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Membership, governance, and lobbying in standard-setting organizations[☆]

Clemens Fiedler[a,b,1,2], Maria Larrain[a,b,2], Jens Prüfer[c,b,*,2]

[a] CentER, Tilburg University, P.O. Box 90153, 5000 LE Tilburg, The Netherlands
[b] TILEC, Tilburg University, P.O. Box 90153, 5000 LE Tilburg, The Netherlands
[c] School of Economics and Centre for Competition Policy, University of East Anglia, Norwich Research Park, Norwich NR4 7TJ, United Kingdom

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ABSTRACT

Standard-setting organizations (SSOs) are collectively self-governed industry associations, formed by innovators and implementers. They are a key organizational form to agree on and manage technical standards, and form the foundation for many technological and economic sectors. We develop a model of endogeneous SSO participation that highlights different incentives for joining (namely licensing, learning, and implementation). We analyze equilibrium selection and conduct comparative statics for a policy parameter that is related to implementer-friendly Intellectual Property Rights policies, or alternatively, minimum viable implementation. The results can reconcile existing evidence, including that many SSO member firms are small. The extent of statutory participation of implementers in SSO control has an inverted U-shape effect on industry profits and welfare.

1. Introduction

Standard-setting organizations (SSOs) are collectively self-governed industry associations. They are formed by innovators and implementers to set and update technological standards. Such standards enable industry participants to coordinate on a single technical solution. Thereby, they exploit network effects, diffuse valuable information, and decrease transaction costs. Such positive welfare effects of compatibility and standardization are well documented.[3] Due to the steady growth of information & communication technologies over the past decades and the high importance of network effects in these industries, standardization has become especially valuable: it reduces uncertainty, facilitates interoperability, provides investment opportunities, and lowers the cost of innovating (Bresnahan and Greenstein, 1999). SSOs are an important coordinator of technological standardization, especially in the presence of network effects (Gandal and Regibeau, 2014). Hence, studying *how* SSOs set standards is important for innovation.

Being industry associations, membership in SSOs is usually open to all industry participants, subject to paying a membership fee.[4] The club character with collective self-governance, where members vote which candidate technologies are included in a standard, avoids monopolization and ensures wide acceptance of once-decided standards. The latter is important because patents on elected technologies become standard-essential, which provides respective patent holders with market power and, hence, high expected profits as standard-essential patents become de facto monopolies.

However, self-governance has specific issues. First, the objectives of various would-be member firms differ and may even clash: upstream innovators vs. downstream implementers; innovators with high-value technologies vs. those with low-value technologies; implementers with strong market power and coverage vs. smaller ones. Second, innovating

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* Corresponding author at: School of Economics and Centre for Competition Policy, University of East Anglia, Norwich Research Park, Norwich NR4 7TJ, United Kingdom.

E-mail addresses: clemens.mb.fiedler@gmail.com (C. Fiedler), m.j.larrainaylwin@uvt.nl (M. Larrain), j.prufer@uea.ac.uk (J. Prüfer).

1 Present address: Zalando SE, Valeska-Gert-Straße 5, 10243 Berlin, Germany.

2 All three authors contributed in equal parts to this manuscript.

3 See Katz et al. (1985) for an early example. For an overview of the empirical literature estimating network effects, and the positive welfare effects of standardization in network industries, see Gandal and Regibeau (2014).

4 For a typology of SSO-models and membership requirements, see Baron and Kanevskaia Whitaker (2022).

5 See Larrain and Prüfer (2015) for a general model of trade associations, where lobbying can have negative or positive spillovers for the rest of the economy.

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SSO members may lobby for their technologies to be included in the standard specification. This might result in standards which do not adopt/include the best available technologies.[5] The empirical evidence is mixed in this respect. Bekkers et al. (2011) find that involvement in the standardization process is a stronger factor than the technical merit of a patent in determining the likelihood that a firm declares a patent to be standard-essential. Weiss and Sirbu (1990) find a bias towards technologies supported by large firms that provide high contributions to an SSO, which offers indirect evidence that technological quality is not the only factor in standard selection, despite its theoretical pretense. However, large firms could just be more successful in producing the highest-quality technologies, which are more likely to be included in a standard. For example, Rysman and Simcoe (2008) empirically study four major SSOs and find that the patents selected by the standards have significantly more citations than average patents before they were disclosed to the SSO. This suggests that these SSOs are selecting technologies with a higher inherent value.

