Standard Setting Organizations and Standard Essential Patents: Voting Power versus Market Power

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Abstract

The key finding is that Standard Setting Organizations (SSOs) choose efficient technology standards because voting power and market power have counterbalancing effects. Agents on the long side of the market have less added value in the marketplace but more voting power in cooperative organizations and conversely for the short side of the market. In a two-stage model, industry members choose technology standards by voting and then compete in the marketplace. When there is disagreement among industry groups, without Standard Essential Patents (SEPs), SSO members vote for the efficient standard unanimously. In an equilibrium with SEPs, inventors and technology adopters choose efficient standards, although voting may not be unanimous. With disagreements within industry groups, SSO members choose efficient standards

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by majority rule. The results help explain the choice of technology standards by SSOs, the design of SSO voting rules, and the selection of SSO rules governing intellectual property (IP).

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I Introduction

Do Standard Setting Organizations (SSOs) choose efficient technology standards? To answer this question it is useful to understand the interactions between standard setting and market competition. Most SSOs choose standards by voting (Goerke and Holler, 1995; Baron and Spulber, 2015). These standards affect markets by changing costs, benefits, prices, outputs, products, and technologies. In turn, markets affect voting because industry members anticipate the effects of standards on market outcomes. To study these interactions, I introduce a model in which industry members vote on standards in an SSO and compete in the market after choosing the standard.

The key insight of the analysis is that voting power and market power counterbalance each other. Because of these countervailing effects, SSOs choose efficient technology standards. When a group of industry members is larger than other groups, they have greater voting power but less market power, and the converse holds as well. As a result, SSOs choose efficient technology standards, whether markets are competitive or monopolistic. This effect holds even when there are Standard Essential Patents (SEPs) so that SSOs choose efficient standards when inventors have market power. The analysis of how voting and markets interact has institutional implications because it helps explain observed variations across SSOs of rules on voting and intellectual property (IP).

The question of whether SSOs choose efficient technology standards is an important one. SSOs are ubiquitous, with more than one thousand organizations developing hundreds of thousands of technology standards.¹ For example, the European

¹In addition to hundreds of specialized industry SSOs there are many general organiza-
Telecommunications Standards Institute (ETSI) and the 3rd Generation Partnership Project (3GPP) establish standards for cellular telecommunications networks. The Institute of Electrical and Electronics Engineers (IEEE) develops standards for telecommunications, information technology, and power generation. The International Electrotechnical Commission (IEC) sets standards for electronic and electrical technologies. Many organizations develop Internet standards including the World Wide Web Consortium (W3C), the Internet Engineering Task Force (IETF), and the Industrial Internet Consortium (IIC). The American National Standards Institute (ANSI) is an U.S. umbrella that includes industry organizations representing more than 125,000 companies.

The efficiency of technology standards also is important because standards have major economic effects. This is evidenced by familiar standards such as USB, LTE, WiFi, HTTP, and MP3. Standards provide the coordination needed to achieve technological interoperability in many industries. Standards increase market efficiency by lowering transaction costs (Kindleberger, 1983). Standards perform other valuable functions including adjusting product variety, maintaining product quality and

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2 ETSI includes over 800 member organizations (http://www.etsi.org/). 3GPP "covers cellular telecommunications network technologies, including radio access, the core transport network, and service capabilities - including work on codecs, security, quality of service - and thus provides complete system specifications. The specifications also provide hooks for non-radio access to the core network, and for interworking with Wi-Fi networks," see http://www.3gpp.org/about-3gpp/about-3gpp, accessed May 7, 2015.


performance, measuring consistently, codifying knowledge, assuring compatibility, articulating a vision of the industry, assuring health and safety, and controlling environmental quality (Swann, 2010). Standards set by private SSOs complement and interact with standards set by market transactions and by government regulation and procurement. The efficiency of standards also has important implications for antitrust policy towards SSOs and intellectual property (IP).

I develop a two-stage model with voting on standards in the first stage and market competition in the second stage. SSO members include four types of industry participants: distributors, producers, suppliers, and inventors. Inventors own patents that are SEPs for various standards. The relative numbers of these economic agents affect voting power in the SSO and also affect market power in competition. The main results of the analysis are as follows.

First, I show that without SEPs, SSO members unanimously choose the efficient standard. The result builds on the following intuition. Even though there are no financial transfers before voting takes place, agents anticipate the effect of standards on market outcomes after standards are chosen. Ex post financial transfers in a competitive market equilibrium harmonize ex ante net benefits so that industry members consistently favor the efficient standard. This result is robust to variations in membership composition of the SSO, different voting rules, any number of potential standards, and any sizes of the various industry groups. This result holds even though the preferences over standards of individual distributors, producers or suppliers differ substantially across industry groups so that voting based on those preferences would encounter typical voting problems.

Market competition induces unanimous voting for the efficient standard because of the countervailing effects of the size of industry groups. Economic agents that are relatively few in number tend to have relatively less voting power in SSOs but tend to have greater market power in competition and vice versa. If the competitive market is not capacity constrained, marginal returns are exhausted in equilibrium. Then, market returns are such that the greatest number of agents are active with the most efficient standard. However, when the market is capacity constrained, marginal returns are positive in equilibrium. Then, the relative numbers of different
types of economic agents affects their incremental contribution to economic value and their share of marginal returns. Agents that are relatively scarce capture economic returns at the margin and favor the efficient standard. Agents that are relatively abundant are indifferent across standards and support the efficient standard. The countervailing effects of the size of groups of economic agents imply that standards organizations will chose efficient standards and market outcomes will implement those efficient standards.

Second, I show that with SEPs, the SSO again chooses the efficient standard, although the decision need not be unanimous. When some inventors have SEPs, they can extract monopoly rents subject to industry capacity constraints and the presence of alternative existing technologies. With SEPs, inventors capture all available incremental returns at the margin. As a result, distributors, producers, and suppliers again unanimously prefer the efficient standard. However, individual inventors will prefer those standards for which they have SEPs and will choose the standard that provides them with the greatest average returns. The analysis shows that inventors also face a trade-off between voting power and market power, which will rule out their joining larger groups to vote for inefficient standards because that would reduce average licensing revenues. Voting rules can deter inventors from joining smaller groups to vote for inefficient standards as a means of raising average licensing revenues. The presence of adopters of SEPs in the SSO allows the design of voting rules to induce the choice of the efficient standard. The efficient of the standard with SSOs is robust to whether or not there are rules limiting ex post licensing revenues for SEPs.

Third, I introduce the concept of a drastic innovation, extending Arrow’s (1962) term for individual inventions to technology standards. The SSO’s choice of a technology standard determines the group of inventions covered by SEPs that apply to the standard. A new technology standard represents a drastic innovation if and only if total royalties for the SEPs that apply to the standard are not constrained by a royalty based on a benchmark standard. With drastic innovations, there is no need for the SSO to regulate ex post royalties and less need for adopters of inventions to participate in SSOs to balance the influence of inventors. Conversely, in industries with nondrastic innovations, there is a greater need for participation by many
industry groups to regulate royalties and counter the influence of inventors.

Fourth, I consider disagreements about standards within industry groups. When there is disagreement about standards within groups of distributors, producers, or suppliers, a group will no longer unanimously support a standard. This occurs because the market equilibrium does not involve transfers within industry groups, in contrast to market equilibrium transfers among industry groups. I show that with disagreements within a group, a majority of the group always supports the efficient standard. The reason for this result is that efficient standards increase the number of active members of the group at the market equilibrium in comparison to other standards, generating greater support for the efficient standard. Combined with the previous result showing unanimity when there is agreement within industry groups, the analysis implies that SSOs will have different voting rules based on the extent of disagreements within industry groups. This helps explain why SSO rules vary from majority voting to full consensus. The results suggest why specific voting rules are observed and also how these rules may vary over time.

The results have empirical implications that will be discussed further in a later section. Although standards have complex multidimensional technology specifications, the analysis yields a one-dimensional quality measure of innovation. The quality of the innovation affects market outcomes in a way that is potentially testable. The analysis also yields predictions about the voting rules of SSOs, which are generally observable.

The results also have some public policy implications that will be discussed in a later section. It is often argued that dominance of the SSO by particular interest groups affects the choice of standards. The main results obtained here suggest instead that the choice of technology standards is efficient so that dominance need not be a problem. Also, the discussion shows that even in the worst case scenario, when inventors with SEPs exercise market power after standards are chosen, SSOs choose efficient standards.

These results reflect the fact that SSOs generally engage in decision making without *ex ante* financial transfers, primarily using voting and discussion in committees. The combination of voting and market competition helps clarify the distinction
between voting power and market power. Because there are no *ex ante* transfers, voting power of players (political power) differs from coalitional power in cooperative games (economic value) as Barry (1980a, 1980b) points out.\(^5\) It is therefore possible to distinguish between voting power in the SSO and market power after standards are established. However, when SSOs choose technology standards, markets create *ex post* transfers, which explains why it is fruitful to consider the interactions between cooperative standard setting and market competition.

Theoretical models of SSOs generally have not considered voting. An important exception is the contribution of Goerke and Holler (1995) that focuses on the coordination function of standard setting. They consider the choice between two product standards by two groups of buyers. The buyers benefit from selecting a standard because of network effects even though each group would prefer a different standard. Goerke and Holler (1995) examine voting as a way of addressing multiple Nash equilibria in standards adoption. In their model, a supermajority voting rule is necessary to induce the standards organization to choose an efficient standard. The present model differs from their analysis by considering a market equilibrium after standards are chosen that generates transfers among economic agents. This yields additional results on voting rules when there are disagreements within and across industry groups. The literature on public goods has considered mixed models in which individuals simultaneously vote on the provision of public goods and engage in market transactions. On such mixed voting and market models of public goods, see particularly Bowen (1943), Slutsky, (1977), Denzau and Parks (1983), and Greenberg and Shitovitz (1988).\(^6\)

There is a growing theoretical literature on SSOs.\(^7\) Lévêque and Ménière (2011) suggest that *ex ante* patent pools can address market power issues associated with SEPs. Simcoe (2012) applies the stochastic sequential bargaining model of Merlo

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\(^5\) Barry (1980a, 1980b) distinguishes measures of voting power without transfers from measures such as those in Shapley and Shubik (1954) that are based on voting as a contribution to coalitions.

\(^6\) On dividing a pie by voting, see for example Rosenthal (1975) and Greenberg (1979).

\(^7\) Farrell and Saloner (1986) consider problems of coordination when standardization offers benefits from network effects. Farrell and Saloner (1988) compare negotiation and market bandwagon effects for two players choosing whether to not to standardize products, although they do not combine voting and markets.
and Wilson (1995) to consensus standard setting in committees and tests whether distributional conflicts are linked to delays. Dewatripont and Legros (2013) consider incentives for inventors to misrepresent patents as essential when there is asymmetric information. Llanes and Poblete (2014) show that with multiple inventors, standards are efficient when firms form patent pools that determine sharing rules before the technology standard is chosen. Layne-Farrar and Llobet (2014) examine an SSO when there are two inventors and a monopoly producers or duopoly producers downstream. Layne-Farrar et al. (2014) show that rate caps can affect adversely incentives to innovate and participate in SSOs. Lerner and Tirole (2015) provide conditions under which adopters and inventors choose inefficient technology standards. In their setting, inventors with SEPs choose licensing royalties non-cooperatively so that total royalties exceed the monopoly level, see also Lerner and Tirole (2004). The present analysis differs from these models by considering voting on standards and bargaining over licensing royalties.

There is a substantial empirical literature on standards organizations, including SSOs, standards development organizations (SDOs), industry consortia (Baron et al. 2014), alliances and trade associations. Leiponen (2008) studies the Third Generation Partnership Project (3GPP) and finds that industry associations and consortia facilitate the activities of SSOs; see also Rosenkopf and Tushman (1998). Firms form private alliances and consortia to exchange information and coordinate their participation in SSOs; see Leiponen (2008) and Baron and Pohlman (2013). Spencer and Temple (2013) consider the contribution of technology standards to economic growth in the U.K.

The paper is organized as follows. Section 2 presents the basic two-stage model of standard setting and market competition. Section 3 characterizes the equilibrium choice of technology standard and the resulting market equilibrium prices. Section 4 extends the analysis to the choice of standards when inventors have SEPs. Section 6 extends the analysis to consider disagreements about standards within vertical industry groups. Section 6 discusses some empirical and public policy implications and Section 7 concludes the discussion.
II The basic framework

This section develops a two-stage model of the interaction between a standards organization and market competition. In the first stage of the model, the members of a standards organization engage in voting to choose a technology standard. In the second stage of the model, distributors, input suppliers and output producers apply the technology standard and compete in the market. The model will be solved by backward induction. The model is a hybrid of competition and voting that allows a comparison of the effects of relative numbers of agents in the market and in the standards organization. The next section extends the basic model to include SEPs.

