RAND) licensing terms are insufficient to prevent IP owners from exercising any market power they gain from having their technology selected by an SSO.[5]

A simple hypothetical example helps to illustrate the point. An SSO wants to develop a standard method of attaching peripheral devices to cell phones. There are two possible ways to configure four metal pins on the plug that will attach a device to a phone. The four pins can be aligned in a single row or they can be arranged in two rows. Call these technologies X and Y respectively. Technology X is marginally better than Y. Under the *status quo* system, the SSO would choose X. Then the patent owner would be able to set its royalty knowing that it no longer faced competition from technology Y. Under the proposed *ex ante* system, the SSO would first request licensing terms from both patent owners and then select the best combination of technology and licensing terms. Thus,

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[4] Robert Skitol provides an excellent description of the problem and summary of related legal literature and filings (Skitol, 2005). In 2002 the Department of Justice and the Federal Trade Commission held joint hearings on "Competition and Intellectual Property Law and Policy in the Knowledge-Based Economy." Two of the sessions focused specifically on the issues of licensing technology implicated by *de jure* standards set by SSOs. Transcripts and written testimony of the hearings are available at http://www.ftc.gov/opp/intellect/index.htm. *Ex ante* licensing discussions were also at the center of a debate over the "Standards Development Organization Advancement Act of 2004," a law which extended the "National Cooperative Research Act" to limit the antitrust liability of registered SSOs as well as research joint ventures. See (Schwartz & Gorman, 2004).

SSO members have also voiced a related complaint: some participants have allegedly violated rules that require them to disclose any patents that might read on the standard being developed. This has been the subject of several high profile lawsuits. See Micron v. Rambus, 189 F.Supp.2d 201(D.Del. 2002); Rambus v. Infineon Technologies, 318 F.3d 1081, Fed. Cir. 2003; and the FTC's suit against Union Oil Company of California, *In re* Union Oil Company of California, No. 9305, March 2003.

[5] Relatively few disputes over "reasonable and non-discriminatory" licensing terms have been settled by the courts. In one such case Rockwell International Corp. claimed that Motorola Corporation's licensing terms for patented technology incorporated in the ITU standard for 33.6K modems were "unreasonable." See (Shapiro, 2000). In another court case, Soundview Technologies charged that Sony and other members of the Electronic Industries Alliance (EIA) violated antitrust laws by collectively fixing royalties for Soundview's patented technologies used in the "V-Chip," the standardized chip that the government requires to be installed in all televisions to enable parents to block violent programming.

if the terms offered for technology Y were sufficiently superior, the SSO would select technology Y as the standard.

This process would allow SSO members to benefit from increased competition between substitute technologies before they commit to one technology. Without such *ex ante* competition, the SSO members suffer from a holdup problem similar to that examined in (Williamson, 1989) and (Grossman & Hart, 1986): after SSO members have made asset-specific investments (specific to a patented technology) in developing and implementing a particular standard, the patent owner is able to extract rents from those investments.[6]

Despite the potential advantages of *ex ante* competition, most large SSOs have rules that explicitly prohibit any public discussions of licensing terms during the standard setting process and many of their members have vigorously opposed any change.[7] At the 2002 Federal Trade Commission / Department of Justice hearings on IP and antitrust, representatives from large firms spoke on both sides of the issue; some downplayed the frequency and importance of such licensing hold up while others insisted that it is a significant problem.[8]

Opponents of *ex ante* competition have argued that such licensing discussions are likely to extend into areas that would be *per se* violations of antitrust laws, such as agreements on product prices.[9] Further, opponents contend that *ex ante* competition would introduce many practical problems that would greatly impede an already cumbersome standard setting process primarily because business people and lawyers would be required to negotiate licensing terms and ensure that discussions do not violate antitrust laws. Proponents of *ex ante* competition argue that SSOs create market power for the IP owner when they select its patented technology and that the SSO should be able to counter that artificial market power through joint *ex ante* consideration of licensing terms. Citing the possible efficiency justifications, proponents have sought guidance from the antitrust agencies on the issue.[10] Federal Trade Commission Chair-

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[6] Carl Shapiro provided a definition of "holdup" in this context in (Federal Trade Commission and Department of Justice, 2002a) pp. 15-16. An amicus brief filed by Joseph Farrell and other leading academics in the Federal Trade Commission's Rambus proceeding also describes holdup in the context of standard setting (Farrell, Joseph, et al., 2004).

[7] For example, IEEE policies state that "[t]he validity, terms, or cost of specific patent use" should be avoided during standard setting meetings. However, the SSO rules do not explicitly prohibit bilateral *ex ante* negotiations between an IP owner and a potential licensee. Even so, to the extent that such bilateral negotiations are effective they also dampen incentives to innovate.

[8] For example, Scott Peterson of Hewlett-Packard spoke out in favor of allowing *ex ante* licensing discussions. Carl Cargill of Sun Microsystems explained that RAND licensing terms are not sufficiently well defined. See (Federal Trade Commission and Department of Justice, 2002b) on pp.246-251 and pp. 109-111. They were opposed by Earle Thompson of Texas Instruments and Richard Holleman of the IEEE.

[9] See the testimony of Earle Thompson, Intellectual Asset Manager and Senior Counsel of Texas Instruments and attorney Paul Vishny in (Federal Trade Commission and Department of Justice, 2002a) pp.32-33 and p.44 respectively.

[10] (Lemely, 2002) provides an excellent in-depth review of current legal issues surrounding SSOs and IP rights. (Lemely, 2002), (Curran, 2003), and (Gifford, 2003) all make the case that *ex ante* licensing discussions have potential efficiency justifications and thus should be subject to a rule of reason analysis. Scott Peterson, of Hewlett-Packard, and Robert Skitol

man Deborah Majoras has agreed that, "joint ex ante royalty discussions that are reasonably necessary to avoid hold up do not warrant per se condemnation." (Majoras, 2005) This echoes the view expressed in June 2005 by outgoing Assistant Attorney General for Antitrust R. Hewitt Pate.(Pate, 2005) The European Commission has also indicated that it will study the issue.(European Commission, 2005)

Aside from the practical and legal issues surrounding *ex ante* discussions, there is a concern that adopting the *ex ante* system may harm welfare by dampening innovation incentives. If SSO members extract more favorable terms from IP owners by engaging in *ex ante* licensing discussions, then firms will likely invest less in researching and developing technologies that could form the basis of new standards.[11] To analyze the effects of adopting the *ex ante* system one must assess both the social benefits of lower royalties and the social costs of diminished innovation incentives.[12] This paper develops a model of R&D investment and standard setting to analyze the effects of adopting the *ex ante* system on the surpluses enjoyed by IP owners who license technology to manufacturers, manufacturers who buy licenses in order to produce an end product, and consumers who purchase the end product. The model predicts that greater competition between IP owners under the *ex ante* system benefits both consumers and producers (manufacturers that buy licenses to use the technology) as long as the cost of innovation is not "high." The model also predicts that innovators (R&D firms) are harmed by the competition introduced by the *ex ante* system.