Gandal and Regibeau (2014) conclude from the divergent evidence: "SSOs are politico/economic institutions where influence within the SSO might matter as much as technical merit when it comes to having one's patents included in the agreed-upon standard. A natural target for improving the performance of SSOs are therefore the rules that determine how power within the SSO is divided". This statement explains the starting point of our paper. We aim at a better understanding of the decision-making rules of SSOs and their influence on standard selection (*SSO governance*), which can have a profound impact on the abilities of innovators to coordinate in developing new technologies and on innovation incentives (Chiao et al., 2007).

Moving from governance to *membership*, in most of the theoretical literature studying SSOs,[6] there is an implicit assumption that the only motivation for innovators to join an SSO is to promote their technology and, hence, to receive corresponding licensing fees once their technology is standard-essential. However, there can be other reasons: there is evidence that SSOs can also have a direct effect on innovation if their meetings provide an environment that promotes knowledge sharing, with positive dynamic effects of membership over investment (Gandal et al., 2004; Baron et al., 2014). A robust empirical result is that of patent disclosure to SSOs is correlated with firms' valuations (Hussinger and Schwiebacher, 2013). Attending SSO meetings and actively participating in SSOs, including authorship of technical contributions made to standards, have a significant positive effect on firms' revenues (Baron et al., 2014).

There are two alternative explanations for the latter result. The first one interprets a member firm's activism as *lobbying*: active firms promote their proprietary technologies to the detriment of higher quality but less promoted rival technologies, which has a negative overall welfare effect. The second explanation is that firms benefit from *knowledge spillovers* from attending SSO meetings, which facilitates future innovations and hence positively affects welfare in the long run. Baron et al. (2014) find no evidence of the first effect but show that knowledge spillovers are an important reason for firms to join an SSO.[7]

The different membership motivations of firms are reflected by patterns in the composition of real-world SSOs. Gupta (2017) shows that the 3GPP SSO is characterized by a few major active players and many smaller players that attend the meetings but only make very little direct contributions to the standard.[8] Blind and Thumm (2004), however, find that the higher the patent intensity of a firm, the less likely it is to join an SSO. This is a puzzling result in light of the current theoretical literature.

In light of this evidence, we study the following questions: What are the incentives for innovators with heterogeneous R&D-profiles and for implementers with heterogeneous market shares to participate in SSOs? Which members have an incentive to invest effort in lobbying and to become active in the SSO's committees? How do these decisions affect the pricing of standard-essential patents (royalties), industry profits, and welfare? How do the answers to these questions change depending on the relative power of implementers, as compared to innovators, within the SSO?

We develop a model of endogeneous SSO participation that highlights different incentives for joining (namely licensing, learning, and implementation). We analyze equilibrium selection and conduct comparative statics for a policy parameter that is related to implementer-friendly Intellectual Property Rights (IPR) policies, or alternatively, minimum viable implementation, i.e. if a technology can only be rolled out successfully if at least a certain share of implementers license and sell it. The results can reconcile existing evidence, including that many SSO member firms are small. The extent of statutory participation of implementers in SSO control has an inverted U-shape effect on industry profits and welfare.

Specifically, we develop a game-theoretic model, where an SSO is formed endogenously by a subset of upstream patent holders (innovators) and downstream firms (implementers). Innovators are endowed with a patent of varying quality, while implementers differ in their strength in the downstream market. Upstream firms benefit from SSO membership via two channels: (i) by being an SSO member, a firm learns from other SSO members via knowledge spillovers; (ii) through active membership a firm can have its technology included in the standard, which secures them a share of the royalty revenues. Downstream members benefit from the sale of standard-compliant products to consumers. After membership decisions are made, each innovator among the members can decide whether to become "active" (to invest effort in committees and lobbying), or to remain passive. Being active is a prerequisite for getting one's technology into the standard. Finally, we assume that innovators with standard-essential patents (SEPs) form a patent pool, the manager of which sets the licensing fee for implementers who want to use the pool's technologies to sell products on the downstream market. Crucially, depending on the SSO's governance rules, a specific share of implementers have to agree that an upstream firm's technology is included in the standard, which prevents SEP-holders from fully exploiting their monopolistic market power.