II.1 The industry

Consider an industry with three vertically differentiated groups consisting of input suppliers, producers, and distributors. Input suppliers include providers of materials, parts, components, software, and services. Producers include manufacturers and supply chain managers. Distributors denote marketers, assemblers, wholesalers, retailers, original equipment manufacturers (OEMs), and service providers who sell to final consumers. This framework allows the study of how the allocation of economic rents across vertical levels of the industry affects participation and outcomes in standards organizations. The discussion extends readily to more industry groups.

Assume that input suppliers, producers, and distributors have unit capacity. This setting helps illustrate how the relative numbers of agents determine the outcome of competition in the market, with the short side of the market generally having greater added value and the long side of the market generally having less added value. At the same time, this setting illustrates how the relative numbers of agents affect participation and voting power in the standards organization. This allows us to observe how agent participation affects incremental value in the marketplace and affects voting power in the standards organization.

There is a set of potential technology standards $S = \{s_1, s_2, ..., s_T\}$. The standards $s \in S$ are not necessarily in any order can represent complex multi-dimensional
technologies or qualitative descriptions of technologies. Standards represent specifications that affect product quality and interoperability of parts and components. Standards apply to inputs, components, and final products. For example, standards exist for software, wireless networking technologies, mobile communications, automobile parts, and aircraft components. Because standards represent complex technologies, we do not specify how standards affect the benefit and cost functions of industry members.

The technology standard affects distributor benefits, producer costs, and supplier costs. Distributors have unit demands with positive benefits \( u_i(s) = u(s) - \eta(i) > 0 \), where distributor types \( i \) are in the interval \([0, I]\). Producers have unit capacity and production costs \( c_h(s) = c(s) + \theta(h) \), where producer types \( h \) are in the interval \([0, H]\). Input suppliers have unit capacity with costs \( k_j(s) = k(s) + \zeta(j) \), where seller types \( j \) are in the interval \([0, J]\). Assume that \( \eta(i) \), \( \theta(h) \), and \( \zeta(j) \) are differentiable and increasing. With these benefits and costs, there is agreement about the effects of standards within industry groups. A later section considers benefits and costs such that there is disagreement about the effects of standards within industry groups. Agreement or disagreement on standards within industry groups has important consequences for the voting rules of SSOs.

Groups of suppliers, producers, and distributors can rank standards very differently. For this reason, standards differ from public goods for which more is better. We do not restrict the effects of a standard on the distributor benefit function \( u(s) \), the producer cost function \( c(s) \), or the supplier cost function \( k(s) \). The groups of distributors, producers, and suppliers can agree or disagree on how they value and rank standards. For example, with three standards, a distributor may have preferences \( s_1 \succ s_2 \succ s_3 \), a producer may have preferences \( s_2 \succ s_3 \succ s_1 \), and a supplier may have preferences \( s_3 \succ s_2 \succ s_1 \). This suggests that based on these preferences, it would be possible to have voting paradoxes of the type identified by Condorcet (1976) and Arrow (1951). However, as we will see, the preferences of economic agents are modified by anticipation of market-mediated transfers after standard setting occurs.

Let \( q \) denote industry output. Because all agents have unit capacity, the size of
the smallest industry group gives an industry capacity constraint

$$ \bar{q} = \min\{H, I, J\}. $$

(1)

The three industry groups are complementary in the production of the final industry output. For ease of presentation, assume that the sizes of each industry group differ, \( H \neq I \neq J \). If two or more categories of economic agents are equal, market prices depend on relative bargaining power. It will be shown that this does not change the results.

Market equilibrium prices are determined by competition among producers, distributors, and suppliers. The final output price is \( p(s) \) and the input price is \( r(s) \). The market equilibrium industry output \( q^0 \) determines the marginal agents. Given the market equilibrium prices, it follows that active producers have profits

$$ \pi_h(s) = p(s) - r(s) - c_h(s), \quad h \in [0, q^0]. $$

(2)

Active input suppliers have profits

$$ g_j(s) = r(s) - k_j(s), \quad j \in [0, q^0]. $$

(3)

Active distributors have profits

$$ v_i(s) = u_i(s) - p(s), \quad i \in [0, q^0]. $$

(4)

An agent is active only if it has non-negative profits, and inactive agents have zero profits. Define the total profits of each group as \( V(s, q) = \int_0^q v_i(s)di \), \( \Pi(s, q) = \int_0^q \pi_h(s)dh \), and \( G(s, q) = \int_0^q g_j(s)dj \).

Social welfare equals total distributor benefits net of total producer and supplier costs,

$$ W = \int_0^q u_i(s)di - \int_0^q c_h(s)dh - \int_0^q k_j(s)dj. $$

(5)

Let \( s^* \) and \( q^* \) maximize social welfare subject to the industry capacity constraint,
The economic effects of the technologies that make up a standard constitute an innovation. We refer to the incremental effects of the standard \( \varphi(s) \) as the quality of the innovation,

\[
\varphi(s) \equiv u(s) - c(s) - k(s).
\] (6)

Let \( \psi(q) \) denote the incremental effects of output evaluated at the marginal distributor, producer and seller,

\[
\psi(q) \equiv \eta(q) + \theta(q) + \zeta(q).
\] (7)

The marginal effects of output on social welfare equal \( \frac{\partial W}{\partial q} = \varphi(s) - \psi(q) \). It is useful to write welfare as a function of the incremental effects of the standard and output, \( W(\varphi(s), q) \).

Social welfare is strictly concave in output, \( \frac{\partial^2 W(\varphi(s), q)}{\partial q \partial q} = -\psi'(q) < 0 \), because the incremental effects of output are increasing, \( \psi'(q) = \theta'(q) + \eta'(q) + \zeta'(q) > 0 \). So, there is a unique output \( \hat{q} \) that maximizes social welfare without the capacity constraint,

\[
\psi(\hat{q}) = \varphi(s).
\] (8)

We can write the unconstrained output as a function of the incremental effects of the standard, \( \hat{q} = \hat{q}(\varphi(s)) \).

The unconstrained optimum is strictly increasing in the incremental effects of the standard, \( \frac{d\hat{q}(\varphi(s))}{ds} = \frac{1}{\psi'(\hat{q}(\varphi(s)))} > 0 \). It follows that the efficient industry output level \( q^* \) is unique. The efficient industry output can be written as a function of the innovation and the industry capacity constraint, \( q^*(\varphi(s), \bar{q}) = \min\{\hat{q}(\varphi(s)), \bar{q}\} \).

Because the set of standards is finite, there exists an efficient standard \( s^* \). Assume that the efficient standard \( s^* \) is unique.
II.2 Inventors and SEPs

Suppose that there is a set of individual inventors \( y \in [0,Y] \), each of whom owns a unique patent portfolio with various technological features. These technological features may be necessary to implement technologies associated with the set of standards. The inventor designations \( y \) are a general index that represents complex patent portfolios with multiple technological features. As noted previously, the standard designations \( s \in S \) are also an index that represents complex technological standards.

Inventors can have patents "reading on" multiple standards. To represent SEPs, let \( \lambda : [0,Y] \times S \rightarrow \{0,1\} \) be an indicator function such that \( \lambda_y(s) = 1 \) if inventor \( y \) has patents that are essential for standard \( s \) and \( \lambda_y(s) = 0 \) otherwise. The number of inventors with SEPs applying to the standard \( s \) is given by

\[
N(s) = \int_{y=0}^{Y} \lambda_y(s)dy. \tag{9}
\]

This setting implicitly assumes that SEPs are perfect complements in the sense that companies must apply a set of SEPs to achieve the standard. The analysis can be extended to allow imperfect complements and substitutes.

When there are SEPs, we refer to distributors, producers, and suppliers as technology adopters. Assume that technology adopters always choose to license patents from inventors that own the relevant SEPs. Patents are assumed to be valid. Issues of infringement or patent enforcement are beyond the scope of the present discussion. After a technology standard \( s \) is chosen by the standards organization, SEP owners whose patents apply to a standard \( s \) choose licensing royalties.

Assume that the inventors with SEPs that apply to the standard can coordinate their licensing activities and engage in bargaining. This implies that after the standard is chosen by the standards organization, inventors with SEPs choose licensing royalties that maximize total licensing revenues \( R \). We will show that monopoly licensing revenues \( R^M(\varphi(s)) \) can be expressed as a function of the quality of the innovation. We will also consider bargaining subject to constraints on royalties im-
posed by the SSO.

Suppose that SEP owners with patents that apply to a standard evenly divide total royalties. This simplifies the discussion although the analysis can be extended readily to allow bargaining with uneven division.\textsuperscript{8} This implies that for a standard $s$ an inventor $y$ receives licensing revenues contingent on owning SEPs for that standard,

$$
\xi_y(s) = R^M(\varphi(s))\frac{\lambda_y(s)}{N(s)},
$$

$y \in [0,Y]$ and $s \in S$.

The combination of patented inventions and technology standards in the present model will is sufficiently general that it can be applied to any association of inventions and standards.\textsuperscript{9} In practice, there is an imperfect association between patents and standards, with some SSOs providing limited monitoring of what patents inventors declare as essential. However, Baron and Pohlmann (2015) provide an extensive mapping of patents to technology standards that helps to analyze SEPs.

### II.3 Voting in the standards organization

The standards organization selects a standard on the basis of voting by its members. All of the standards in the set $S$ are voted on simultaneously and each member votes for only one standard. Members of the organization vote as individuals not in voting blocs.

Participation in the standards organization generates benefits from coordination. For the purposes of the present analysis, it is not necessary to specify explicitly the sources of coordination benefits such as economies of scale, network effects, or transaction efficiencies. The returns to coordination are implicit in the benefits of the suppliers, producers and distributors.

\textsuperscript{8}On bargaining, see Edgeworth (1881), Shapley (1952), Aumann (1987), Aumann and Shapley (1974), and Shubik (1982, 1984).

\textsuperscript{9}Lerner and Tirole (2015) consider a set of patented technological features and map those features to the set of standards.
In evaluating standards, industry members anticipate the market equilibrium that would be observed after the standard is chosen. So, the functions $\pi_h(s), v_i(s), g_j(s)$ represent the market-mediated preferences over the set of standards of producers, distributors, and suppliers respectively. Assume that if an economic agent is indifferent between standards $s$ and $s^*$, the agent will choose efficient standard.

One or more industry groups are members of the standards organization. Define the sets of distributors, producers, and suppliers by $F_I = [0,I]$, $F_H = [0,H]$, and $F_J = [0,J]$. The sets consisting of the union of two industry groups are $F_{H,I}$, $F_{H,J}$, and $F_{I,J}$ and the full set of industry participants is $F_{H,I,J}$. Let $\Lambda$ denote the possible membership sets of the standards organization,

$$\Lambda = \{F_H, F_I, F_J, F_{H,I}, F_{H,J}, F_{I,J}, F_{H,I,J}\}.$$  \hspace{1cm} (11)

When there are SEPs, the set of inventors $F_Y = [0,Y]$ also may participate in the standards organization.

Define the voting game by $g(\delta; F)$. All members of the organization participate in voting. The organization chooses a standard only if the proportion of votes for that standard exceeds $\delta$, where $0 \leq \delta \leq 1$. If $\delta \leq 1/2$, ties are resolved in favor of the efficient standard. The set $F \in \Lambda$ refers to the members of the organization and, when there are inventors with SEPs, the organization can consist of adopters $F \in \Lambda$, inventors $F = F_Y$, or both inventors and adopters $F \in F_Y \cup F'$ where $F' \in \Lambda$.

**II.4 Timing**

The equilibrium of the two-stage game is as follows. In stage one, producers, distributors, and suppliers vote for the standard that maximizes their respective net benefits, $\pi_h(s), v_i(s),$ and $g_j(s)$. The standards organization chooses a standard $s^0 \in S$. In stage two, after the standard is established, producers, distributors, and suppliers transact in the market given the standard $s^0$. Market competition determines equilibrium output $q^0(s)$ and prices $p(s^0)$ and $r(s^0)$.

When inventors have SEPs, the two-stage game is modified as follows. In stage
one, adopters (producers, distributors, and suppliers) and inventors vote for the standard $s^0 \in S$ that maximizes their net benefits. In stage two, inventors with SEPs that apply to the standard $s^0 \in S$ choose total royalties $\rho(s^0)$, adopters transact in the market and competition determines equilibrium output $q^0(s)$ and prices $p(s^0)$ and $r(s^0)$.