The remainder of this section provides a brief review of the economic literature on licensing, which forms the foundation of the model presented in this paper. Section 2 outlines a three-stage model of R&D investment and collaborative standard setting. Section 3 solves for the equilibrium innovation investments, R&D profits, producer profits, and consumer surplus of the three-stage model for two separate games: one without *ex ante* licensing competition, and one with *ex ante* licensing competition. Section 4 compares the welfare outcomes of the two games and Section 5 concludes.

1.1 Review of licensing literature

From its inception, formal modeling of optimal licensing has been concerned with the relationship between licensing revenues and the amount of resources allocated for innovation. Kenneth Arrow's pioneering work relates an inventor's royalty revenues to the structure of the downstream market in which its licensees compete (Arrow, 1962). In Arrow's three-stage model, a single IP owner sets

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call for Agency guidance in (Petersonn, 2002) and (Skitol, 2005).

[11] See (Holleman, 2002). Joseph Farrell also comments on the issue in (Federal Trade Commission and Department of Justice, 2002a) pp. 47-48.

The same concern arises from some SSO policies that require participants to license any patents covered by the standard royalty free or to transfer the ownership of covered patents to the SSO itself.

[12] The tradeoff considered here is similar to the tradeoff implicit in granting patent protections. Market power is the currency with which society purchases innovation effort.

royalties for its cost-reducing innovation, then producers choose whether or not to purchase a license, and finally producers compete downstream.[13] In the 1980s, a series of papers began to apply variations of Arrow's basic three-stage model to questions about the optimal structure of licensing fees: Should licensors charge lump-sum royalties, or per-unit royalties, or both? Should licensors sell to all comers or limit the number of licenses they offer? Should licensors auction off a limited number of licenses?[14] In his *Handbook of Game Theory* chapter (Kamien, 1992), Morton Kamien provides an excellent summary of several extensions of Arrow's basic model developed by himself and various coauthors as well as by Michael Katz, Carl Shapiro, and others. See (Kamien & Tauman, 1992), (Kamien & Tauman, 1986), and (Kamien & Tauman, 2002). Also see (Quelin *et al.* , 2001) for a summary of the literature on technology standards in network industries, including (Katz & Shapiro, 1986a) and (Wang, 1998). Some of the extensions developed incorporate an initial stage in which the licensor must first invest in R&D in order to develop the cost-reducing technology.[15]

This paper makes several modifications to the basic model established in the literature to address the new question of which standard setting system yields the highest profits, consumer surplus, and total welfare. To compare the two standard setting systems, this paper develops two parallel versions of the same theoretical model: one models the *status quo* system of standard setting where industry standards are chosen without open competition over licensing terms, while the other allows for *ex ante* competition in licensing terms before the standard is chosen. The two models have the same three stages. First, research and development firms (R&D firms) invest in innovation to develop new technologies. Second, an SSO selects one of the new technologies as the industry standard. Third, the SSO members compete in a Cournot market selling the standardized product. The Subgame Perfect Nash Equilibrium (SPNE) of each of these two models are solved through backward induction starting with Cournot competition in the downstream market and the innovation effort, profits, and welfare associated with each of the two games are compared.

The current model differs from the literature in four important ways. First, unlike the existing literature, where a single IP owner competes with an existing free technology, the current model allows two R&D firms to behave strategically when investing in R&D and setting their royalty rates, somewhat like firms engaged in a patent race.[16] Second, in the existing literature downstream firms

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[13] The model predicts that an owner of a cost-reducing innovation who charges a per-unit royalty can earn higher profits when the downstream market is competitive than when it is monopolistic.

[14] (Katz & Shapiro, 1986c) does not explicitly model the downstream competition among licensees.

[15] A new generation of licensing models, pioneered by (Segal, 1999), focuses on bilateral licensing contracts in an environment where licensees (and even the licensor) compete in the downstream market.

[16] Much of the literature on investment incentives and innovation considers patent races (See (Tirole, 1995) pp. 394-399), where the first firm to develop the technology (and patent it) gets a monopoly payoff. The current model has a similar "winner-take-all" element which

can generally decline to license the new cost-reducing technology and to continue producing using the old, higher-cost (but royalty-free) production technology. This is not possible in the current model because a downstream firm that chooses not to take a license simply cannot legally sell the standardized product in the downstream market. Third, some of the existing literature allows for flexible licensing structures, but the current paper considers only per-unit licenses. While this may be a strong assumption, it is probably appropriate in the context of an SSO where IP owners routinely commit to licensing on "non-discriminatory" terms.[17] Fourth, the current model interprets innovation as an advancement that increases a consumer's willingness to pay (a common interpretation of "quality"). Although most of the existing literature has interpreted innovations as reducing production costs, the basic Cournot model can accommodate either interpretation.

2 A Model of R&D Investment and Collaborative Standard Setting

The model proceeds in three stages. In the first stage, two R&D firms simultaneously invest effort in developing new technologies. The results of the R&D effort are not deterministic. Instead, each of the two firms realizes an unidimensional innovation that is a random draw from a distribution determined by the firm's innovation efforts. A firm that invests more draws its innovation from a distribution that first order stochastically dominates the distribution of a firm that invests less. In the second stage, the R&D firms submit their patented innovations to an SSO, whose members then decide which of the two innovations (technologies) to implement as the standard, and set per-unit royalty fees. In the third stage, the licensees (producers) compete to sell the standardized product in the downstream market.

The model is analyzed in the context of several important maintained hypothesis. 1) The SSO members are homogeneous. 2) The two R&D firms are not SSO members. 3) Individual SSO members are not able to negotiate licensing terms bilaterally with the R&D firms either before or after the standard has been set. 4) The SSO members make sunk investments in developing and implementing the standard. 5) The patented technology is essential to implementing the standard. 6) There are no alternative uses for the technologies; specifically, neither R&D firm is in a position to promote its technology as a

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is common in models of patent races. In both the *status quo* model and the *ex ante* model, the firm that produces the greatest innovation becomes the monopoly provider of licenses in equilibrium. However, unlike the patent race models, innovation occurs simultaneously so neither firm innovates first.

[17] There is an ongoing debate about the legal meaning of "nondiscriminatory" in this context. It appears that uniform per-unit licensing fees are not considered discriminatory whereas combinations of lump-sum and per-unit fees may be considered discriminatory. IP is often licensed as a percentage of sales. However, equilibria solutions to the games using a percentage royalty become intractable.

de facto standard outside the structure of the SSO. 7) There is no uncertainty regarding whether the R&D firms' patents cover the technologies in question.[18]

The first two maintained hypotheses are probably the most critical abstractions. In reality, SSO members are often a diverse group with individual vested interests in the competing technologies. For example, IP owners themselves are often SSO members and they actively promote their own technologies during the standard setting process. These two maintained hypotheses abstract from the complicated internal decision making process common in most SSOs because the homogeneous SSO members in the model all agree on which technology to choose. The third maintained hypothesis may be somewhat redundant given the first two, but it is important to point out that bilateral licensing arrangements, especially cross licensing, are common. The remaining maintained hypotheses simply ensure that there is an interesting holdup problem and abstract from some potential issues that would limit the applicability of the model in some cases.