The main result of the paper is that, depending on the effort cost required of innovators to have their technology incorporated in the standard, one of four possible equilibrium types occurs: (i) If these costs are very low, all innovators join the SSO. (ii) If the effort costs are at a medium level, both small innovators and large innovators – but not innovators with medium R&D stocks – join. The intuition is that "large" upstream firms (innovators with very valuable innovations) join because they aim for the profits from having their technology included in the standard. Small upstream firms, which do not expect to get

[6] For example, Llanes and Poblete (2014).

[7] Specifically, Baron et al. (2014) find that positive returns from investing in standard development are not restricted to firms with standard-essential proprietary technologies or large knowledge assets. Instead, they find a large extent of involvement in 3GPP standardization by firms who do not claim any standard-essential proprietary technology and no evidence for a systematic bias in favor of either large patent holders or manufacturers of standard-compliant devices. Moreover, they find that firms with little R&D investment benefit more from attending meetings in which firms that heavily invest in R&D also participate.

[8] Bloom et al. (2013) also support the spillovers hypothesis: "the productivity of a firm does not only depend upon its R&D activities but also upon the contributions of other firms' R&D transferred to the firm via involuntary spillovers". They argue that this complementarity of R&D activities is especially strong for standardized technologies because the knowledge produced by one firm is more relevant to other firms participating in the same standard. In the same line, Waguespack and Fleming (2009) show that especially small firms (startups) use participation in standard-setting as a source of learning and gain from knowledge spillovers (in open standards). Gandal et al. (2004) and Tsukada and Nagaoka (2010) show that firms use the knowledge acquired in standard meetings in their subsequent R&D activities.

their technology into the standard, benefit from knowledge spillovers, which boosts their expected profits in the future, making membership profitable in expectation. On the other hand, medium-sized upstream firms, just like small firms, have a low chance of getting their technology into the standard—but they can learn less from the large firms than the small firms. Consequently, they are the first to abstain from SSO membership. (iii) For high effort costs, only very large upstream firms join as they can still profitably market their technology. Small upstream firms stop participating as the benefits from learning from only a few remaining upstream firms is not sufficient to compensate them for their own costs of participation. (iv) For prohibitively high effort costs, nobody joins.

Based on these results, we find that the governance structure of the SSO is crucial for its outcomes. As implementers get more statutory bargaining power, royalty fees decline, which leads to an increase in industry profits and expands the downstream market, thereby benefiting welfare. Upstream firms lose but downstream firms win, and the net effect is positive. However, above a certain threshold of implementers' power, the incentives of innovators to contribute their technologies decline. This lowers the standard's quality and industry profits. Hence, industry profits follow an inverted U-shape in the participation of implementers in SSO control. In our model with monopolistically competitive markets, consumer surplus qualitatively follows industry profits. Hence, the inverted U-shape in implementers' participation/control transcends to consumer surplus and to welfare.

Contributing to a better understanding of the political economy of SSOs, we find that implementers who obtain a large benefit from adopting the technology have an incentive to raise the statutory participation level of low-strength implementers because this forces innovators to lower the royalty rate, which the high-strength implementers profit the most from. This implies that especially large implementers have an interest in broad participation even if it harms innovation.

These theoretical results can point policy makers at important tradeoffs. First, high levels of decision-making power for implementers, despite the apparent attractiveness of being inclusive, can backfire for all involved groups and, hence for welfare. Moreover, in a specific way of raising rivals' cost, innovators with high-quality technologies could even use increased downstream participation as a way to discourage low-quality innovators from joining the standard — and hence push for a governance structure that gives a lot of control to downstream firms. Similarly, strong implementers benefit most from the inclusion of more downstream firms, as this implies lower royalty fees to innovators. Consequently, policy makers should be aware that relying on large implementers to act as stewards of the interests of the implementer side can be misleading. Otherwise, they can expect to end up with a cheap but bad standard. Instead, the optimal SSO-governance structure requires a subtle balancing of the incentives of all involved parties. Radical regulation that shifts too much control to one type of firms is to be avoided.

The remainder of the paper is organized as follows. Section 2 contains a literature review. In Section 3, we describe the model, which we analyze in Section 4. In Section 5, we discuss key model assumptions and conclude in Section 6 with policy implications. Proofs are in Appendix A, extensions in Appendices B and C.