### III The technology standard without SEPs and disagreement among industry groups

This section considers the technology standard when there are no SEPs. There is disagreement among industry groups regarding the preference rankings of the standard. The game is solved by backward induction. The market equilibrium depends on the choice of the technology standard by the SSO. SSO members vote on the standard in anticipation of its effects on the market equilibrium. The proofs of the main results are given in the appendix.

### III.1 The competitive market equilibrium

The market equilibrium is perfectly competitive when there are no SEPs. This provides a benchmark for the market equilibrium when there are SEPs. The market equilibrium with industry capacity constraints involves positive returns at the margin for scarce industry groups. The market equilibrium with capacity constraints is related to Makowski's (1980a) and Ostroy's (1980) characterization of a competitive equilibrium using the "no surplus" condition. An allocation satisfying the "no surplus" condition allocates to each individual their contribution to total surplus in the economy, see Makowski (1983), Ostroy (1984), and Makowski and Ostroy (1995).

As would be expected, the competitive market equilibrium output equals the efficient output for any standard $s$, $q^0 = q^* (\varphi(s), \overline{q})$. If the industry is not capacity constrained, marginal producers, distributors, and suppliers have zero profits and
prices are given by

\[ u(s) - \eta(q) = p(s) = c(s) + \theta(q) + r(s), \] (12)

\[ r(s) = k(s) + \zeta(q). \] (13)

When the market equilibrium is capacity constrained, marginal benefits are positive and prices depend on the relative numbers of producers, distributors, and suppliers. Because of competition among market participants, constrained market equilibria assign all marginal benefits to one of the groups of economic agents. The scarce group captures economic rents at the margin because of competition among agents in groups that are relatively abundant. This confers market power on the scarce group.

There are three capacity-constrained market equilibria. (i) If distributors are in the scarce category, \( \bar{q} = I < \min\{H, J\} \), market equilibrium prices depend on marginal costs of input supply and production at the industry output, \( p(s) = c(s) + \theta(\bar{q}) + k(s) + \zeta(\bar{q}) \) and \( r(s) = k(s) + \zeta(\bar{q}) \). (ii) If producers are in the scarce category, \( \bar{q} = H < \min\{I, J\} \), the market equilibrium output price equals marginal consumer benefits, \( p(s) = u(s) - \eta(\bar{q}) \), and the input price equals the marginal cost of input supply, \( r(s) = k(s) + \zeta(\bar{q}) \). (iii) Finally, if suppliers are in the scarce category, \( \bar{q} = J < \min\{H, I\} \), the market equilibrium output price depends on marginal consumer benefits \( p(s) = u(s) - \eta(\bar{q}) \) and the input price equals marginal consumer benefits net of marginal production costs, \( r(s) = u(s) - \eta(\bar{q}) - c(s) - \theta(\bar{q}) \).

### III.2 The equilibrium technology standard with disagreement among industry groups

The members of the standards organization vote on standards taking into account the effects of the standard on their net benefits at the market equilibrium. This implies that the number of agents in each category affects the choice of the technology standard by the standard organization. As shown in the preceding discussion, the re-
relative numbers of economic agents in each category also affect the market equilibrium prices and output. The equilibrium standard thus depends on how the population of economic agents affects both the choice of standards and market outcomes.

Given the efficient industry output level, we can write social welfare as a function of the incremental effects of the standard,

$$w(\varphi(s)) = \varphi(s)q^*(\varphi(s), \bar{q}) - \int_0^{q^*(\varphi(s), \bar{q})} \psi(x) dx.$$  

(14)

From the envelope theorem, it follows that social welfare is strictly increasing in the incremental effects of the standard, $w'(\varphi(s)) = q^*(\varphi(s), \bar{q})$.

This implies that a standard $s^*$ maximizes social welfare $w(\varphi(s))$ over $S$ if and only if it maximizes the quality of the innovation $\varphi(s)$ over $S$. This is a useful observation because the innovations represented by $\varphi(s)$ are important in determining individual agents’ voting for standards.

Although the market equilibrium may depend on the relative numbers of agents in each group, we show that the organization’s equilibrium standard does not depend on the relative numbers of agents in each group. The standards organization chooses the efficient standard unanimously because ex post market equilibrium transfers coordinate distributor and supplier preferences so that they agree on the choice of the efficient standard. The main result of the analysis is as follows.

**Proposition 1.** Without SEPs, for any sizes $H$, $I$, $J$ of the industry groups, any number of standards $T$, any membership set $F \in \Lambda$, and any decision rule $\delta$, the members of the standards organization unanimously choose the efficient standard $s^0 = s^*$.

Proposition 1 shows that the allocation of economic rents at a competitive market equilibrium is sufficient to induce members of a standards organization is sufficient to induce voting for efficient standards. The intuition for the result is as follows. If the market equilibrium is not capacity constrained, equilibrium prices exhaust marginal net benefits. Economic agents thus benefit from the having the greatest total incremental benefits of standards. Because the profits of any agent depend
on the total incremental benefits of the standard, rather than on the effect of the standard on their own benefits or costs, all agents will prefer the efficient standard.

The result continues to hold even if the market equilibrium is capacity constrained. Even if a group of agents has market power after the standard is chosen, this does not translate into voting power in the standards organization. If a group of agents is relatively scarce, its members obtain all of the marginal net benefits at the margin at the market equilibrium. Therefore, the members of the relatively scarce group prefer the efficient standard. If a group of agents is relatively abundant at the market equilibrium, its members do not obtain a share of marginal net benefits at the market equilibrium. Therefore, members of groups that are relatively abundant at the market equilibrium are indifferent between technology standards and therefore choose the efficient standard.

Proposition 1 demonstrates that with market competition after standard setting, market power counterbalances voting power. It should be emphasized that there is no assumption on how standards affect distributor utility, producer costs or supplier costs. This means that suppliers, producers, and distributors may rank standards in a similar way or very differently in terms of their respective utility or costs. However, the result shows that the preferences of agents over standards are affected instead by the surplus they receive at the market equilibrium. The market equilibrium affects the allocation of surplus to the various industry groups. For any market equilibrium, either perfectly competitive or imperfectly competitive, generates efficient standards.

Although voting on standards potentially depends on the relative numbers of agents in various groups, the market effects of the relative numbers of agents enhance coordination within the standards organization. Because the efficient standard is chosen unanimously, it follows that the result is robust to whether any one or two, or all three groups participate in the standard-setting process. This suggests that even if a standards organization does not have representation by a particular industry group, it will have an incentive to choose the efficient standard because of market incentives.

Because voting is unanimous, the result is robust to relative majority, majority and super-majority voting. This helps explain why many standards organizations are
able to operate effectively with super-majority voting rules and appear to operate by consensus.

The result also helps to explain how standards organizations can operate effectively without representation by some industry groups. Because markets determine rent transfers, unanimity is preserved with only some industry groups in the organization. In addition, the result also suggests that industries with multiple organizations may choose the same standards. In practice, some standards organizations adopt or incorporate the standards of other organizations.

**PROPOSITION 2.** The market equilibrium output is efficient, \( q^0 = q^*(\varphi(s^*), \bar{q}) \). The equilibrium standard \( s^* \) maximizes the market equilibrium output \( q^*(\varphi(s), \bar{q}) \) and the total profits of distributors \( V(s, q^*(\varphi(s), \bar{q})) \), producers \( \Pi(s, q^*(\varphi(s), \bar{q})) \), and suppliers \( G(s, q^*(\varphi(s), \bar{q})) \) over the set of standards \( S \).

The results in Propositions 1 and 2 hold if two or more groups have the same number of members. For example, suppose that all three groups have the same total numbers, \( H = I = J = \bar{q} \). Let the bargaining power of distributors \( \alpha \), producers \( \beta \), and suppliers \( \gamma \) take values in the unit interval and \( \alpha + \beta + \gamma = 1 \). If the capacity constraint is binding, market equilibrium prices divide rents at the margin.\(^{10} \) Then, prices depend on the relative bargaining power of the economic agents,

\[
p(s) = (1 - \alpha)u_\bar{q}(s) + \alpha[c_\bar{q}(s) + k_\bar{q}(s)]. \tag{15}
\]

The market equilibrium input price is

\[
r(s) = (1 - \gamma)k_\bar{q}(s) + \gamma[u_\bar{q}(s) - c_\bar{q}(s)]. \tag{16}
\]

\(^{10}\)The market equilibrium is related to Bohm-Bawerk’s (1891, p. 213) method of marginal pairs. In his framework, the marginal agents determine the market-clearing price and quantity, that is, the buyer–seller pair who have the smallest positive difference between the buyer’s value and that of the seller, or by the marginal pair who are excluded from trade, see Spulber (2006) for additional discussion. Bohm-Bawerk’s (1891, p. 213) states "If all are to exchange at one market price, the price must be such as to suit all exchanging parties; and since, naturally, the price which suits the least capable contracting party suits, in a higher degree, all the more capable, it follows quite naturally, that the relations of the last pair whom the price must suit, or, as the case may be, the first pair whom it cannot suit, afford the standard for the height of the price."
Similar prices result if any two industry groups have the same number of members. These prices give expressions for profits, 
\[ \psi_j(s) = \gamma[\varphi(s) - \psi(q)] + \zeta(q) - \zeta(j), \]
\[ \pi_h(s) = \beta[\varphi(s) - \psi(q)] + \theta(q) - \theta(h), \] and 
\[ v_i(s) = \eta(q) - \eta(i) + \alpha[\varphi(s) - \psi(q)]. \] Notice that the expressions for profits depend on the incremental effects of the standard. It follows immediately that agents unanimously choose the efficient standard.

IV The technology standard with SEPs

This section extends to basic model to consider standard setting when inventors have patents that are essential for technologies that comply with the technology standard. The standards organization consists of inventors and industry groups, some or all of which may need to license patents from the inventors. In the first stage of the model, the members of a standards organization vote to choose a technology standard. In the second stage of the model, inventors with SEPs choose licensing royalties offered to technology adopters. Then, distributors, input suppliers and output producers apply the technology standard and compete in the market.

IV.1 The market equilibrium and efficiency with SEPs

Any or all groups of distributors, producers, or suppliers are technology adopters that pay licensing fees to inventors with SEPs that apply to a particular standard. With licensing royalties \( \rho^I(s), \rho^H(s), \) and \( \rho^J(s), \) the profits of producers, distributors, and suppliers are 
\[ \pi_h(s) = p(s) - r(s) - c_h(s) - \rho^H(s), \] 
\[ v_i(s) = u_i(s) - p(s) - \rho^I(s), \] and 
\[ g_j(s) = r(s) - k_j(s) - \rho^J(s). \] If the industry is not capacity constrained, market prices are given by

\[ u(s) - \eta(q) - \rho^I(s) = p(s) = c(s) + \theta(q) + r(s) + \rho^H(s), \] 
\[ r(s) = k(s) + \zeta(q) + \rho^J(s). \]
Note that a particular patent can only be licensed at one vertical level, but inventors can have multiple SEPs in their portfolios and different inventors may license their patents at different industry levels.

Because the costs of licensing to producers and suppliers are ultimately passed through to distributors, there is no need to distinguish between licensing fees for distributors, producers, or suppliers. So, let \( \rho_s = \rho^I(s) + \rho^H(s) + \rho^J(s) \) represent the total royalties per unit of final output for SEPs that are associated with a given standard \( s \). Total licensing royalties per unit of output determine industry output at the margin,

\[
\varphi(s) - \psi(q) = \rho_s. \tag{19}
\]

Inventors jointly choose royalties to maximize total licensing revenues, \( R = \rho q \). It is useful to study this problem as a choice of industry output,

\[
R(\varphi(s), q) = (\varphi(s) - \psi(q))q. \tag{20}
\]

Inventors choose total per-unit royalties subject to the industry capacity constraint, \( q \leq \bar{q} \). This constraint places a lower limit on total per-unit royalties, \( \rho_s \geq \varphi(s) - \psi(\bar{q}) \). The monopoly royalties need not be unique. We assume that inventors choose the lowest total royalties among the profit-maximizing royalties so as to generate the largest output.

Assume that the default technology standard is based on existing technologies that continue to be available after the new standard is chosen. Assume further that the default technology standard \( \bar{s} \) does not require SEPs or that there are no licensing costs for the necessary technologies. This standard corresponds to an alternative that limits royalties after the standard is chosen. Distributors, producers, and suppliers can use the existing technology so that unconstrained total market royalties cannot exceed the incremental benefits of the new standard. If \( \varphi(s) \geq \varphi(\bar{s}) \), inventors face a constraint on royalties reflecting improvements in the incremental effects of the standard, \( \rho_s \leq \varphi(s) - \varphi(\bar{s}) \).