3 Solving for the SPNE Both With and Without *Ex Ante* Licensing Competition

Two different standard setting systems are modeled using the same first and last stages; the systems differ only in the structure of the second stage of the model. Under the *status quo* "*ex post* licensing" game ($G1$), the SSO members simply choose the best technology (the largest innovation drawn by the two R&D firms) and then the winning R&D firm sets a revenue-maximizing royalty. Under the proposed "*ex ante* licensing" game ($G2$), the two R&D firms commit to specific royalties before the SSO members choose one technology as the industry standard. The different methods of selecting a standard induce different equilibrium levels of investment, returns on R&D, profits for the SSO members, and consumer surpluses. Thus, the equilibrium outcomes of the two parallel games can be compared to evaluate whether the welfare benefits of the additional competition under the *ex ante* system exceed the harm of reduced innovation. The SPNE equilibria can be found through backward induction, starting with the third stage.

3.1 Stage Three: Downstream Cournot Competition

As is common in models of optimal licensing, consumer demand is given by the simple inverse demand function

$$P = \alpha - Q, \tag{1}$$

where P is the market clearing price and Q is the total quality of a homogeneous product. Although products are probably heterogeneous in reality, the assumption of product homogeneity is somewhat plausible because the products

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[18]Similar assumptions were made in (Besen, 2002).

have to have at least one thing in common: they must adhere to the industry standard. The parameter α represents the value that results from technological innovations. As innovations improve the quality of the product, each customer's willingness to pay increases. The demand curve (1) suggests that different customers value the basic product differently, but that they all value improvements in the product equally.

When $N \geq 2$ producers compete in the downstream market their combined Cournot equilibrium profits are

$$\pi^C(\alpha, r) = \frac{N}{(N+1)^2}(\alpha - r)^2,\tag{2}$$

where r is the positive per-unit royalty.[19] The R&D firm receives r for each of the Q units sold by the downstream Cournot competitors (SSO members) and its equilibrium revenues are

$$\pi(\alpha, r) = \frac{N}{(N+1)}(\alpha - r)r.\tag{3}$$

In Stage Two, the R&D firms choose r to maximize (3), the revenues that they ultimately earn in Stage Three. Because $G1$ and $G2$ diverge in Stage Two, the two games are considered separately in the next section.

3.2   Stage Two: $G1$

In the *status quo* game $(G1)$ the SSO selects the best technology (the highest of the two realizations of α) and the winning R&D firm sets its royalty to maximize (3). Let H denote the winning firm and r^M denote its monopoly royalty choice. Setting the derivative of (3) with respect to r equal to zero yields the revenue maximizing per-unit royalty $r^M = \frac{\alpha_H}{2}$ and corresponding licensing revenues $\pi^M(\alpha_j) = \frac{N}{(N+1)}\left(\frac{\alpha_H}{2}\right)^2$.

3.3   Stage Two: $G2$

Stage Two in the *ex ante* game $(G2)$ is divided into two sub-parts. First the R&D firms set their royalties, and then the SSO chooses which technology to incorporate into the standard. The SPNE of the stage is solved by backward induction, starting with the SSO's technology choice and then considering the R&D firms' optimal royalties.

3.3.1   Technology Choice

When considering licensing terms *ex ante*, the SSO chooses the best combination of technology (α) and per-unit royalty (r). To do so, the SSO members compare

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[19]This is the same downstream market structure that Kamien employs in his 1992 summary of the literature (Kamien, 1992). In reality, licensing terms have many more dimensions than just price. For example, the licensing terms may restrict the use of the technology or account for cross licenses.

the total expected profits of the N licensees, given the two (α, r) combinations offered by the R&D firms.[20] By inspection of (2), it is clear that downstream industry profits are higher when the SSO selects the R&D firm that offers the higher value of $(\alpha - r)$.[21]

3.3.2 Royalty Choice

In Stage Two of $G2$ the two R&D firms compete in a Bertrand setting, each lowering its royalty to undercut the other's $(\alpha - r)$ value. Let L denote the firm with the lower innovation value. The ability of Firm H to extract profits is limited by the willingness of Firm L to price at marginal cost, a royalty of zero.[22] Let the superscript D indicate the duopoly royalty and profits. However, when the difference between α_H and α_L is sufficiently large, the SSO will choose Firm $H's$ innovation even if Firm H charges the monopoly royalty. That is, Firm H is effectively a monopolist because Firm L would have to offer a negative royalty to compete with it superior technology.

Proposition 1 *In equilibrium, the R&D firm with the lesser innovation offers its license for free (equal to marginal cost). The R&D firm with the superior innovation charges $r^D = \alpha_H - \alpha_L$ if $\alpha_L > \frac{\alpha_H}{2}$ and charges $r^M = \frac{\alpha_H}{2}$ if $\alpha_L \leq \frac{\alpha_H}{2}$. The SSO chooses Firm $H's$ technology as the standard.*

Proof. When Firm H sets a royalty rate of $r_H = \alpha_H - \alpha_L$ and Firm L sets a rate of 0, then neither firm can profitably deviate if $\alpha_L > \frac{\alpha_H}{2}$. Firm L will earn zero profits at any positive royalty because it will not be selected by the SSO and could only earn negative profits from setting a negative royalty. Firm H can increase its royalty (and thus profits) up to $\alpha_H - \alpha_L$ and its technology will still be selected by the SSO. If Firm H sets a royalty greater than $a_H - \alpha_L$ the SSO will choose Firm $L's$ technology and Firm H will earn zero royalties.

However, if $\alpha_L \leq \frac{\alpha_H}{2}$, then $a_H - \alpha_L$ would exceed the monopoly royalty rate $\frac{\alpha_H}{2}$. Thus Firm H would maximize profits by setting its royalty to $\frac{\alpha_H}{2}$. Firm L could not profitably deviate for the same reasons described above. ∎

Substituting r^D into (3) yields Firm $H's$ Stage Two equilibrium licensing revenues

$$\pi^D(\alpha_H) = \frac{N}{(N+1)} \alpha_L (\alpha_H - \alpha_L) \text{ if } \alpha_H < \frac{\alpha_L}{2}. \tag{4}$$

Firm $L's$ equilibrium licensing revenues are zero because it is not selected by the SSO. The R&D firms consider the Stage Two profits of $G1$ and $G2$ when deciding how much effort to invest in innovation effort in Stage One.