2. Literature

We contribute to the literature on standard setting by endogenizing firms' participation in SSOs. In our model, innovators benefit from obtaining royalty revenues from their technology. However, innovators can also passively participate in the SSO and benefit from knowledge spillovers only. As the literature has shown, both aspects are empirically relevant (Baron et al., 2014). By studying them together, we find novel results on firms' participation choices and how commitments made to downstream firms can lead to positive or negative effects.

The literature on SSOs has pointed to a multitude of important aspects for the performance and functioning of SSOs. One of the most crucial aspects of SSO performance is participation. Only if the participation of industry partners is broad and includes the firms with the best technologies, there is any hope that the standard is as good as technically (and economically) possible (Gandal and Regibeau, 2014). We directly address aspects of membership and participation by modeling innovators' and implementers' participation in an SSO whose by-laws place a requirement on minimum participation by the implementers in the SSO. Doing so allows us to show how increased membership of implementers can have benefits to society by lowering innovators' ability to charge a high royalty and negative effects by lowering innovators' incentives to contribute their technology in the standard. Simcoe (2014) elaborates on this point, underlining shared control of innovators and implementers in many real-world organizations.

One of the most important challenges SSOs face is how to prevent holdup, i.e., the possibility of patent owners to use their technology's increased importance to (ex-post) charge an excessive royalty (Lemley and Shapiro, 2006). This topic has generated lots of controversy among scholars and is considered an important challenge by authorities.[9] Theoretically, Elhauge (2008) argues that royalty rates are rather insufficient than excessive. Other papers have highlighted that the repeated and continuous interaction of firms during the standard-setting process acts in reducing the risk of holdup (Epstein et al., 2012; Brooks, 2013). We add to this literature by showing how statutory participation of downstream firms can discipline innovators and limit their ability to charge high royalty rates, thus mitigating the threat of holdup. We show that implementers' participation mitigates the risk of holdup.

A widely discussed alternative solutions to deal with the problems associated with SEP licenses are FRAND commitment over disclosed patents (*Fair, Reasonable, And Non-Discriminatory*). However, there is an intense debate over whether FRAND commitments can effectively prevent patent owners from imposing excessive royalty over SEPs. Theoretical models assume that FRAND terms do not constrain SEP owners at all. Instead, they propose that firms should commit to ex-ante price caps (structured price commitments Lerner and Tirole, 2015), that firms should be allowed to form a patent pool before the standard is selected (Llanes and Poblete, 2014), or that SSOs should establish an internal arbitration procedure to investigate the costs of alternative standards before adopting one (Lemley, 2002) or to resolve intellectual property conflicts (Lemley and Shapiro, 2013). These studies suggest that ex-ante licensing leads to more efficient outcomes. However, under certain conditions, ex-ante licensing can be less efficient than ex-post licensing (Tarantino, 2015).[10] Moreover, recently it has been shown that repeated interaction can help make FRAND rates binding such that innovators refrain from charging unreasonably high royalty rates as they expect future interaction within standard-setting (Larouche and Schuett, 2019; Llanes, 2019).

While FRAND commitments are often seen as vague or difficult to evaluate, we contribute by proposing a mechanism leading to a FRAND license: to attract implementers, innovators are constrained when setting the royalty rate. In this paper, we consider a minimal limit, in the sense that innovators need to make sure that implementers make non-negative profits. By doing so, we draw attention to the benefits of ex-ante commitments aimed at tying innovators' hands in the ex-post setting of royalty rates—ultimately for mutual benefit.

On the empirical side, Simcoe (2012) studies documents of working groups of the Internet Engineering Task Force (IETF). A key finding is that the consensus-building process in self-governed SSOs has many benefits but that coordination delays, due to individual participants'

[9] See, e.g., Gupta (2013) and Galetovic et al. (2015).