Suppose that the SSO imposes an upper limit on inventors’ \textit{ex post} licensing royalties.
Contreras (2013) proposes that SSOs should establish ex ante royalty caps when choosing technology standards. The upper limit on licensing royalties also can be viewed as inventors making ex ante commitments through other mechanisms such as patent pools.

Let the SSO’s upper limit on royalties be based on a benchmark standard $s \in S$. The benchmark standard is better than the default standard, $\varphi(s) > \varphi(\bar{s})$, but is not available after the new standard is chosen. Let $\mu \in [0, 1]$ be a policy parameter that represents the strictness of SSO controls on royalties. If the SSO chooses the technology standard $s$, the upper limit $\bar{p}(s, \bar{s}, \mu)$ on total royalties is given by

$$\bar{p}(s, \bar{s}, \mu) = \mu[\varphi(s) - \varphi(\bar{s})] + (1 - \mu)[\varphi(s) - \varphi(\bar{s})].$$

(21)

If $\mu > 0$, the SSO restricts ex post bargaining based on a standard $\bar{s}$ that was available ex ante. If the SSO does not restrict ex post bargaining, then $\mu = 0$ and inventors are only constrained by default standard $\bar{s}$. The greater is the value of the policy parameter, the stricter is the SSO’s constraint on ex post royalties, $\frac{\partial \bar{p}(s, \bar{s}, \mu)}{\partial \mu} = \varphi(\bar{s}) - \varphi(\bar{s}) < 0$.

The upper limit on royalties can be recast as a lower limit on industry output. The constraint $\rho_s \leq \bar{p}(s, \bar{s}, \mu)$ is equivalent to $\bar{q}(\mu\varphi(\bar{s}) + (1 - \mu)\varphi(\bar{s})) \leq \bar{q}(\varphi(s) - \rho_s)$, where $\bar{q}(\varphi(s) - \rho_s)$ solves the market equilibrium condition $\varphi(s) - \rho_s = \psi(q)$. So, the output constraint is

$$q \geq q_\mu \equiv \bar{q}(\mu\varphi(\bar{s}) + (1 - \mu)\varphi(\bar{s})).$$

Note that the output constraint is increasing in $\mu$, $\frac{dq_\mu}{d\mu} = \bar{q}^'(\mu\varphi(\bar{s}) + (1 - \mu)\varphi(\bar{s}))[\varphi(\bar{s}) - \varphi(\bar{s})] > 0$. Suppose that the constraint is less than industry capacity, $q_\mu < \bar{q}$.

Given that the SSO has chosen a standard $s$, the inventors with SEPs that apply to that standard choose output to maximize licensing revenue $R(\varphi(s), q)$ subject to $q_\mu \leq q \leq \bar{q}$. The unconstrained monopoly output $\hat{q}^M(\varphi(s))$ solves

$$\varphi(s) - \psi(q) - \psi'(q)q = 0,$$

(22)

where the monopoly output is less than the competitive output, $\hat{q}^M(\varphi(s)) < \hat{q}(\varphi(s))$. 

23
Output and the incremental effects of the standard are complements, $\frac{\partial^2 R(\varphi(s), q)}{\partial q \partial \varphi(s)} = 1$. By standard monotone comparative statics arguments, the highest profit-maximizing monopoly output $\hat{q}^M(\varphi(s))$ is increasing in the incremental effects of the standard. The highest monopoly output is continuous because the incremental effects of output $\psi(q)$ is twice differentiable.

The inventors with SEPs applying to the standard choose industry output $q^M(\varphi(s), q_\mu, \overline{q}) = \hat{q}^M(\varphi(s))$ if the constraints are non-binding and $q^M(\varphi(s), q_\mu, \overline{q}) = q_\mu$ for sufficient low $\varphi(s)$ and $q^M(\varphi(s), q_\mu, \overline{q}) = \overline{q}$ for sufficiently high $\varphi(s)$. The equilibrium per-unit royalty can be written as a function of the incremental effects of the standard, $\rho_s = \rho(\varphi(s))$,

$$\rho(\varphi(s)) = \varphi(s) - \psi(q^M(\varphi(s), q_\mu, \overline{q})).$$ (23)

Total royalties can be written as a function of the incremental effects of the standard,

$$R^M(\varphi(s)) = \rho(\varphi(s))q^M(\varphi(s), q_\mu, \overline{q}).$$ (24)

To evaluate the efficient standard, it is necessary to consider second-best social welfare. We examine the technology standard that maximizes social welfare evaluated at the monopoly output,

$$w^M(\varphi(s)) \equiv W(\varphi(s), q^M(\varphi(s), q_\mu, \overline{q})).$$

The next result establishes that the first-best technology standard also maximizes second-best social welfare.

**PROPOSITION 3.** The first-best technology standard $s^*$ is the unique standard that maximizes monopoly revenue $R^M(\varphi(s))$ and maximizes social welfare evaluated at the monopoly output $w^M(\varphi(s))$.

---

11If the industry capacity constraint is not binding, the first order condition for the monopoly output implies that the equilibrium royalty equals

$$\rho(\varphi(s)) = \psi(q^M(\varphi(s), q_\mu, \overline{q}))q^M(\varphi(s), q_\mu, \overline{q}).$$
The proof also shows that $s^*$ also maximizes output $q^M(\varphi(s), q_\mu, \bar{q})$ over $S$ although other standards may generate the same output when the upper or lower constraint is binding.

IV.2 The equilibrium technology standard with SEPs

Suppose that inventors vote among themselves on the choice of standards. We will return to voting by producers, distributors, and suppliers shortly. In the absence of transfers among inventors, it is clear that inventors will only vote for those standards for which they own SEPs. It is easy to construct examples that rule out inventors choosing the efficient standard. For example, suppose that there are three inventors and two standards, $s^0$ and $s^{00}$. Inventor 1 has SEPs only for standard $s^0$ and inventors 2 and 3 have SEPs only for standard $s^{00}$. Then, a majority of inventors will always choose the standard $s^{00}$, whether or not it is efficient. If a majority of inventors own the efficient standard, say $s'$, so that $N(s') > \frac{1}{2}$, this rules out the possibility that the largest distinct group of inventors chooses the standard based only on whether or not they own SEPs for that standard.

Inventors face an interesting trade-off between the level of total licensing revenues and number of inventors sharing revenues. A more efficient standard may involve a greater number of owners. So more owners can increase total revenues and yet lower the revenue per inventor. This has important effects on voting. For example, suppose that there are seven inventors and two standards, $s'$ and $s''$. The standards generate revenues $R' = 110$ and $R'' = 100$, so that standard $s'$ is the efficient standard. Suppose further that three inventors have SEPs that cover only the standard $s'$, two inventors have SEPs that cover the standard $s''$, and two inventors owns SEPs that cover both standards. So that the revenue per inventor for $s'$ is 22 and the revenue per inventor for the standard $s''$ is 25. Then, three inventors will choose standard $s'$ and four inventors will choose standard $s''$. So, although a majority of inventors owns SEPs for the efficient standard, a majority of inventors will choose the inefficient standard $s''$ to obtain larger shares of lower revenues. Inventors choose the inefficient standard because of "defections" by two inventors that own SEPs that apply to the
efficient standard.\footnote{One way to rule out this situation is to assume that if $Y(s) \cap Y(s') \neq \emptyset$, then either $N(s) \leq \frac{N}{2}$ or $N(s) \geq N(s^*)$.} This situation is ruled out by the voting rule $\delta = \frac{N(s^*)}{Y}$ when a majority of inventors owns SEPs for the efficient standard.

Consider the choice of a technology standard by the group of inventors when the decision rule is $g(\delta; F_Y)$.

**Proposition 4.** If $\frac{N(s^*)}{Y} > \frac{1}{2}$ and $\delta = \frac{N(s^*)}{Y}$, then for all values of the policy parameter $\mu$, inventors choose $s^*$.

The intuition for this result is that inventors with patents that are SEPs for the efficient standard as well as a competing standard will not join a larger group of inventors to support the competing standard. The competing standard generates lower total revenues and the larger size of the group will lower average revenues. This result provides another interesting aspect of the trade-off between voting and market value. A larger group of inventors could support a less efficient standard but a less efficient standard offers lower average returns to that group.

There might be situations in which inventors would join a smaller group to support a less efficient standard because even though revenues are lower, the smaller size of the group would increase average revenues. This possibility is blocked by the supra-majority voting rule.

Inventors' choice of the efficient standard is not affected by the policy parameter $\mu$ restricting royalties. This is because royalties per unit reflect improvements in the incremental effects of the standard that result from more efficient standards. When the upper or lower output constraint is binding, royalties vary exactly with the incremental effects of the standard because $\rho(\varphi(s)) = \varphi(s) - \psi(q^M(\varphi(s), q_\mu, \bar{q}))$. So, if either output constraint is binding, licensing revenues vary with incremental effects of the standard, $\rho'(\varphi(s)) = 1$. If neither output constraint is binding, royalties may only partly reflect the effects of the standard,

$$\rho'(\varphi(s)) = 1 - \psi'(q^M(\varphi(s), q_\mu, \bar{q})) \frac{d\tilde{q}^M(\varphi(s))}{d\varphi(s)} \leq 1.$$
The following result holds whether or not inventors are members of the SSO. It can be the case that owners of SEPs are not participants in the SSO, including individual inventors, universities, and firms that have exited the market (Contreras, 2016). Inventors that are not participants are not subject to SSO constraints on patent licensing so the constraint would not apply to their patents. The following result also applies when owners of SEPs are participants in the SSO because it describes how technology adopters vote when there are SEPs. The result shows that whether or not SEP owners are not participants, adopters choose the efficient standard unanimously.

**PROPOSITION 5.** When inventors have SEPs, for any sizes \( H, I, J \) of the industry groups, any number of standards \( T \), any membership set \( F \in \Lambda \), any number of inventors with SEPs \( Y \), any decision rule \( \delta \), and for all values of the policy parameter \( \mu \), the members of the standards organization unanimously choose the efficient standard \( s^0 = s^* \).

The intuition for this result is as follows. If the industry capacity constraint is binding for all standards, agents are indifferent across standards and the marginal agents are unaffected by the standard, so agents are indifferent across standards and choose \( s^* \). If the policy constraint is binding across standards, then again agents are indifferent and choose \( s^* \). If neither capacity constraint is binding across standards, then more agents have positive profits with the efficient standard, so all agents choose \( s^* \). Finally, the industry capacity and policy constraints are binding for some standards but nonbinding for other standards, it follows that the policy constraint cannot be binding at the efficient standard. This holds because unrestricted output is increasing in the incremental effects of the standard. By increasing output, the efficient standard increases the number of agents with positive profits, so all agents choose \( s^* \).

We can further characterize the effects of the standard on output and profits.

**PROPOSITION 6.** The market equilibrium output is greater than or equal to that with other standards, \( q^M(\varphi(s^*), q_\mu, \overline{q}) \geq q^M(\varphi(s), q_\mu, \overline{q}), s \neq s^* \). The equilibrium standard \( s^* \) maximizes the total profits of distributors \( V(s, q^M(\varphi(s), q_\mu, \overline{q})) \), producers
\( \Pi(s, q^M(\varphi(s), q_\mu, \bar{q})), \) and suppliers \( G(s, q^M(\varphi(s), q_\mu, \bar{q})) \) over the set of standards \( S \).

Now consider a mixed standards organization that consists of both inventors and technology adopters. Because adopters of inventions unanimously prefer the efficient standard, but inventors prefer standards that depend on their inventions, there are incentives for as many adopters as possible to form an SSO.

Suppose that adopters outnumber inventors with SEPs for the efficient standard \( Y(s^*) \) and inventors who do not have SEPs for the efficient standard, \( H + I + J \geq \max\{N(s^*), Y - N(s^*)\} \). This rules out dominance in voting by a group of inventors with SEPs for an inefficient standard but not for the efficient standard. From the proof of Proposition 4, none of the \( N(s^*) \) inventors will defect to a larger group of inventors because that would reduce average earnings. Also, none of the \( N(s^*) \) inventors will defect to a smaller group of inventors because they would be outvoted by adopters. This implies that all of the \( N(s^*) \) inventors will vote for the efficient standard. So, the SSO that contains all adopters and inventors attains the efficient standard is consistent with the following voting rule,

\[
\delta = \frac{H + I + J + N(s^*)}{H + I + J + Y}.
\]

This voting rule approaches a consensus.