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[20] Because members of the SSO are homogeneous, this decision rule could be defined in terms of aggregate or individual downstream profits.

[21] Letting L denote the firm with the lower innovation value, the SSO maximizes industry profits by choosing Firm H if $(\alpha_H - r_H) < (\alpha_L - r_L)$.

[22] It is assumed that the costs of abandoning the chosen standard are sufficiently high that they do not constrain the winning R&D firm's royalty choice.

3.4 Stage One: Expected Profits

The first stages of $G1$ and $G2$ are essentially the same; the forward-looking R&D firms make their innovation investment decisions in Stage One based on the equilibrium royalty revenues they expect to earn in the subsequent stages.[23] This decision depends on the relationship between the cost of innovation effort and the corresponding expected licensing revenues. In equilibrium, each R&D firm chooses an innovation effort that is a best response to the other's choice. Because the R&D firms' expected profits depend on the cost of the innovation effort they expend, it is necessary to establish the innovation process before fully characterizing profits.

3.4.1 The Innovation Process

The development of new technologies is an inherently uncertain process. Large innovations may result from only a small amount of effort just as large amounts of effort may yield only small innovations. However, in general, a firm that expends more effort can expect to produce a larger innovation. To reflect the uncertainty of the process, a firm's innovation, α, is modeled as a random draw. Let j denote an R&D firm.[24] Firm $j's$ innovation, α_j, is drawn from

$$f\left(\alpha_j | \lambda_j\right) = \lambda_j \left(\alpha_j\right)^{\lambda_j - 1}, \tag{5}$$

a family of probability density functions defined over the support $\alpha_j \in [0, 1]$. The different distributions in the family are distinguished by Firm $j's$ innovation effort, λ_j. It is useful to note that $E\left[\alpha_j | \lambda_j\right] = \frac{\lambda_j}{1 + \lambda_j}$. Thus, the expected marginal product of innovation effort λ_j is positive and decreasing.[25] Finally, let the cost of innovation effort be specified as a linear function of effort, $C\left(\lambda_j\right) = c\lambda_j$.[26]

3.4.2 Expected Profits

R&D firms choose their innovation efforts in Stage One to maximize their expected profits from royalties earned in subsequent stages. These expected royalties depend on three factors: whether the firm generates the best of the two innovations (if it does not, it gets no future royalties in equilibrium); the absolute level of its innovation (the greater its innovation, the more royalty revenue it will earn); and, in the case of $G2$, the relative level of the firm's innovation compared to the other R&D firm's innovation. These factors are captured in the

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[23] The R&D firms are assumed to be risk neutral.

[24] The j and $-j$ subscripts replace the H and L subscripts because the firms' actual innovations are not realized until the end of Stage One.

[25] It is easy to extend the model to account for differing levels of productivity of innovation effort. If innovations are drawn from $f\left(\alpha_j | \lambda_j\right) = \rho\lambda_j\left(\alpha_j\right)^{\rho\lambda_j - 1}$, then marginal changes in λ_j have a greater effect of moving probability from the lower end of the distribution to the higher end of the distribution when ρ is higher.

[26] This linear specification indicates that the R&D firms have no monopsony power in the market for innovation effort (hiring engineers) and that there are no lumpy or sunk costs associated with innovation effort.

following expected profit functions that integrate royalties over the two R&D firms' distributions of α.

Expected Profits: $G1$ In the equilibrium of $G1$ Firm j earns the monopoly royalty, $\pi^M(\alpha_j)$, conditional on the fact that it draws a higher innovation value than its rival. Thus the expected profit for Firm j is

$$E[\pi_j^{G1}(\lambda_j|\lambda_{-j})] = \int_0^1 \left(\int_0^{\alpha_j} \pi^M(\alpha_j) f(\alpha_{-j}|\lambda_{-j}) d\alpha_{-j}\right) f(\alpha_j|\lambda_j) d\alpha_j - C(\lambda_j),$$
(6)

where the subscript $-j$ denotes the other R&D firm. The inner term of the double integral integrates the monopoly royalty revenues of Firm j (with innovation α_j) over the truncated distribution of $\alpha_{-j} \in (0, \alpha_j)$. In this range, Firm $j's$ technology would be selected by the SSO in equilibrium and Firm j would earn royalties. The outer term integrates over the entire distribution of α_j. Substituting the functional forms of $f(\alpha_j|\lambda_j)$, $\pi^M(\alpha_j)$, and $C(\lambda_j)$ into (6) and solving the integral yields

$$E[\pi_j^{G1}(\lambda_j|\lambda_{-j}, N)] = \frac{1}{4} \frac{N}{(N+1)} \frac{\lambda_j}{(2 + \lambda_j + \lambda_{-j})} - c\lambda_j.$$
(7)

Before turning to the equilibrium innovation efforts in $G1$ consider the expected profits in $G2$.

Expected Profits: $G2$ The expected profit function for $G2$ is more complex because the R&D firm with the higher innovation will set the monopoly royalty if its innovation is sufficiently superior and the duopoly royalty if it is not. Thus in (8) the inner term of the double integral is split into two terms. The first is similar to the inner term in (6). However, (8) only integrates the *monopoly* royalty revenues over the range $\alpha_{-j} \in \left(0, \frac{\alpha_j}{2}\right)$, the outcomes when Firm j would price as a monopolist due to the superiority of its innovation. The second integrates the *duopoly* royalty revenues over the truncated distribution of $\alpha_{-j} \in \left(\frac{\alpha_j}{2}, \alpha_j\right)$, the outcomes when Firm $j's$ technology would still be selected by the SSO but the firm would be constrained to price as a duopolist. Again, the outer term integrates over the entire distribution of α_j. Thus Firm $j's$ equilibrium profits are

$$E[\pi_j^{G2}(\lambda_j|\lambda_{-j})] = \int_0^1 \left(\begin{matrix} \int_0^{\frac{\alpha_j}{2}} \pi^M(\alpha_j) f(\alpha_{-j}|\lambda_{-j}) d\alpha_{-j} + \\ \int_{\frac{\alpha_j}{2}}^{\alpha_j} \pi^D(\alpha_j, \alpha_{-j}) f(\alpha_{-j}|\lambda_{-j}) d\alpha_{-j} \end{matrix} \right) f_j(\alpha_j|\lambda_j) d\alpha_j - C(\lambda_j).$$
(8)

Substituting the functional forms of $f(\alpha_j|\lambda_j)$, $\pi^M(\alpha_j)$, $\pi^D(\alpha_j, \alpha_{-j})$, and $C(\lambda_j)$ into (8) and solving the integral yields

$$E[\pi_j^{G2}(\lambda_j|\lambda_{-j}, N)] = \frac{N}{(N+1)} \frac{\lambda_j \left(1 + 2^{1+\lambda_{-j}} \lambda_{-j}\right)}{2^{1+\lambda_{-j}} (1 + \lambda_{-j})(2 + \lambda_{-j})(2 + \lambda_j + \lambda_{-j})} - c\lambda_j.$$
(9)