[10] When there is competition between standards, ex-ante licensing does not always lead to a more efficient outcome than ex-post licensing (Llanes and Poblete, 2015).

rent-seeking behavior, are one important cost of using the institution. This empirically confirms Hansmann (1996)'s description of the "costs of collective decision making", which are prevalent in all clubs governed by private ordering and increasing in the heterogeneity of members: in Simcoe (2012)'s sample, the number and heterogeneity of IETF's members significantly increased over the time of his study,1993–2003. Such changes could be reflected in our model in various ways: increased member heterogeneity can be captured by an increased effort or lobbying cost (e; see next section) that innovators have to spend to convince a qualified majority of other members to include their technology in the standard. Similarly, it drives the costs both for innovators and for implementers to participate in the SSO, as a larger organization leads to more interactions, which comes at additional costs (denoted F_p and F_d below).

Baron et al. (2019) study 17 SSO-case studies, a survey of SSO-stakeholders, an expert workshop, and a comprehensive review of the legal and economic literature, and hence serve as a treasure for scholars interested in the details of SSO-governance. Just as Simcoe (2012), they underline the positive aspects of private ordering – or self-governance without governmental intervention – and the great variety of purposes and procedures met in real-world SSOs, which serve a multitude of purposes.[11] They conclude "that the interests of under-represented groups are best served when public authorities look out for the public interest within the current regulatory scheme" (p.17). Our model takes the next step by formalizing the "interests" of heterogeneous innovators and heterogeneous implementers and showing (in Section 4.4) what the "public interest" depends on in a specific case—but that it is always hump-shaped in the relative power of implementers and, hence, that all stakeholder groups should share control.

Baron and Kanevskaia Whitaker (2021, 2022) empirically study a large dataset on individuals occupying SSO-leadership positions. They underline that SSOs share some governance features, such as consensus, openness, and transparency. Nevertheless, they also offer a typology of four SSO-governance types, thereby delineating structural differences. They distinguish between the "entity-based approach" (e.g. at 3GPP) that seeks to balance commercial interests, and the "individual-based approach" (e.g. at IETF) that is focused on individual experts of a subject matter. "In reality, these models are often combined in SDOs' governance frameworks" (Baron and Kanevskaia Whitaker, 2021, p. 6). Our model proposes a formal language to capture some of these differences, notably adopting the "entity-based approach", as the players in our model are upstream or downstream firms. Our key parameter (λ), which is defined as the share of implementers that must support a standard to make it economically viable, can be widely interpreted to capture some of real-world SSOs governance features (see especially Sections 4.4 and 5).

3. The model

We develop a stylized model of a standard-setting organization that involves making multiple assumptions in order to clearly expose the characteristics of interest. The assumptions we will fall into three groups. First, we only consider a simplified downstream market, which abstracts from many considerations relevant to understanding how implementers develop products based on standards and the implications on competition between implementers. Second, we assume a streamlined model of standard setting that allows standards to make credible commitments when bargaining over the outcome of the standard. Third, we assume that the royalty rate charged directly depends on the implementation ability of firms. Each of these assumptions, which we discuss in detail below, enable us to rationalize patterns of SSO participation and engagement noted by the literature and to analyze our research questions. However, this abstracts from other important aspects of the standard-setting process at large.

Consider a market consisting of upstream firms (innovators, $\mathcal{N} = \{1, \ldots, n\}$) and downstream firms (implementers, $\mathcal{M} = \{1, \ldots, m\}$). Each upstream firm $i \in \mathcal{N}$ is characterized by an exogenous, fixed, and observable R&D stock/technology $R_i \in [0, \bar{R}]$ that determines the potential quality of the firm's only patented technology and, thus, its potential marginal contribution to the quality of the standard. Each downstream firm $j \in \mathcal{M}$ is characterized by an exogenous, fixed and observable level of strength $S_j \in [0, \bar{S}]$ that reflects the firm's ability to make use of the technology (e.g., market share).[12]

Innovators choose whether to join a Standard-Setting Organization as members, or not. The SSO brings firms together and thereby enables them to inform others about one's technology and to learn from each other. Joining costs F_p, the fixed cost of being a passive member, which includes a monetary membership fee covering the SSO's operating costs and the opportunity cost of employees attending SSO meetings.