### IV.3 Drastic versus nondrastic innovations

We can interpret the SSO’s policy constraint in terms of the extent of the innovation associated each standard. The standards organization compares the innovation given by the efficient standard \( \varphi(s^*) \) with the incremental effects \( \varphi(\bar{s}) \) of a benchmark standard \( \bar{s} \). Let the standards organization apply its tightest constraint on royalties, \( \mu = 1 \), so the policy benchmark is the greatest minimum output level, \( q_\mu = \tilde{q}(\varphi(\bar{s})) \).

It is useful to extend Arrow’s (1962) terminology for individual inventions to the innovation represented by a standard \( s \). Define the innovation \( \varphi(s) \) as a drastic innovation if the tightest output constraint is nonbinding, \( \tilde{q}^M(\varphi(s)) \geq \tilde{q}(\varphi(\bar{s})) \), and
a nondrastic innovation if the tightest output constraint is binding, \( \hat{q}^M(\varphi(s)) < \hat{q}(\varphi(\overline{s})) \). When the innovation is drastic, the lower output constraint is nonbinding for any value of \( \mu \), so the policy parameter does not affect equilibrium royalties per unit of output nor does it affect equilibrium output.

When the innovation is non-drastic and the lower output constraint is binding, an increase in the policy parameter \( \mu \) decreases royalties per unit of output, \( \frac{d\varphi(\varphi(s))}{d\mu} = -\psi'(q_\mu) \frac{dq_\mu}{d\mu} < 0 \). Because the unconstrained output maximizes \( R(\varphi(s), q) \), it follows that when the innovation is nondrastic and the lower output constraint is binding, an increase in \( \mu \) decreases total licensing revenue for inventors. Also, when the innovation is nondrastic and the lower output constraint is binding, agent profits are \( \pi_h(s) = \theta(q_\mu) - \theta(h) \), \( v_i(s) = \eta(q_\mu) - \eta(i) \), and \( g_j(s) = \zeta(q_\mu) - \zeta(j) \). So, total distributor profits are increasing in \( \mu \).

\[
\frac{d}{d\mu} \int_0^{q_\mu} v_i(s) \, ds = \eta'(q_\mu) q_\mu \frac{dq_\mu}{d\mu} > 0,
\]

and similarly for producers and suppliers.

This implies that for drastic innovations, that is \( \hat{q}^M(\varphi(s)) \geq \hat{q}(\varphi(\overline{s})) \), the lower output constraint is not binding for any \( \mu \). So, members of the standards organization are indifferent about restrictions on ex post bargaining and distributors, producers or suppliers do not have an incentive to increase the policy parameter \( \mu \). Conversely, for nondrastic innovations, \( \hat{q}^M(\varphi(s)) < \hat{q}(\varphi(\overline{s})) \), the members of the standards organization are concerned about the effects of the policy parameter. All other considerations aside, distributors, producers and suppliers have an incentive to increase the policy parameter until it equals one and conversely inventors have an incentive to decrease the policy parameter until it equals zero or until the constraint is no longer binding.

This implies that tighter price regulation by the SSO increases social welfare if and only if the lower output constraint is binding at the efficient standard.

**PROPOSITION 7.** Second-best social welfare is increasing in the policy parameter,

\[
\frac{dw^M(\varphi(s^*))}{d\mu} > 0,
\]
if and only if $\widehat{q}^M(\varphi(s^*)) < \widehat{q}(\mu\varphi(\bar{s}) + (1 - \mu)\varphi(\bar{s}))$.

This effect is possible only if the efficient standard is a nondrastic innovation and inventors with SEPs for the efficient standard have sufficient market power. This may help explain variation in the IP rules of standards organizations, with SSOs in some industries focusing more on restricting ex post royalties as compared to other industries. When industries have incremental innovations, there may be a greater desire by distributors, producers, and suppliers to limit ex post royalties than when innovations are proceeding by leaps and bounds.

The result also helps explain variation across industries in participation in standards organizations. In industries with incremental innovations, there is a greater need for participation by many industry groups to counterbalance inventors. However, with sufficiently dynamic technological change, the standards organization can contain a greater number of inventors.

The result also suggests that the mission and the membership of standards organizations can change over time. In some industries, more significant technological changes occur in the early stages of industry development than in more mature stages. As a consequence, we may observe that in the early stages of industry development, inventors and early adopters dominate standards organizations. In later stages of industry development, greater numbers of distributors, producers, and suppliers participate in the standards organizations. Greater participation of technology adopters in the standards organizations over time is consistent with a desire to regulate licensing royalties as the pace of innovation diminishes.

The participation of inventors and early adopters in the initial stages of industry development is also likely to reflect the composition of the market. There are likely to be fewer distributors, producers and suppliers in the market in the early stages of industry development. Over time, innovation stimulates industry growth and more distributors, producers and suppliers enter the market and then begin to participate in standards organizations. This suggests that in the initial stages of industry growth, inventors and early adopters may battle over the direction of technological change. Licensing royalties will be less important because of the beneficial effects of
drastic innovations. In the later stages of industry growth, the focus of standards organizations may shift to licensing royalties, reflecting the effects of both market composition and the rate of technological change.

V Technology standards with disagreement among and within industry groups

The basic framework studied thus far demonstrates that market equilibrium prices are sufficient to align the interests of distributors, producers, and suppliers. The alignment of interests was observed both with market competition and with monopoly when inventors have SEPs. The market may not align interests as effectively when there is disagreement within industry groups about the effects of a standard.

To represent disagreements within the group of distributors, partition the set of standards $S$ into two nonempty sets $\{S_A, S_B\}$. For standards in $S_A$, preferences of distributors are represented as before, with low types receiving the greatest benefits,

$$u_i(s_A) = u(s_A) - \eta(i), \quad i \in [0, I].$$

However, for standards in $S_B$, the preferences of distributors are opposite those for standards in $S_A$, with high types receiving the greatest benefits,

$$u_i(s_B) = u(s_B) - \eta(I - i), \quad i \in [0, I].$$

If the market equilibrium output is $q$, active distributors for standard $s_A$ are $i \in [0, q]$ and active distributors for standard $s_B$ are $i \in [I - q, I]$.

Let disagreements within the group of producers and within the group of suppliers be represented in the same way. The partitions of the set of standards can differ among the three groups. Disagreements within groups about standards do not affect the market outcome considered in a previous section. The market equilibrium outputs and prices will remain the same as in Section II. The welfare measure and
other notation remain the same. So, the only affect of disagreements within groups is on voting for standards.

The efficient standard generates an innovation with quality \( \varphi(s^*) \). The next proposition shows that we can write the number of votes for the efficient standard as a function of the incremental effects of the standard, \( H(\varphi(s^*)) \), \( I(\varphi(s^*)) \), and \( J(\varphi(s^*)) \). This allows us to define a voting rule \( \delta(\varphi(s^*); F) \) as a function of the incremental effects of the standard for any \( F \in \Lambda \). For example, if all three groups are members of the SSO, let the voting rule equal

\[
\delta(\varphi(s^*); F_{HIJ}) = \frac{H(\varphi(s^*)) + I(\varphi(s^*)) + J(\varphi(s^*))}{H + I + J}.
\] (25)

Proposition 8 shows that the voting rule parameter increases with the quality of the innovation. The following result holds whether or not inventors with SEPs are members of the SSO.

**PROPOSITION 8.** Without SEPs, for any sizes \( H, I, J \) of the industry groups, any number of standards \( S \), any membership set \( F \in \Lambda \), any number of standards \( T \), and disagreement within each industry group, the members of the standards organization choose the efficient standard \( s^0 = s^* \) by majority rule, \( \delta(\varphi(s^*); F) \geq \frac{1}{2} \). The number of votes for the efficient standard, \( H(\varphi(s^*)) \), \( I(\varphi(s^*)) \), and \( J(\varphi(s^*)) \), and the voting rule \( \delta(\varphi(s^*); F) \) are nondecreasing in the incremental effects of the standard.

Because a majority of each group favors the efficient standard, it follows that a majority of members of an SSO composed of any set \( F \in \Lambda \) will also favor the efficient standard. The proof is based on the fact that output is greater at the efficient standard than with other standards. The intuition of the proof is as follows. Consider first the set of distributors. The efficient standard is in one of the sets in the partition, say \( s^* \in S_A \). Then, distributors will unanimously prefer \( s^* \) over other standards in \( S_A \). Now compare the efficient standard with a standard in \( S_B \). If active distributors for the two standards are distinct groups, and some distributors are inactive for both standards, the indifferent distributors vote for the efficient standard. Because the efficient standard increases output, a greater number of distributors are active under the efficient standard, and combined with the indifferent distributors, a majority of
distributors vote for the efficient standard. Conversely, if active distributors for the two standards are not distinct groups, there must exist a distributor that is indifferent between the two standards. Because the efficient standard increases output, there must be a majority of distributors that prefers the efficient standard, $I^{(\varphi(s^*))}/I \geq \frac{1}{2}$. The same result holds for producers and for suppliers.

The proof of Proposition 8 shows that a tie very rarely occurs within any group. A tie requires several conditions to be satisfied simultaneously: the market is capacity constrained for both standards, distributors are not in the scarce category of agents, and the groups of active distributors for the two standards overlap with each other. A tie cannot occur when all groups are included.

Propositions 1 and 8 help explain why different standards organizations have different voting rules. Suppose that all three industry groups are members of the SSO. When there is agreement on ranking standards within all three industry groups, a near-consensus voting rule can be implemented, as shown by Proposition 1. When there are disagreements within all three groups, a majority voting rule can be implemented. The greater is the extent of the innovation, the more likely it is that the SSO can adopt supra-majority voting rule.

In addition, when only one or two groups have disagreements, other voting rules between the majority and near-consensus levels may be sufficient to achieve an efficient outcome. Suppose for example that distributors are the only group with internal disagreements, so $I^{(\varphi(s^*))}/I \geq \frac{1}{2}$. Producers and suppliers choose the efficient standard unanimously by Proposition 1. So, an SSO composed of all three industry groups chooses the efficient standard with a voting rule given by

$$\delta = \frac{H + I(\varphi(s^*)) + J}{H + I + J} \geq \frac{2H + I + 2J}{2(H + I + J)}.$$  

If the three groups are about the same size, this implies that the voting rule is $\delta \geq 5/6$.

Consider now the outcome with SEPs when there are disagreements within industry groups. We can write the number of votes for the efficient standard as a function of the incremental effects of the standard, $H^M(\varphi(s^*))$, $I^M(\varphi(s^*))$, and
This allows us to define a voting rule $\delta^M(\varphi(s^*); F)$ as a function of the incremental effects of the standard for any $F \in \Lambda$.

**PROPOSITION 9.** When inventors have SEPs, for any sizes $H$, $I$, $J$ of the industry groups, any number of standards $S$, any membership set $F \in \Lambda$, any number of standards $T$, and disagreement within each industry group, the members of the standards organization choose the efficient standard $s^0 = s^*$ by majority rule, $\delta^M(\varphi(s^*); F) \geq \frac{1}{2}$. The number of votes for the efficient standard, $H^M(\varphi(s^*))$, $I^M(\varphi(s^*))$, and $J^M(\varphi(s^*))$, and the voting rule $\delta^M(\varphi(s^*); F)$ are nondecreasing in the incremental effects of the standard.

The intuition for the proof of Proposition 9 is the same as that for Proposition 8. When inventors have SEPs, output is still increasing in the incremental contribution of the standard. This implies that a majority of the members of any group will vote for the efficient standard. This further implies that the more significant is the innovation $\varphi(s^*)$, the closer is the voting rule to a consensus.

Consider a mixed standards organization that consists of both inventors and technology adopters. Suppose that adopters outnumber inventors with SEPs for the efficient standard $s^*$ and inventors who do not have SEPs for the efficient standard, $H(\varphi(s^*)) + I(\varphi(s^*)) + J(\varphi(s^*)) \geq \max\{N(s^*), N - N(s^*)\}$. So, the SSO that contains all adopters and inventors attains the efficient standard is consistent with the following voting rule,

$$
\delta(\varphi(s^*)) = \frac{H(\varphi(s^*)) + I(\varphi(s^*)) + J(\varphi(s^*)) + N(s^*)}{H + I + J + Y}.
$$

If a majority of inventors has SEPs for the efficient standard, $\frac{N(s^*)}{Y} > \frac{1}{2}$. Because a majority of adopters votes for the efficient standard, it follows that $\delta(\varphi(s^*)) > \frac{1}{2}$. This rules implies that in an SSO with inventors and disagreements among adopters, the more significant is the innovation $\varphi(s^*)$, the closer is the voting rule to a consensus.