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3.5 Equilibrium Innovation Efforts

The expected profit functions (7) and (9) imply that each game ($G1$ and $G2$) has a unique symmetric SPNE level of innovation effort in Stage One. This result is established by setting the first order conditions (FOCs) of the expected profit functions (taken with respect to λ_j) equal to zero and then solving the resulting system of two equations and two unknowns.[27]

Proposition 2 *The unique symmetric SPNE of $G1$ is given by*

$$\frac{N}{(N+1)} \frac{\left(2 + \lambda^{G1}\right)}{16\left(1 + \lambda^{G1}\right)^2} = c. \tag{10}$$

Proof. In $G1$, Firm j maximizes its expected profits by choosing λ_j^* to satisfy

$$\frac{N}{(N+1)} \frac{\left(2 + \lambda_{-j}\right)}{4\left(2 + \lambda_j^* + \lambda_{-j}\right)^2} = c. \tag{11}$$

In equilibrium both firms' FOCs must be satisfied and thus, by inspection of (11), λ_j^* must equal λ_{-j}^*. Denote this symmetric equilibrium effort as λ^{G1}. Substituting λ^{G1} for both λ_j^* and λ_{-j}^* in (11) yields (10). ■

Proposition 3 *The unique symmetric SPNE of $G2$ is given by*

$$\frac{N}{(N+1)} \frac{\left(1 + 2^{1+\lambda^{G2}} \lambda^{G2}\right)}{2^{3+\lambda^{G2}}\left(1 + \lambda^{G2}\right)^3} = c. \tag{12}$$

Proof. In $G2$, Firm j chooses λ_j^* to satisfy

$$\frac{N}{(N+1)} \frac{\left(1 + 2^{1+\lambda_{-j}} \lambda_{-j}\right)}{2^{1+\lambda_{-j}}\left(1 + \lambda_{-j}\right)\left(2 + \lambda_j^* + \lambda_{-j}\right)^2} = c. \tag{13}$$

Both firms' FOCs are satisfied when $\lambda_j^* = \lambda_{-j}^*$.[28] This symmetric equilibrium must be unique. Because $\frac{\left(1 + 2^{1+\lambda_j^*}\lambda_j^*\right)}{2^{\lambda_j^*}\left(1 + \lambda_j^*\right)}$ is monotonically decreasing in λ_j^* (for

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[27] Only interior profit maximization solutions are considered here. The Appendix provides a proof that corner solutions to the profit maximization problem can not be Nash equilibria in either $G1$ or $G2$ if $\frac{1}{8}\frac{N}{(N+1)} < c$ and neither firm will invest in innovation if $\frac{1}{8}\frac{N}{(N+1)} \geq c$.

[28] If both firm's FOCs hold then $\frac{\left(1 + 2^{1+\lambda_{-j}^*}\lambda_{-j}^*\right)}{2^{\lambda_{-j}^*}\left(1 + \lambda_{-j}^*\right)} = \frac{\left(1 + 2^{1+\lambda_j^*}\lambda_j^*\right)}{2^{\lambda_j^*}\left(1 + \lambda_j^*\right)}$. Because $\frac{\left(1 + 2^{1+\lambda_j^*}\lambda_j^*\right)}{2^{\lambda_j^*}\left(1 + \lambda_j^*\right)}$ is monotonically decreasing in λ_j^*, no two values of λ_j^* yield the same value of $\frac{\left(1 + 2^{1+\lambda_j^*}\lambda_j^*\right)}{2^{\lambda_j^*}\left(1 + \lambda_j^*\right)}$. Thus $\lambda_{-j}^* = \lambda_j^*$ is the SPNE of $G2$.

$\lambda_j^* > 0$) there can be only one value of λ_j^* corresponding to any given λ_{-j}^*. Substituting the symmetric equilibrium effort, λ^{G2}, for both λ_j^* and λ_{-j}^* in (13) yields (12). $\blacksquare$

As predicted, the equilibrium level of effort is lower under the *ex ante* licensing system.

Proposition 4 *The equilibrium innovation effort in $G1$ exceeds the equilibrium innovation effort in $G2$, or $\lambda^{G1} > \lambda^{G2}$.*

Proof. The value of the left-hand sides of (10) and (12) are monotonically decreasing functions of λ^{G1} and λ^{G2} respectively. Thus, if the left-hand side of (10) exceeds the left-hand side of (12) when $\lambda^{G1} = \lambda^{G2}$, then when the left-hand sides of (10) and (12) are both set to c, it must be true that $\lambda^{G1} > \lambda^{G2}$. Following a proof by contradiction, suppose that (10) evaluated at λ is smaller than (12) evaluated at λ. This implies that

$$\left(2 - \lambda + \lambda^2\right) < 2^{1-\lambda}, \tag{14}$$

which does not hold for $\lambda > 0$. For $\lambda^{G1} = \lambda^{G2} > 0$ the left-hand side of (10) must exceed the left-hand side (12). Thus λ^{G1} must exceed λ^{G2} when (10) and (12) hold. $\blacksquare$

4 The Effect of the *Ex Ante* System on Equilibrium Surpluses and Welfare

The equilibrium innovation efforts in each game determine the expected surpluses of the R&D firms, the downstream firms, and consumers. (The formulas for the producer and consumer surpluses are constructed in the same manner as the expected R&D firm profit functions described above and are given in the Appendix.) After solving for the equilibrium innovation efforts and finding the corresponding surpluses, it is possible to evaluate the model's predictions regarding the effects of adopting the *ex ante* licensing system on each group's surplus (and the total surplus) by comparing the $G1$ and $G2$ equilibrium results.

One would expect that adopting the *ex ante* system would decrease the profits of the R&D firms because it introduces an additional element of competition. Further, one would generally expect that consumers and downstream firms would benefit from the additional competition among R&D firms.[29] The equilibrium outcomes of the two games are generally consistent with these expectations. The model predicts that both consumers and downstream firms are better off with the *ex ante* system unless the costs of innovation are "high" and that R&D firms are always worse off with the *ex ante* system. The model also predicts that the benefits of the *ex ante* system to consumers and downstream

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[29]It is theoretically possible that additional competition among R&D firms would induce them to invest even more in innovation.

firms (and the harm to R&D firms) are inversely related to the cost of innovation effort.

Ideally, one could analytically solve for the equilibrium innovation efforts in each game (as functions of N and c) and then use those findings to solve for the surpluses enjoyed by consumers, downstream producers and R&D firms. However, such a straightforward analytical approach is not possible in this case because general analytic solutions for the equilibrium innovation effort in $G2$ do not exist. (Analytic solutions exist for particular combinations of the parameters. For example, when $N = 2$ and $c = \frac{5}{192}$ then (12) holds for $\lambda^{G2} = 1$.)