Upstream members can become *active* by presenting their technology in SSO working groups, lobbying other members and, thereby, having their patented technology included in the standard. Alternatively, innovators remain *passive members* and only obtain knowledge spillovers from listening to and interacting with the active firms. For upstream member i, exerting lobbying costs effort e_i, where $e_i \in \{0, F_a\}$.[13] Let $\mathcal{N}_a = \{i \in \mathcal{N} | e_i = F_a\}$ be the set of all innovators who exert lobbying effort F_a and become active members. We assume that F_a is an exogenous transaction cost of the standardization process. It is unproductive by itself but necessary to convince members to vote for inclusion of a technology in the standard.[14] In reality, SSOs may make decisions that are informally based on the contribution of innovators to the standard and treat firms that contribute more preferentially. Furthermore, some SSOs, such as ETSI and IEC, offer tiered memberships with higher tiers granting additional rights (such as specific voting and information rights, seats on committees, or the ability to submit proposals) but also additional obligations, such as paying higher fees (Baron et al., 2019, p 87).

We define two quality levels of the standard[15]:

$$\tilde{R} = \sum_{l \in \mathcal{N}_a} R_l \tag{1}$$

$$\tilde{R}_{-i} = \sum_{l \in \mathcal{N}_a \setminus \{i\}} R_l$$

In general, we will use $\tilde{}$ to denote aggregate quantities of the standard. The first expression, $\tilde{R}$, captures that the quality of the standard is determined by the combined quality of all active innovators, which denotes the quality downstream implementers can derive profits from. The marginal contribution of one patent to the quality of the standard is assumed to be independent of the other patents in the standard such that patents are neither complements nor substitutes (Lerner and Tirole, 2015).[16] The second expression in Eq. (1), $\tilde{R}_{-i}$, excludes an

[11] See Bernstein et al. (2015) for a more general introduction to private ordering.

[12] Strength S_j can also capture aspects like j's brand reputation or the ability to incorporate the standard into j's other products.

[13] Restricting e_i to assume one of two values is a simplification, which means innovators can choose to work hard to get their technology into the standard, or not.

[14] Exerting effort can take many forms: talking to other members to inform them about the great features of one's technology, coordinating to make technologies compatible with each other, bringing in technical proposals, other committee work or supporting the organizational management by participating in the board of the SSO, or pure persuasion/lobbying. See Baron and Kanevskaia Whitaker (2021) for a detailed description of such activities.

[15] Eq. (1) assumes that at least one firm joins the standard. If the set of active firms is empty, the quality of the standard is $\tilde{R} = 0$.

[16] In reality, patents may indeed be complements or substitutes to each other, depending on the technology considered. However, for the sake of parsimony and tractability, we focus on the essential aspects of our research question, which are independent of the relationship between SEPs.

innovator's own technology from the standard's quality and, hence, captures *knowledge spillovers* received from other innovators. Below we will use Π to denote the payoffs of individual firms and W to denote payoffs of the group of firms derived from the standard itself. Specifically, a firm's payoff from *knowledge spillovers* is:

$$\Pi^{u}_{KS}(R_i) = \alpha \max\{\tilde{R}_{-i} - R_i, 0\}, \tag{2}$$

where $\alpha \in \mathbb{R}^{+}$ represents the importance of knowledge spillovers within the SSO and $\tilde{R}_{-i}$ is the knowledge stock that firm i can derive spillovers from. Like all Greek letters it denotes a key parameter of the economics of the standard. As a firm cannot obtain spillovers from itself, $\tilde{R}_{-i}$ is independent of firm i's decision (not) to become an active member.[17] Moreover, the potential for spillovers is reduced by R_i such that a firm with an already high R&D stock can learn less than firms with a smaller knowledge stock.[18]

An innovator's profit is given by:

$$\Pi^{u}(R_i, \tilde{R}) = \begin{cases} \alpha\left(\tilde{R}_{-i} - R_i\right) - F_p + \frac{W_u(p_u,\tilde{R})}{\tilde{n}} - F_a & \text{if active member} \\ \alpha\left(\tilde{R}_{-i} - R_i\right) - F_p & \text{if passive member} \\ 0 & \text{if non-member} \end{cases} \tag{3}$$

Summarizing Eq. (3), for each innovator firm, the first factor denotes the benefit from knowledge spillovers. The second factor, F_p, denotes the cost of SSO membership, which contains both a monetary cost that helps run the organization and an opportunity cost to send a firm's employees to SSO meetings. The parameters α, F_p, and F_a are exogenously given and depend on the market setup.