The main problem with disagreements within groups is that the market equilibrium need not provide ex post transfers that induce consensus. However, in this case it is also possible for alliances to form. In particular, agents that are high-cost under
one standard and low-cost under another standard can form alliances with those agents that have the opposite situation. For example, distributors with opposite preferences across standards can form alliances. The alliances involves contractual transfers among members of the group, including mergers, acquisitions, industry consortia, technology sharing, and subcontracting production or distribution. Companies form alliances to develop technology and to sponsor standards in SSOs (Axelrod et al., 1995).

Alliances can form ex ante and determine transfers contingent on the outcome of standard setting. Such alliances serves to align preferences and coordinate voting in the standards organization. So, alliances with transfers would allow the standards organization to implement near-consensus voting rules even with disagreements. So, the evolution of the industry and agreements among industry participants affect the formation and rules of SSOs.

Conversely, the rules of SSOs could affect market agreements within industry groups. If standards organizations choose consensus rules and diverse agents later enter the industry, the rules may generate incentives for some agents to form alliances as means of addressing the voting requirements.

VI Discussion

Because the efficiency of standards often cannot be observed directly, theoretical analysis of standard setting becomes all the more necessary. This section considers some empirical implications of the analysis. The discussion briefly examines some public policy aspects of technology standards.

VI.1 Empirical implications

The present analysis has a number of empirical implications. One set of implications is based on the significance of the quality of the innovation $\varphi(s)$ embodied in the standard $s$. The analysis shows that the greater is the innovation, the larger will
be downstream output. This suggests that adoption of significant standards and substantial revisions in standards should promote increased industry output growth and reduced prices of products based on the standard. The analysis finds that greater innovations embodied in standards increase the profits of distributors, producers, or suppliers. In practice, adoption of significant standards and substantial revisions in standards may translate into the growth of the industry either in the form of expansion of existing firms in the industry or perhaps instead the entry of new firms accompanied by creative destruction.

The analysis of innovation embodied in the standard $\varphi(s)$ also suggests that when new industries form and drastic innovations occur, SSOs need not be as concerned with rules that regulate licensing revenues after standards are established. As the industry develops and incremental innovation are observed, SSOs will be more concerned with regulating licensing revenues. This further suggests that the SSO will reflect the interests of inventors and early adopters in the initial stages and will involve greater participation from distributors, producers and suppliers over time.

The analysis further suggests that more homogeneity within industry groups will be associated with consensus voting rules and less homogeneity will be associated with majority voting rules. Alternatively, the result of disagreements within industry groups may be the formation of multiple SSOs, and perhaps consolidation of SSOs as industry groups become more homogeneous. The discussion suggests that diversity of membership can help increase efficiency of standards, particularly when there are disagreements within industry groups.

The efficiency of technology standards can be tested by considering the standard setting process itself. Baron and Spulber (2015) provide a data set that considers the membership and rules of SSOs and the development and revision of standards over time. Tsai and Wright (2015) consider SSO IP policies and find that changes over time are consistent with a competitive contracting process and diversity of technology adopters and contributors to the standard.

It is difficult to evaluate directly whether or not technology standards are efficient in practice.\textsuperscript{13} To determine whether technology standards are efficient in comparison

\textsuperscript{13}The reason is analogous to the evaluating the efficiency predictions of neoclassical models of
to other potential standards, it would be necessary to consider all of the alternatives, which may not be observable or fully developed. Even if the alternatives can be observed, technology standards often are highly complex because they involve specifications covering a wide range of technologies. Technology standards also address interoperability of technologies, which can involve an extremely large number of potential interactions. The technologies embodied in standards often develop at the same time as the standards, and there is interaction between standard setting and invention (Spulber, 2013). Finally, the proof of the pudding is in the eating, the efficiency of technology standards ultimately depend on how they affect market outcomes. It is unlikely that the effects of standards on market outcomes can be directly observed, and certainly the effects of alternative standards that were not chosen by the SSO will not be observed.

The question of whether or not standards are efficient can be tested indirectly by studying the economic effects of standards. Rysman and Simcoe (2008) examine the efficiency of standards by considering patents disclosed to four major SSOs (ANSI, IEEE, IETF, and ITU) and find that disclosure increases citations and shifts citations toward later years. Rysman and Simcoe (2008, p. 1932) find that SSOs "perform well in selecting important technologies" and, if patents citations indicate a causal relationship, their results suggest that SSO endorsements contribute to technology adoption.

The choice of efficient standards by SSOs suggests that companies will send engineers and other technical personnel as representatives to SSO meetings. This is in part because these specialized individuals can understand and contribute to the discussion of potential standards in highly technical committees that work on the details of technology standards. However, delegation to specialized technical representatives occurs because the focus of the discussions will be the choice of the best

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competitive markets. Neoclassical analysis predicts that market equilibria will be Pareto optimal. In practice, it is usually not possible to directly observe how individuals rank market allocations, particularly in comparison to allocations that have not happened. However, it is possible to observe whether some of the predictions of market models are consistent with competitive market equilibria. For example, we observe some relationships between prices, outputs, and costs and we observe variations across markets and changes over time. This allows tests of the predictions of competitive market models.
technologies. This can be confirmed empirically by examining the areas of expertise of company representatives.

VI.2 Public policy

Antitrust authorities and other public policy makers are concerned that some industry groups will dominate standards organizations. Such industry groups could include distributors, producers, input suppliers or inventors. The results presented here provide sufficient conditions under which voting on standards by SSOs selects the most efficient standard.

One concern is that SSOs will choose inefficient technology standards that confer market power on some industry groups, see Weiss and Sirbu (1990), Axelrod et al. (1995), Teece and Sherry (2003), and Lerner and Tirole (2015). Teece and Sherry (2003) argue that SSOs could choose inefficient technology standards because adopters seek to avoid royalties, SSO rules favor adopters over inventors, and engineers making decisions are biased against technologies protected by IP. Conversely, others argue that technology standards will be inefficient because owners of SEPs seek those standards that increase their patent licensing revenues. Simcoe et al. (2009) discuss market power effects of standards, suggesting that smaller firms that own IP face a trade-off between opening a standard to encourage technology adoption and closing a standard to create monopoly rents, whereas larger firms prefer with market power downstream favor greater competition upstream in technology markets.

The present analysis suggests that even with SEPs, technology adopters will choose efficient standards. Even if inventors with SEPs extract monopoly rents, adopters are either indifferent or better off in comparison with other standards. The same reasoning applies if royalties are constrained by low-cost alternative technologies or by royalty constraints imposed by SSO rules.

A related policy concern is that if some industry group dominates the standards organization, it will seek standards that give them a competitive advantage in the marketplace. Then, technology standards would distort outputs and prices in favor of distributors, producers, or input suppliers. Bar and Leiponen (2014) find that
standards affect competition in communication and information technology (CIT) industries. Schmidt (2014) considers the complementarity of SEPs and compares the effects of vertical and horizontal integration. Technology standards would increase the prices of licenses of SEPs and distort the market equilibrium after standards are established (Lerner and Tirole, 2015). On the concerns that industry members will use cooperative agreements to raise prices, thereby reducing economic welfare see FTC and U.S. DOJ (2000) and FTC (2011, p. 192).

Standards organizations have different policies and rules regarding the disclosure of IP by their members and licensing of IP after standards are chosen. Some SSOs require owners of SEPs to license their technologies on terms that are Fair, Reasonable, and Non-Discriminatory (FRAND), see Geradin and Rato (2007), Epstein and Kappos (2013), Contreras (2013), and Sidak (2013, 2015). FRAND commitments may address market power concerns, see Chiao et al. (2007), Epstein and Kappos (2013), Carlton and Shampine (2013). Layne-Farrar et al. (2007) consider allocating returns among owners of SEPs using the Shapley value.

The present analysis finds that industry members may be concerns with incremental inventions that generate monopoly rents and may seek commitments to lower royalties. If the efficient standard represents a drastic innovation, it generates monopoly royalties that are not limited by the tightest royalty constraint. With drastic innovation, the welfare gains from technological improvements outweigh the effects of higher royalties. The efficient technology generates an innovation that increases the profits of adopters.

Monopoly rents for inventors represents a worst case scenario. In practice, there often are competitive alternatives for the inventions that make satisfy the standard. Also, there may be multiple substitute inventions because inventors simply declare their inventions to be SEPs, even though adopters can satisfy the standard with alternative inventions. In addition, continual technological change makes technologies obsolete, reducing or eliminating royalties for SEPs. Also, in practice, there are competing standards and competing SSOs. Adopters also have complementary assets that are necessary to implement innovations and further limit the returns to SEPs. Spulber (2013) discusses some implications of the interaction between technology
standards, market conduct, and economic performance.

The analysis considers the efficiency of standards for a given organization that contains subsets of members of an industry. Many industries have multiple standards organizations, with entry and exit of organizations in response to changes in technology and market conditions. Standards organization may compete with each other to provide standardization services to their members, so there may be excessive or insufficient standardization. This raises the question of whether standards organizations are efficient in terms of the numbers of participants and the numbers of organizations within an industry. To answer this question requires consideration of how the formation of cooperative standards organizations interacts with market competition among members of the industry.

The present analysis shows that technology standards satisfy static efficiency for a given set of potential technologies. Technology standards affect dynamic efficiency because they affect incentives for invention and innovation. Companies invent in anticipation of technology standards and technology standards depend on invention, so standard setting and invention are interconnected (Spulber, 2013). Additional research is needed to examine whether the choice of technology standards by SSOs generates efficient investment in invention and innovation.

VII Conclusion

The combination of voting on standards and market competition generates efficient standard setting. The choice of technology standards by SSOs depends on interactions between voting power and market power. In a competitive market, the long side of the market has greater voting power but competes away economic rents at the margin, and the opposite is the case for the short side of the market. The countervailing effects of the size of groups of economic agents in cooperative organizations and competitive markets generate efficient standards.

In a competitive market, the analysis suggests that standards are invariant to changes in industry structure. This means that standards will tend to be stable even
with entry, exit, mergers and other market structure developments. The transaction costs of industry coordination and the costs of revising or replacing standards should further reinforce stability in standards. In addition, the organizational costs of implementing new standards in new products and production processes will tend to promote stability of standards. These forces help explain the stability of standards during periods of significant change in industry structure. Although standards are steadily revised and replaced with new generations, these changes may be less frequent than changes in market conditions.

The discussion helps explain the variation of voting rules among SSOs, ranging from majority rule to consensus requirements. When the main disagreements are among industry groups and there are no SEPs, SSO members unanimously prefer technology standards. This is because ex post transfers in competitive markets are sufficient to generate efficient standards. When there are disagreements both within and among industry groups and there are no SEPs, a majority of SSO members prefer efficient standards. This is because there are more active market participants with the efficient standard than with other standards, so that a majority of industry members prefer the efficient standard.

Even in the extreme case in which inventors capture monopoly rents, the analysis showed that SSOs choose the efficient standard. When inventors share monopoly rents, they have incentives to avoid larger coalitions that support inefficient standards. Although inventors may have incentives to support smaller coalitions to support inefficient standards, voting rules limit this outcome. In addition, the participation of adopters in SSOs tends to dilute inefficient choices by inventors. When standards generate incremental inventions, voting by technology adopters in SSOs and voting rules help achieve efficient standards. When standards generate drastic innovations, there is no need to restrict ex post royalties because the benefits of the efficient standard outweigh the lower costs of inefficient standards.

Industry growth and development often involves both entry of technology adopters in the market and participation of industry members in SSOs. In this way, greater competition in the market accompanies increased interaction within cooperative standards organizations. Technology standards will be efficient when SSO
decision making reflects the countervailing effects of voting power and market power.

VIII Appendix

PROOF OF PROPOSITION 1. Suppose first that market equilibria are not capacity constrained for any $s \in S$. Then, the marginal producer, distributor, and supplier have zero profits for all $s \in S$ and are indifferent. Inframarginal producers have profits $\pi_h(s) = \theta(\hat{q}(\varphi(s))) - \theta(h)$. Inframarginal distributors have profits $\nu_i(s) = \eta(\hat{q}(\varphi(s))) - \eta(i)$. Inframarginal suppliers have profits $g_j(s) = \zeta(\hat{q}(\varphi(s))) - \zeta(j)$.

Because $\hat{q}(\varphi(s))$, $\psi(\varphi(s))$, and $\theta(s)$ are increasing and $\hat{q}(\varphi(s))$ is increasing in $\varphi(s)$, all inframarginal agents prefer $s^*$ to all other $s \in S$ and so choose $s^*$.