However, if one fixes the value of N it is possible to perform comparative statics on the welfare effects of adopting the *ex ante* system for different values of c by expressing each of the surpluses in $G1$ as a function of λ^{G2}. This can be done by first inverting (10) to solve the $G1$ equilibrium condition for λ^{G1} as a function of c and then replacing c with the left hand side of (12), the $G2$ equilibrium condition.[30] The result gives λ^{G1} as function of λ^{G2}. Finally, this $\lambda^{G1}\left(\lambda^{G2}\right)$ can be substituted into the $G1$ surplus functions. Although conceptually simple, this process produces algebraic monstrosities. Thus, it is necessary to illustrate the resulting comparative statics using graphs. In the graphs below $N = 2$.

Before doing so, it is useful to review the mechanics of this process, which are illustrated in Figure 1. In the first panel of Figure 1, the horizontal axis measures equilibrium innovation effort and the vertical axis measures the cost of innovation effort. The curves labeled $G1$ and $G2$ plot the costs of innovation that are associated with each equilibrium level of innovation effort, as given by the equilibrium equations (10) and (12).

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[30]Solving (10) for λ^{G1} yields

$$\lambda^{G1} = \frac{-(2\theta - 1) + \sqrt{(2\theta - 1)^2 - 8\theta}}{2\theta},$$

where $\theta = 16\frac{N}{N+1}c$.
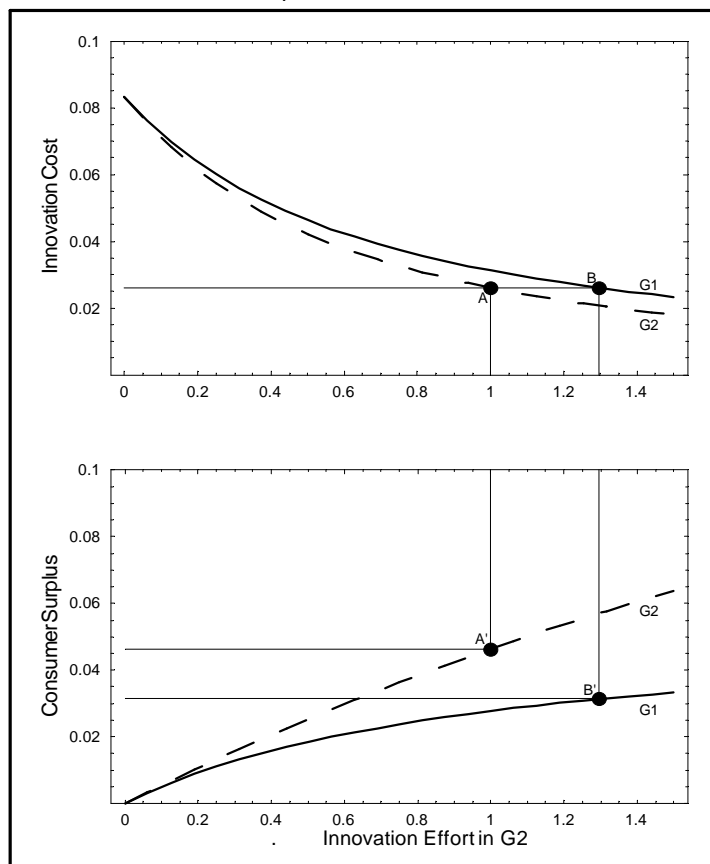
Consumer Surplus and Costs in G1 and G2

Figure 1

For example, the intersection labeled A indicates that when $\lambda^{G2} = 1$ then $c = 0.026$. Despite the fact that it is on the vertical axis, c is clearly the independent variable, not the dependent variable. Because (10) can be inverted to express λ^{G1} and a function of c, one can find the λ^{G1} associated with the cost given by intersection A. The intersection labeled B gives this point as $\lambda^{G1} \approx 1.3$. In the second panel of Figure 1, the curves labeled $G1$ and $G2$ plot the consumer surplus associated with the equilibrium level of effort in each of the two games, as given by (15) and (16) in the Appendix. By comparing the heights of the intersections labeled A' and B', which give the consumer surpluses associated with $\lambda^{G2} = 1$ and $\lambda^{G1} \approx 1.3$, which are in turn associated with $c = 0.026$, it is clear that consumer surplus is greater under the *ex ante* system when $c = 0.026$.

Using the substitution process described above, Figure 2 illustrates the equilibrium consumer surplus for a range of $G2$ equilibrium efforts. Because λ^{G2} depends on the cost of innovation effort one can use this figure to compare con-

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sumer surplus over a range of possible values of c even though the results do not allow for a direct algebraic relationship between changes in c and changes in consumer surplus.[31]

The line labeled $G2$ in Figure 2 simply plots the equilibrium consumer surplus (equation (16) in the Appendix) for each equilibrium level of innovation effort, λ^{G2}. The line labeled "Cost" relates each level of c to the resulting effort in $G2$. Exploiting the equilibrium conditions (10) and (12) as described above to find $\lambda^{G1}\left(\lambda^{G2}\right)$, the line labeled $G1$ plots the equilibrium consumer surplus in $G1$ for each λ^{G2}. For any particular c, the Cost curve yields the equilibrium effort, $\lambda^{G2}(c)$. The $G2$ curve gives consumer surplus in $G2$ when effort is $\lambda^{G2}(c)$. Finally, the $G1$ curve gives consumer surplus in $G1$ when effort is $\lambda^{G1}\left(\lambda^{G2}(c)\right)$. In words, the $G1$ curve gives the consumer surplus from the equilibrium effort that R&D firms would make in $G1$ when costs are such that R&D firms would make effort $\lambda^{G2}(c)$ in $G2$.

Figure 2 illustrates that the consumer surplus in $G2$ exceeds the consumer surplus in $G1$ for most levels of c. However, careful examination of the $G1$ and $G2$ curves near the origin reveals that the consumer surplus generated in $G1$ is actually slightly greater than in $G2$ when λ^{G2} is very low, which occurs when the cost of innovation effort is "high." The straight dashed lines highlight the finding that the two systems result in the same consumer surplus when $c = 0.064$. For innovation costs above that level (but less than $\frac{1}{8}\frac{N}{N+1}$) $G1$ yields slightly higher consumer surplus. The graph also reveals that the difference between the consumer surplus generated in $G2$ and the consumer surplus generated in $G1$ increases as costs fall below 0.064. Thus the model predicts that, as long as the costs of innovation effort are not "too high," the expected benefits to consumers of the additional competition between the R&D firms, under the *ex ante* system, outweigh the costs of having less expected innovation. Moreover, the absolute effect of introducing more competition is larger when innovation costs are smaller and expected innovations are larger.