The third and fourth factors capture the additional net benefits of being an active instead of a passive member, where p_u denotes the royalty fee charged to implementers for licensing the technology and $\frac{W_u(p_u,\tilde{R})}{\tilde{n}}$ is the royalty revenue per active innovator. $\tilde{n}$ denotes the number of active innovators. The active innovators bundle their patents into a patent pool of quality $\tilde{R}$ and delegate setting the royalty fee to its manager, who maximizes total revenues. The manager of the patent pool then makes a Take-It-Or-Leave-It (TIOLI) offer setting a per-unit royalty fee of p_u on behalf of the active upstream members to the downstream members.[19]

Crucially, the manager is bound by the by-laws of the SSO specifying that membership of a proportion of $\lambda \in [0, 1]$ of the implementers is required for the standard to be implemented. This reflects the process of standardization laid out by Gupta (2017) wherein a standardized technology is first developed by what we call the innovators, the standard-compliant products are developed, and finally the standard is deployed.[20]

In our interpretation, λ is set during the innovators' technological development process in order to limit their bargaining power as implementers make investments in the product development phase.[21] λ could, for example, reflect the share of implementers who are called to serve on the board of the SSO, their collective voting rights, or just the necessary critical mass for the technology to be considered technically feasible. If the SSO fails to reach participation of λm implementers, the standard collapses and all firms receive negative profits amounting to the investments made.[22] While λ could be freely determined when setting up an SSO, it could also reflect underlying technological complementarities. E.g., the set of technologies combined in a standard could only be economically viable if a certain share λ of implementers licenses and distributes it on the downstream market ("minimum viable implementation"). By adopting this level of λ in its by-laws, the SSO could reduce the breakdown risk of the downstream market.

In reality, standard-setting organizations are very heterogeneous in how they reach decisions. According to Baron et al. (2019), SSOs can vary depending on if decisions are made by a dedicated leadership of the standard (e.g., IEEE), or if decisions are made by the general assembly of the members with extensive contributions of the members (e.g., IETF). Moreover, some SSOs (e.g., ANSI and ETSI, DVB) segment their members into categories based on their role (e.g., manufacturers vs. infrastructure providers). These categories may have an impact on how decisions are formed.[23] Finally, SSOs typically choose their leadership and board appointments based on a proportional roll.[24] The parameter λ reflects how all these choices impact the implementer focus of the standard, such that an existing SSO that gives explicit rights to downstream firms has a higher λ in our model than an existing SSO that implements top-down decision making.

Moving towards the downstream market, we assume that an implementer's strength S_j is distributed at regular intervals with step-size σ, such that $S_j = \bar{S} - (j-1)\sigma$, with $\sigma \in (0, \frac{\bar{S}}{m-1})$. Each implementer decides independently if they join the standard-setting organization and adopt the technology, or not. We assume that an implementer adopting the standard exerts no externality on other downstream firms: adopter j cannot use their higher quality to gain market power (and thus increase S_j). Think of implementers as monopolists on separate niche markets.

Market demand is fixed, by assumption, and prices charged to consumers are a linear function of the standard's quality (cf. Eq. (1)). Hence, for a per-unit royalty fee p_u the profits of downstream firms are

[17] Consequently, if firm i is an active innovator $\tilde{R}_{-i} = \tilde{R} - R_i$ and if its a passive innovator $\tilde{R}_{-i} = \tilde{R}$.

[18] In reality, innovators gain additional insights by attending meetings, networking with the representatives of other firms, and listening to the deliberations of committees. Such insights could be about the technology developed by other innovators, future technological paths expected, or the relevance of current technology to different markets. In the model, we consider spillovers to be proportional to the quality of the active firms. This captures that firms will learn directly from the SSO's deliberations which technologies to include and whether the SSO will develop a higher quality standard. The latter might attract more "activity" (measured by e) of all firms involved and, thus, a higher opportunity for spillovers. We explicitly rule out that there is an overlap in the technologies submitted by the firms such that the quality of the standard is the sum of the qualities of all technologies. However, the probability that another technology may be built with knowledge that an innovator already knows – and hence can learn less from – increases in the quality of the innovator's technology.

[19] Once upstream firms have decided on whether they join the standard actively or passively, their incentives are perfectly aligned. Thus, the identity of the manager making the Take-It-Or-Leave-It offer is irrelevant.