Next suppose that market equilibria are capacity constrained for all $s \in S$. (i) Let distributors be in the scarce category, $\hat{q} = I < \min\{H, J\}$. All distributors have positive profits $\nu_i(s) = \varphi(s) - \psi(\hat{q}) + \eta(I) - \eta(i)$ and so strictly prefer $s^*$ to all other $s \in S$. Producers have profits $\pi_h(s) = \theta(\hat{q}) - \theta(h)$ and are indifferent across standards. Suppliers have profits $g_j(s) = \zeta(q) - \zeta(j)$ and are indifferent across standards. So, all agents choose $s^*$. (ii) Let producers be in the scarce category, $\hat{q} = H < \min\{I, J\}$. Producers have positive profits $\pi_h(s) = \varphi(s) - \psi(\hat{q}) + \theta(\hat{q}) - \theta(h)$. Distributors and suppliers are indifferent across standards. So, all agents choose $s^*$. (iii) Let suppliers be in the scarce category, $\hat{q} = J < \min\{H, I\}$. Suppliers have positive profits $g_j(s) = \varphi(s) - \psi(\hat{q}) + \zeta(\hat{q}) - \zeta(j)$. Producers and distributors are indifferent across standards. So, all agents choose $s^*$.

Finally, suppose that market equilibria are capacity constrained for all $s \in \overline{S}$ and not capacity constrained for $s \in \hat{S}$, where $\overline{S} \cup \hat{S} = S$ and $\overline{S} \cap \hat{S} = \emptyset$. Then, because $\hat{q}(\varphi(s))$ is increasing in $\varphi(s)$ it follows that $s^* \in \overline{S}$. So, if restricted to standards in $\overline{S}$, all agents would choose $s^*$, as already shown. Now, choose any standard $s' \in \hat{S}$. Then, given $s'$, the marginal producer, distributor, and supplier have zero profits. Note that $\varphi(s^*) > \varphi(s')$ and

$$q^*(\varphi(s'), \overline{q}) = \hat{q}(\varphi(s')) < \overline{q} = q^*(\varphi(s^*), \overline{q}).$$
This implies that $v_i(s') < 0 \leq v_i(s^*)$, $\pi_h(s') < 0 \leq \pi_h(s^*)$, and $g_j(s') < 0 \leq g_j(s^*)$ for all agents with types $h$, $i$ or $j$ in the set $(\hat{q}(\varphi(s'))\), \hat{q}]$, so those agents prefer $s^*$ to $s'$. Agents with types $h$, $i$ or $j$ greater than $\hat{q}$ are indifferent and choose $s^*$. Consider agents with types $h$, $i$ or $j$ less than $\hat{q}(\varphi(s'))$. Consider first $\hat{q} = I < \min\{H, J\}$, so that the market equilibrium is of type (i). Because $\bar{q} = q^*(\varphi(s^*), \hat{q})$ it follows that $\hat{q}(\varphi(s^*)) \geq \bar{q}$ and so $\varphi(s^*) = \psi(\hat{q}(\varphi(s^*))) \geq \psi(\bar{q})$. For distributors with type $i$ less than $\hat{q}(\varphi(s'))$, this implies

$$v_i(s^*) = \varphi(s^*) - \psi(\bar{q}) + \eta(I) - \eta(i).$$

It follows that $v_i(s^*) > \eta(I) - \eta(i)$. Also, because $\hat{q}(\varphi(s')) < \bar{q} = I$, we have

$$\eta(I) - \eta(i) > \eta(\hat{q}(\varphi(s')))) - \eta(i) = v_i(s').$$

So, $v_i(s^*) > v_i(s')$ for all $i$ less than $\hat{q}(\varphi(s'))$, so those distributors choose $s^*$. For producers with type $h$ less than $\hat{q}(\varphi(s'))$, profits with standard $s'$ equal $\pi_h(s') = \theta(\hat{q}(\varphi(s'))) - \theta(h)$ and profits with standard $s^*$ equal $\pi_h(s^*) = \theta(\bar{q}) - \theta(h)$. So, $\hat{q}(\varphi(s')) < \bar{q}$ implies that $\pi_h(s^*) > \pi_h(s')$, so those producers choose $s^*$. For suppliers with type $j$ less than $\hat{q}(\varphi(s'))$, profits with standard $s'$ equal $g_j(s') = \zeta(\hat{q}(\varphi(s)))-\zeta(j)$, and profits with standard $s^*$ equal $g_j(s^*) = \zeta(\bar{q}) - \zeta(j)$. So, $\hat{q}(\varphi(s')) < \bar{q}$ implies that $g_j(s^*) > g_j(s')$, so those suppliers choose $s^*$. So, all distributors, producers, and buyers choose $s^* \in S$. The same analysis applies for market equilibrium (ii), $\bar{q} = H < \min\{I, J\}$, and for market equilibrium (iii), $\bar{q} = J < \min\{H, I\}$. So, agents unanimously choose $s^*$.

Suppose now that the members of the standards organization include any two groups or only one group. Then, by unanimity, it follows that the members of the standards organization unanimously choose $s^*$ for all $F \in \Lambda$. Also by unanimity, the result holds for any decision rule $\delta$. \(\square\)

**PROOF OF PROPOSITION 2.** Because $\varphi(s^*) > \varphi(s)$, we have $q^*(\varphi(s^*), \bar{q}) \geq q^*(\varphi(s), \bar{q})$, This also implies that the equilibrium standard maximizes distributor
The marginal effects of the standard on second-best welfare equal

\[ \int_0^{q^*(\varphi(s), \overline{q})} v_i(s') di \geq \int_0^{q^*(\varphi(s), \overline{q})} v_i(s') di \geq \int_0^{q^*(\varphi(s), \overline{q})} v_i(s') di. \]

The same holds for producers and suppliers. □

**PROOF OF PROPOSITION 3.** Because \( \varphi(s^*) > \varphi(s) \) for all \( s \in S - s^* \), it follows that \( \overline{q}^M(\varphi(s^*)) > \overline{q}^M(\varphi(s^*)) \). So, if the upper and lower constraints are not binding at \( \varphi(s^*) \), monopoly output is maximized at \( \varphi(s^*) \). If the upper-constraint is binding at \( \varphi(s^*) \), \( q^M(\varphi(s^*), q_\mu, \overline{q}) = \overline{q} \) is the maximum output. If the lower-constraint is binding at \( \varphi(s^*) \), it is also binding for all \( \varphi(s) \) so that \( q^M(\varphi(s^*), q_\mu, \overline{q}) = q_\mu \) is the maximum output. So, if \( s^* \) maximizes \( \varphi(s) \) it also maximizes \( q^M(\varphi(s), q_\mu, \overline{q}) \).

Given the monopoly output level, we can write social welfare as a function of the incremental effects of the standard,

\[ w^M(\varphi(s)) = \varphi(s)q^M(\varphi(s), q_\mu, \overline{q}) - \int_0^{q^M(\varphi(s), q_\mu, \overline{q})} \psi(x)dx. \tag{26} \]

The marginal effects of the standard on second-best welfare equal

\[ \frac{dw^M(\varphi(s))}{d\varphi(s)} = q^M(\varphi(s), q_\mu, \overline{q}) + [\varphi(s) - \psi(q^M(\varphi(s), q_\mu, \overline{q}))] \frac{dq^M(\varphi(s), q_\mu, \overline{q})}{d\varphi(s)}. \]

From the monopolist’s maximization problem, it follows that \( \varphi(s) - \psi(q^M(\varphi(s), q_\mu, \overline{q})) > 0 \) and \( \frac{dq^M(\varphi(s), q_\mu, \overline{q})}{d\varphi(s)} \geq 0 \). It follows that \( \frac{dw^M(\varphi(s))}{d\varphi(s)} > 0 \) so if \( s^* \) maximizes \( \varphi(s) \) it also maximizes \( w^M(\varphi(s)) \). Because \( \varphi(s^*) > \varphi(s) \) for all \( s \in S - s^* \), it follows that \( w^M(\varphi(s^*)) > w^M(\varphi(s)) \) for all \( s \in S - s^* \), so \( s^* \) is the unique standard that maximizes \( w^M(\varphi(s)) \).

By the envelope theorem, the marginal effects of the standard on monopoly profit equals

\[ \frac{dR^M(\varphi(s))}{d\varphi(s)} = q^M(\varphi(s), q_\mu, \overline{q}) > 0. \tag{27} \]

so if \( s^* \) maximizes \( \varphi(s) \) it also maximizes \( R^M(\varphi(s)) \). Because \( \varphi(s^*) > \varphi(s) \) for all \( s \in S - s^* \), it follows that \( R^M(\varphi(s^*)) > R^M(\varphi(s)) \) for all \( s \in S - s^* \), so \( s^* \) is the unique standard that maximizes \( R^M(\varphi(s)) \). □
PROOF OF PROPOSITION 4. Define $Y(s) \subseteq [0, Y]$ as the set of inventors such that $\lambda_y(s) = 1$. If $Y(s) \cap Y(s^*) = \emptyset$ for $s \neq s^*$, then $N(s) \leq Y - N(s^*) < N(s^*)$, so inventors in $Y(s^*)$ have more votes than those in $Y(s)$. Consider now $s \neq s^*$ such that $Y(s) \cap Y(s^*) \neq \emptyset$. If $N(s) < N(s^*)$, inventors in $Y(s)$ cannot choose $s$ because $\delta = \frac{N(s^*)}{Y}$. Suppose now that $N(s) \geq N(s^*)$. Because $R^M(\varphi(s^*)) > R^M(\varphi(s))$ and $N(s) \geq N(s^*)$, for any inventor $y \in Y(s) \cap Y(s^*)$,

$$\xi_y(s^*) = R^M(\varphi(s^*)) \frac{1}{N(s^*)} > R^M(\varphi(s)) \frac{1}{N(s)} = \xi_y(s).$$

This implies that all members of $Y(s^*)$ will choose $s^*$, which satisfies the voting rule $\delta = \frac{N(s^*)}{Y}$. So, given this voting rule, inventors choose $s^*$. □

PROOF OF PROPOSITION 5. Partition the set of standards $S$ into three sets, $S_\bar{q}$, $S_{q^*}$, and $S_{q^*_v}$. The upper constraint on output is binding for all $s \in S_\bar{q}$. Neither of the constraints on output is binding for all $s \in S_{q^*}$. The lower constraint on output is binding for all $s \in S_{q^*_v}$. Recall that $\rho(\varphi(s)) = \varphi(s) - \psi(q^M(\varphi(s), q^*_v, \bar{q}))$.

Suppose first that $S_\bar{q} = S$, so the marginal agents are given by $\bar{q}$. Marginal and supramarginal agents have zero profits and are indifferent across all $s \in S_\bar{q}$. Inframarginal agents have profits $\pi_h(s) = \theta(\bar{q}) - \theta(h)$, $v_i(s) = \eta(\bar{q}) - \eta(i)$, and $g_j(s) = \zeta(\bar{q}) - \zeta(j)$. So, all inframarginal agents are indifferent. So, all agents choose $s^*$. Next, suppose that $S_{q^*_v} = S$, so the marginal agents are given by $q^*_v$. Inframarginal agents have profits $\pi_h(s) = \theta(q^*_v) - \theta(h)$, $v_i(s) = \eta(q^*_v) - \eta(i)$, and $g_j(s) = \zeta(q^*_v) - \zeta(j)$. By the same reasoning, all agents choose $s^*$.

Now suppose that $S_{\bar{q}} = S$, so the marginal agents are given by $\bar{q}$. Marginal and supramarginal agents have zero profits and inframarginal agents have profits $\pi_h(s) = \theta(\bar{q}) - \theta(h)$, $v_i(s) = \eta(\bar{q}) - \eta(i)$, and $g_j(s) = \zeta(\bar{q}) - \zeta(j)$. Agents that are marginal, inframarginal, or supramarginal for all $s \in S_{\bar{q}}$ are indifferent and choose $s^*$. Next, consider the group of agents that are inframarginal for some $s$ but marginal or supramarginal for other $s$. Because $\bar{q}^M(\varphi(s))$ is increasing in $\varphi(s)$, the greatest number of those agents are inframarginal at $s^*$, and therefore strictly prefer $s^*$. So, all agents choose $s^*$.