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[31] As discussed in the Appendix, if $c \geq \frac{1}{8}\frac{N}{N+1}$ then neither R&D firm invests in innovation effort in either game's equilibrium, and thus consumer surplus is zero in both games.
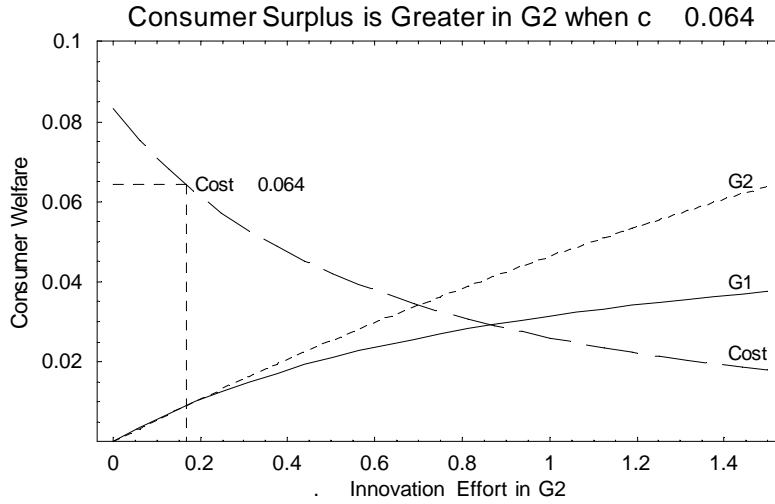
Figure 2

An equivalent (unreported) graph shows a similar pattern for the aggregate surplus of the downstream producers, which (given the Cournot construction) is simply $\frac{2}{N}$ times the consumer surplus. Unsurprisingly, an equivalent graph also reveals that R&D firm surplus is higher in $G1$, when there is no *ex ante* competition in licensing terms, than in $G2$ for all levels of c. Thus, comparing the total welfare results of the two systems yields the same qualitative result: total welfare is greater under $G2$ except for when c is "high." The break-even c for total welfare is slightly lower than 0.064 because total welfare incorporates the fact that R&D firms are always better off without the *ex ante* system.

As one would expect, equivalent graphs of consumer surplus using larger values of N reveal that consumers benefit from increased downstream competition. Such graphs also indicate that consumers gain more from the *ex ante* system when N is larger: the downstream firms pass on a greater share of the reduction in royalties achieved through the *ex ante* system. Although, the break-even level of innovation effort (approximately 0.166 in Figure 2) is independent of N, that effort level is associated with higher c when N is larger.

It is worth noting that the SSO members would not favor the *ex ante* system if they knew that innovation costs were "high." However, the actual cost of innovation effort is probably unknown. Thus it would be appropriate to consider the expected welfare effects of adopting the *ex ante* system taken over a distribution of possible innovation costs. Given that the *ex ante* system has a very small social cost over a small range of possible realizations of c and much larger benefits over all other (smaller) realizations of c, it seems most plausible that adopting the *ex ante* system would have a positive expected welfare effect.

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5   Conclusion

There has been heated debate over whether SSOs should engage in *ex ante* discussions of licensing terms before selecting among the alternative technologies. In addition to many practical and legal arguments, some who oppose the introduction of *ex ante* licensing competition argue that it would diminish social welfare by reducing incentives to innovate. However, the welfare effects of reduced innovation should be weighed against the welfare benefits of increased competition among IP owners. To assess the relative magnitudes of the competition effect and innovation effect on social and consumer welfare, this paper develops a simple three stage model that can be used to analyze both the *status quo* system (without *ex ante* licensing competition) and the *ex ante* system (with *ex ante* licensing competition). The model predicts that the *ex ante* system generally results in lower innovation effort and lower profits for R&D firms, but higher consumer surplus and profits for downstream licensees.

6   Appendix

Proof. There are no equilibria where $\lambda_{-j} = 0$ and $\lambda_j > 0$ in Stage One of either $G1$ or $G2$ if $c < \frac{1}{8}\frac{N}{(N+1)}$.

Suppose that Firm $-j$ chooses $\lambda_{-j} = 0$. Then Firm $j's$ profits in the two games are equivalent (given by $E[\pi_j^{G1}(\lambda_j|0, N)]$ and $E[\pi_j^{G2}(\lambda_j|0, N)]$) and can only be positive if

$$\frac{1}{4}\frac{N}{(N+1)}\frac{1}{(2+\lambda_j)} > c.$$

This condition cannot hold for positive λ_j and $c < \frac{1}{8}\frac{N}{(N+1)}$. ∎

Corollary 5 *If $c > \frac{1}{8}\frac{N}{(N+1)}$ then $\lambda_{-j} = \lambda_j = 0$ is the only equilibrium in Stage One of $G1$ or $G2$.*

6.1   Equilibrium Expected Consumer Surplus

Consumer surplus in Stage Three is given by $\frac{1}{2}(\alpha - P)Q$ where α is the value of the technology selected by the SSO. Substituting in the Stage Three equilibrium values of P and Q yields

$$CS(\alpha, r(\alpha)) = \frac{1}{2}\left(\frac{N}{N+1}(\alpha - r(\alpha))\right)^2.$$

The expected values of equilibrium consumer surplus can be found by first replacing $\pi^M(\alpha_j)$ and $\pi^D(\alpha_j)$ in (6) and (8) with $CS(\alpha, r(\alpha))$, with the appropriate equilibrium value of $r(\alpha)$. This yields the expected consumer surplus when Firm $j's$ technology is selected by the SSO in $G1$ and $G2$, respectively. To find the total expected consumer surplus one must add the expected consumer surplus when Firm $-j's$ technology is selected by the SSO in each game. Substituting the equilibrium innovation efforts chosen by both R&D firms into the expected equilibrium consumer surpluses of each game yields

$$E\left[CS^{G1}(\alpha, r(\alpha))|\lambda^{G1}, \lambda^{G1}\right] = \frac{1}{8}\left(\frac{N}{N+1}\right)^2\frac{\lambda^{G1}}{\left(1+\lambda^{G1}\right)} \tag{15}$$

and

$$E\left[CS^{G2}(\alpha, r(\alpha))|\lambda^{G2}, \lambda^{G2}\right] = \frac{1}{2}\left(\frac{N}{N+1}\right)^2\left(\frac{\left(1+\left(\lambda^{G2}\right)2^{1+\lambda^{G2}}\right)}{2^{1+\lambda^{G2}}\left(2+\lambda^{G2}\right)}\frac{\lambda^{G2}}{\left(1+\lambda^{G2}\right)}\right). \tag{16}$$

Because the combined Cournot profits of the downstream firms are simply $\frac{2}{N}$ times $CS(\alpha)$, the equilibrium downstream profits can be found directly from (15) and (16).

References

Arrow, Kenneth, J. 1962. Economic Welfare and the Allocation of Resources for Innovation. *In:* of Economic Research, National Bureau (ed), *The Rate and Direction of Inventive Activity: Economic and Social Factors.* Princeton: Princeton University Press.

Augereau, Angelique, Greenstein, Shane, & Rysman, Marc. 2004. Coordination vs. Differentiation in a Standards War: 56K Modems. *NBER Working Paper*, **999**(10334), 999–999.

Besen, Stanley M. 2002 (April). *Standard Setting and Intellectual Property Rights: An Outline of the Issues.* Federal Trade Commission. <http://www.ftc.gov/opp/intellect/020418stanleymbesen.pdf>.

Besen, Stanley M., & Farrell, Joseph. 1994. Choosing How to Compete: Strategies and Tactics in Standardization. *Journal of Economic Perspectives*, **8**(2), 117–131.

Curran, Patrick D. 2003. Standard-Setting Organizations: Patents, Price Fixing, and per se Legality. *The University of Chicago Law Review*, **70**, 983–1009.

David, Paul A., & Greenstein, Shane. 1990. The Economics of Compatibility Standards: An Introduction to Recent Research. *Economics of Innovation and New Technology*, **1**, 3–41.

European Commission. 2005 (December). *Competition: Commission Welcomes Changes in ETSI IPR Rules to Prevent ŚPatent AmbushŠ.* Press Release IP/05/1565, Available at <http://www.europa.eu.int>.

Farrell, Joseph. 1996 (January). *Choosing the Rules for Formal Standardization.* Mimeo, University of California, Berkeley.

Farrell, Joseph, & Saloner, Garth. 1988. Coordination Through Committees and Markets. *RAND Journal of Economics*, **19**(2), 235–252.

Farrell, Joseph, et al. 2004 (April). *Brief Amicus Curiae of Economics Professors and Scholars.* Available at <http://www.ftc.gov/os/adjpro/d9302/040415scholarsamicusbrief.pdf>.

Federal Trade Commission and Department of Justice. 2002a (November). Hearings On: Competition and Intellectual Property and Policy in the Knowledge-Based Economy (Transcript). Available at <http://www.ftc.gov/opp/intellect/021106ftctrans.pdf>.

Federal Trade Commission and Department of Justice. 2002b (April). Hearings On: Competition and Intellectual Property and Policy in the Knowledge-Based Economy (Transcript). Available at <http://www.ftc.gov/opp/intellect/020418trans.pdf>.

Gifford, Daniel J. 2003. Developing Models for a Coherent Treatment of Standard-Setting Issues Under the Patent, Copyright, and Antitrust Laws. *IDEA: The Journal of Law and Technology*, **43**(3), 331–394.

Gilbert, Richard J. 1992. Symposium on Compatibility: Incentives and Market Structure. *Journal of Industrial Economics*, **40**(1), 1–8.

Grossman, Stanford J., & Hart, Oliver D. 1986. The Costs and Benefits of Ownership: A theory of Vertical and Lateral Integration. *Journal of Political Economy*, **94**(4), 601–719.

Holleman, Richard J. 2002 (April). *A Response: Government Guidelines should not be Issued in Connection with Standards Setting.* Federal Trade Commission. Available at <http://www.ftc.gov/opp/intellect/020418richardjholleman2.pdf>.

Kamien, Morton I. 1992. Patent Licensing. *In:* Aumann, R.J., & Hart, S. (eds), *Handbook of Game Theory, Vol 1.* North Holland: Elsevier Science Publishers.

Kamien, Morton I., & Tauman, Yair. 1986. Fee Versus Royalties and the Private Value of a Patent. *The Quarterly Journal of Economics*, **101**(3), 471–492.

Kamien, Morton I., & Tauman, Yair. 2002. Patent Licensing: The Inside Story. *The Manchester School*, **70**(1), 7–15.

Kamien, Morton I., Shmuel S. Oren, & Tauman, Yair. 1992. Optimal Licensing of a Cost-Reducing Innovation. *Journal of Mathematical Economics*, **21**, 483–508.

Katz, Michael L., & Shapiro, Carl. 1986a. How to License Intangible Property. *The Quarterly Journal of Economics*, **101**(3), 567–590.

Katz, Michael L., & Shapiro, Carl. 1986b. Network Externalities, Competition, and Compatibility. *American Economic Review*, **75**(3), 424–440.

Katz, Michael L., & Shapiro, Carl. 1986c. Technology Adoption in the Presence of Network Externalities. *Journal of Political Economy*, **94**(4), 822–841.

Lemely, Mark A. 2002. Intellectual Property Rights and Standard Setting Organizations. *California Law Review*, **90**, 1889–1980.

Majoras, Deborah P. 2005 (September). *Recognizing the Procompetitive Potential of Royalty Discussions in Standard Setting.* Standardization And The Law: Developing The Golden Mean For Global Trade, Stanford University Stanford, CA, September 2005. <http://www.ftc.gov/speeches/majoras/050923stanford.pdf>.

Pate, R. Hewitt. 2005 (June). *Competition and Intellectual Property in the US: Licensing Freedom and the Limits of Antitrust.* 2005 EU Competition Workshop, Florence, Italy, June 2005. Available at <http://www.usdoj.gov/atr/public/speeches/209359.pdf >.

Petersonn, Scott K. 2002 (November). *Consideration of Patents during the Setting of Standards.* Federal Trade Commission. Available at <http://www.ftc.gov/opp/intellect/021106peterson.pdf>.

Quelin, Bertrand V., Abdessemed, Tamym, Bonardi, Jean-Philippe, & Durand, Rodolphe. 2001. Standardization of Network Technologies: Market Process or the Result of Inter-Firm Co-Operation? *Journal of Economic Surveys*, **15**(4), 543–569.

Schwartz, Daniel C., & Gorman, Frank M. 2004. Shield for Standards. *Legal Times*, **27**(28).

Segal, Ilya. 1999. Contracting with Externalities. *Quarterly Journal of Economics*, **114**(2), 337–389.

Shapiro, Carl. 2000 (June). *Setting Compatibility Standards: Cooperation or Collusion?* Mimeo, University of California, Berkeley.

Skitol, Robert A. 2005. Concerted Buying Power: Its Potential For Addressing The Patent Holdup Problem In Standard Setting. *Antitrust Law Journal*, **72**, 727–744.

Tassey, Gregory. 2000. Standardization in Technology-Based Markets. *Research Policy*, **29**, 587–602.

Tirole, Jean. 1995. *The Theory of Industrial Organization.* Cambridge, Massachusetts: MIT Press.

Wang, Henry X. 1998. Fee Versus Royalty Licensing in a Cournot Duopoly Model. *Economics Letters*, **60**, 55–62.

Williamson, Oliver E. 1989. Transaction cost economics. *In:* Schmalensee, Richard, & Willig, Robert D. (eds), *Handbook of Industrial Organization, Volume 1.* Amsterdam: Elsevier Science Publishers.