If the set of standards such that industry capacity is binding is empty, $S_{\bar{q}} = \emptyset$, 45
but not the other two sets, $S_{q^u} \neq \emptyset$, and $S_{q} \neq \emptyset$, it must be the case that $s^* \in S_{q}$. All agents choose $s^*$ among standards in $S_q$, as already shown. Now compare $s^*$ with any $s \in S_{q^u}$. Agents that are inframarginal for both or supramarginal for standards, are indifferent and choose $s^*$. Because $\hat{q}^M(\varphi(s))$ is increasing in $\varphi(s)$ and $\hat{q}^M(\varphi(s^*)) > q_{\mu}$, the group of agents that are inframarginal for $s^*$ but marginal or supramarginal for $s \in S_{q^u}$ strictly prefer $s^*$. So, all agents choose $s^*$. Conversely, if $S_{q} \neq \emptyset$, then whatever is the case for the other two sets, it must be the case that $s^* \in S_{q}$. By the same reasoning, all agents choose $s^*$. So, the standards organization always chooses $s^*$. □

**PROOF OF PROPOSITION 6.** Because $\varphi(s^*) > \varphi(s)$, we have $q^M(\varphi(s^*), q_{\mu}, \bar{q}) \geq q^M(\varphi(s), q_{\mu}, \bar{q})$. This also implies that the equilibrium standard maximizes distributor profits,

$$\int_{0}^{q^M(\varphi(s^*), q_{\mu}, \bar{q})} v_i(s^*)di \geq \int_{0}^{q^M(\varphi(s), q_{\mu}, \bar{q})} v_i(s^*)di \geq \int_{0}^{q^M(\varphi(s), q_{\mu}, \bar{q})} v_i(s)di.$$

The same holds for producers and suppliers. □

**PROOF OF PROPOSITION 8.** Suppose without loss of generality that the efficient standard $s^*$ is in the set $S_A$. For ease of notation, let $s_A = s^*$ and let $s_B$ be any standard in $S_B$. It follows that $\varphi(s_A) > \varphi(s_B)$ and $q^*(\varphi(s_A), \bar{q}) \geq q^*(\varphi(s_B), \bar{q})$. Suppose first that $q^*(\varphi(s_A), \bar{q}) < I - q^*(\varphi(s_B), \bar{q})$, so there is no overlap between active distributors under the two standards so that distributors in the set $(q^*(\varphi(s_A), \bar{q}), I - q^*(\varphi(s_B), \bar{q}))$ are inactive and indifferent and vote for $s_A$. Also, distributors in $[0, q^*(\varphi(s_A), \bar{q})]$ vote for $s_A$ and distributors in $[I - q^*(\varphi(s_B), \bar{q}), I]$ vote for $s_B$. So, there are $I - q^*(\varphi(s_B), \bar{q})$ votes for $s_A$ and $q^*(\varphi(s_B), \bar{q})$ votes for $s_B$. A majority choose $s_A$ because

$$I - q^*(\varphi(s_B), \bar{q}) > q^*(\varphi(s_A), \bar{q}) \geq q^*(\varphi(s_B), \bar{q}).$$

Because output depends on $\varphi(s^*)$, the number of votes for $s^*$, $I(\varphi(s^*))$, also is a function of $\varphi(s^*)$. It follows that $\frac{I(\varphi(s^*))}{I} > \frac{1}{2}$.

Suppose next that there is an overlap between the sets of active agents under
the two standards, \( q^*(\varphi(s_A), \bar{q}) \geq I - q^*(\varphi(s_B), \bar{q}) \). Consider market equilibria that are not capacity constrained for \( s_A \) and \( s_B \). Then, the marginal and supramarginal distributors have zero profits both standards. For standard \( s_A \), active distributors are \( i \in [0, \hat{q}(\varphi(s_A))] \) and have profits
\[
v_i(s_A) = \eta(\hat{q}(\varphi(s_A))) - \eta(i).
\]
For standard \( s_B \), active distributors are \( i \in [I - \hat{q}(\varphi(s_B)), I] \) and have profits
\[
v_i(s_B) = \eta(\hat{q}(\varphi(s_B))) - \eta(I - i).
\]
It follows that the indifferent distributor \( i^* \) is given by
\[
\eta(\hat{q}(\varphi(s_A))) - \eta(i^*) = \eta(\hat{q}(\varphi(s_B))) - \eta(I - i^*).
\]
Rearranging terms implies that
\[
\eta(i^*) - \eta(I - i^*) = \eta(\hat{q}(\varphi(s_A))) - \eta(\hat{q}(\varphi(s_B))).
\]
Because \( \eta(\cdot) \) and \( \hat{q}(\varphi) \) are increasing functions, \( \eta(\hat{q}(\varphi(s_A))) > \eta(\hat{q}(\varphi(s_B))) \) so that \( \eta(i^*) > \eta(I - i^*) \). This implies that \( i^* > I - i^* \) so \( \frac{I(\varphi(s^*))}{I} > \frac{1}{2} \).

Next suppose that market equilibria are capacity constrained for \( s_A \) and \( s_B \). Let distributors be in the scarce category, \( \bar{q} = I < \min\{H, J\} \), so that all distributors are active with either standard and have positive profits,
\[
v_i(s_A) = \varphi(s_A) - \psi(\bar{q}) + \eta(\bar{q}) - \eta(i),
\]
\[
v_i(s_B) = \varphi(s_B) - \psi(\bar{q}) + \eta(\bar{q}) - \eta(I - i).
\]
It follows that the indifferent distributor \( i^* \) is given by
\[
\eta(i^*) - \eta(I - i^*) = \varphi(s_A) - \varphi(s_B).
\]
Because \( \varphi(s_A) > \varphi(s_B) \), it follows that \( i^* > I - i^* \) so \( \frac{I(\varphi(s^*))}{I} > \frac{1}{2} \).

Maintaining the hypothesis that market equilibria are capacity constrained for all \( s \in S \), either let producers be in the scarce category, \( \bar{q} = H < \min\{I, J\} \), or let suppliers be in the scarce category, \( \bar{q} = J < \min\{H, I\} \) and \( \bar{q} \geq I - \bar{q} \), so there is an overlap. Active distributors have profits

\[
v_i(s_A) = \eta(\bar{q}) - \eta(i),
\]

\[
v_i(s_B) = \eta(\bar{q}) - \eta(I - i).
\]

So, the indifferent distributor is \( i^* = 1/2 \) and \( \frac{I(\varphi(s^*))}{I} = \frac{1}{2} \).

Next, let the market equilibrium be capacity constrained for \( s_A \) but not for \( s_B \), that is, \( \bar{q}(\varphi(s_B)) \leq \bar{q} < \bar{q}(\varphi(s_B)) \). Let \( \bar{q} = I < \min\{H, J\} \). Given the overlap, \( I - \bar{q}(\varphi(s_B)) \leq \bar{q} \), the indifferent distributor is defined by

\[
\eta(i^*) - \eta(I - i^*) = \varphi(s_A) - \psi(\bar{q}) + \eta(\bar{q}) - \eta(\bar{q}(\varphi(s_B))) > 0,
\]

Because \( \bar{q} \geq \bar{q}(\varphi(s_B)) \) and \( \varphi(s_A) > \psi(\bar{q}) \), it follows that \( i^* > I - i^* \) so \( \frac{I(\varphi(s^*))}{I} > \frac{1}{2} \).

Next, let \( \bar{q} = H < \min\{I, J\} \) or \( \bar{q} = J < \min\{H, I\} \). Then, \( v_i(s_A) = \eta(\bar{q}) - \eta(i) \) and \( v_i(s_B) = \eta(\bar{q}(\varphi(s_B))) - \eta(I - i) \) so that

\[
\eta(i^*) - \eta(I - i^*) = \eta(\bar{q}) - \eta(\bar{q}(\varphi(s_B))) > 0.
\]

Again, \( \bar{q} \geq \bar{q}(\varphi(s_B)) \) implies that \( i^* > I - i^* \) so \( \frac{I(\varphi(s^*))}{I} > \frac{1}{2} \). Finally, notice that because output is nondecreasing in \( \varphi(s) \), it is not possible for the market equilibrium to be capacity constrained for \( s_B \) but not for \( s_A \). This implies that \( \frac{I(\varphi(s^*))}{I} \geq \frac{1}{2} \). The same result holds for producers and suppliers, regardless of the partition. Therefore, the result holds for any set \( F \in \Lambda \). This implies that \( \delta(\varphi(s^*)) \geq \frac{1}{2} \) and \( \delta(\varphi(s^*)) \) nondecreasing in \( \varphi(s^*) \). \( \square \)

**Proof of Proposition 9.** Suppose again without loss of generality that the efficient standard \( s^* \) is in the set \( S_A \). Again for ease of notation, let \( s_A = s^* \) and let \( s_B \) be any standard in \( S_B \). It follows that \( \varphi(s_A) > \varphi(s_B) \) and \( q^M(\varphi(s_A), q, \bar{q}) \geq \varphi(s_B) \).
$q^M(\varphi(s_B), q_\mu, \bar{q})$. If $q^M(\varphi(s_A), q_\mu, \bar{q}) < I - q^M(\varphi(s_B), q_\mu, \bar{q})$, there is no overlap between active distributors under the two standards. Because output depends on $\varphi(s^*)$, the number of votes for $s^*$, we can define $I^M(\varphi(s^*))$ as a function of $\varphi(s^*)$. It follows that $\frac{I^M(\varphi(s^*))}{I} > \frac{1}{2}$.

then by the same reasoning as in the proof of Proposition 8, $\frac{I^M(\varphi(s^*))}{I} > \frac{1}{2}$.

If $q^M(\varphi(s_A), q_\mu, \bar{q}) = q^M(\varphi(s_B), q_\mu, \bar{q}) = \bar{q}$. If $\bar{q} = I < \min\{H, J\}$, all distributors are active and profits are $v_i(s_A) = v_i(s_B) = \eta(\bar{q}) - \eta(I - i)$. So, $i^* = 1/2$ and $\frac{I^M(\varphi(s^*))}{I} = \frac{1}{2}$. If $\bar{q} = H < \min\{I, J\}$ or $\bar{q} = J < \min\{H, I\}$, and $\bar{q} \geq I - \bar{q}$, $i^* = 1/2$

and $\frac{I^M(\varphi(s^*))}{I} = \frac{1}{2}$.

If $q^M(\varphi(s_A), q_\mu, \bar{q}) = \bar{q}^M(\varphi(s_A))$ and $q^M(\varphi(s_B), q_\mu, \bar{q}) = \bar{q}^M(\varphi(s_B))$. Then, $v_i(s_A) = \eta(\bar{q}^M(\varphi(s_A))) - \eta(i)$ and $v_i(s_B) = \eta(\bar{q}^M(\varphi(s_B))) - \eta(I - i)$. Then,

$$\eta(i^*) - \eta(I - i^*) = \eta(\bar{q}^M(\varphi(s_A))) - \eta(\bar{q}^M(\varphi(s_B))) > 0.$$  

So, $i^* > 1/2$ and $\frac{I^M(\varphi(s^*))}{I} > \frac{1}{2}$.

If $q^M(\varphi(s_A), q_\mu, \bar{q}) = q^M(\varphi(s_B), q_\mu, \bar{q}) = q_\mu$. So, $v_i(s_A) = v_i(s_B) = \eta(q_\mu) - \eta(i)$, and $i^* = 1/2$ and $\frac{I^M(\varphi(s^*))}{I} = \frac{1}{2}$.

If $q^M(\varphi(s_A), q_\mu, \bar{q}) = \bar{q}$ and $q^M(\varphi(s_B), q_\mu, \bar{q}) = q_\mu$ so that $v_i(s_A) = \eta(\bar{q}) - \eta(I - i)$ and $v_i(s_B) = \eta(q_\mu) - \eta(i)$. Then,

$$\eta(i^*) - \eta(I - i^*) = \eta(\bar{q}) - \eta(q_\mu) > 0.$$  

So, $i^* > 1/2$ and $I(s^*) > \frac{1}{2}$. If $q^M(\varphi(s_A), q_\mu, \bar{q}) = \bar{q}$ and $q^M(\varphi(s_B), q_\mu, \bar{q}) = \bar{q}^M(\varphi(s_A))$, then $i^* > 1/2$ and $I(s^*) > \frac{1}{2}$. Finally, if $q^M(\varphi(s_A), q_\mu, \bar{q}) = \bar{q}^M(\varphi(s_A))$ and $q^M(\varphi(s_B) = q_\mu$, then $i^* > 1/2$ and $\frac{I^M(\varphi(s^*))}{I} > \frac{1}{2}$. This implies that $\frac{I^M(\varphi(s^*))}{I} \geq \frac{1}{2}$.

The same result holds for producers and suppliers, regardless of the partition. Therefore, the result holds for any set $F \in \Lambda$. □

References