[20] "As a matter of implementation, Lemley and Shapiro (2013) propose that disputes regarding FRAND royalty rates be settled by binding "final offer" or "baseball" arbitration. In such proceedings, each party provides the arbitrator with a sealed "final offer", of which the arbitrator must choose only one, without modification. This approach is supported by CRA" (Baron et al., 2019, p.135).

[21] Thus, everybody knows that $m\lambda$ implementers will need to support the technology. The parameter λ is continuous. However, for readability, we will not make explicit note of this. Thus, a 'small change to λ' implies a change of λ by $\frac{1}{m}$ such that $m\lambda$ increases by 1 implementer.

[22] As we will see, λ limits the royalty that can be charged. Most SSOs require royalties to be set at least at FRAND level Baron et al. (2019). As FRAND can be open to interpretation, λ could also be seen as the degree of burden-of-proof to which a FRAND royalty is held such that a royalty is considered fair and reasonable if a share λ of implementers agrees that it is.

[23] "At DVB for example needs to be endorsed by a majority of members within each category in some cases" (Baron et al., 2019, p. 87).

[24] "According to the DVB Memorandum of Understanding, the Steering Board has a maximum of 51 elected representatives with the pre-defined seats for following constituencies: 14 Content Providers/Broadcasters (public and private); 13 Infrastructure providers (satellite, cable, terrestrial or network operator); 17 Manufacturers/software suppliers; 7 Governments/national regulatory bodies" (Baron et al., 2019, p. 91).

linear in the quality of the standard ($\tilde{R}$).[25] Implementer j's profit is:

$$\Pi^d(S_j,\tilde{R}) = \begin{cases} S_j\left(\tilde{R}-p_u\right)-F_d & \text{if member of SSO} \\ 0 & \text{outside option} \end{cases} \tag{4}$$

Implementer j's strength (S_j) measures their ability to market a standard of quality $\tilde{R}$ to its customers, such that the (expected) revenue derived from the standard is given by $S_j\tilde{R}$. The implementer pays a royalty fee $S_j p_u$ to the patent pool. On top, implementation of the standard comes at a fixed cost of F_d, which may also include a monetary SSO membership cost or opportunity costs. We do not consider knowledge spillovers for downstream firms.[26] For implementers, joining the SSO and licensing the standard is strictly bundled. One is not available without the other.[27]

Let $\mathcal{S}(p_u,\tilde{R})$ be the set of all implementers licensing the standard technology. Downstream demand for the standard ($q_u(p_u,\tilde{R}) = \sum_{j\in\mathcal{S}(p_u,\tilde{R})} S_j$) is the combined strength of all implementers in $\mathcal{S}(p_u,\tilde{R})$ and downstream surplus ($W_d(p_u,\tilde{R})$) is their combined profits.

Assumption 1. Downstream firms' demand for the standard satisfies:

$$\frac{\partial q_u(p_u,\tilde{R})}{\partial p_u} < 0, \qquad \frac{\partial^2\left(p_u q_u(p_u,\tilde{R})\right)}{\partial p_u^2} < 0$$

$$\frac{\partial q_u(p_u,\tilde{R})}{\partial \tilde{R}} > 0$$

Assumption 1 specifies that a higher quality of the standard raises the benefits of downstream firms, who then extend their usage intensity. Similarly, an increase in the licensing fee makes usage of the standard less profitable for implementers and thus lowers its usage. Total royalty revenue $W_u(p_u,\tilde{R}) = p_u q_u(p_u,\tilde{R})$ is concave in the royalty rate p_u. We need to solve:

$$\mathcal{S}(p_u,\tilde{R}) \equiv \{j \mid S_j(\tilde{R}-p_u) \geq F_d\}$$

$$q_u(p_u,\tilde{R}) = \sum_{j\in\mathcal{S}(p_u,\tilde{R})} S_j \tag{5}$$

$$W_d(p_u,\tilde{R}) = \sum_{j\in\mathcal{S}(p_u,\tilde{R})} \left(S_j(\tilde{R}-p_u)-F_d\right) \tag{6}$$

$$W_u(p_u,\tilde{R}) = \sum_{j\in\mathcal{S}(p_u,\tilde{R})} S_j p_u \tag{7}$$

This demand system satisfies Assumption 1, which we will verify as part of the proof of Proposition 2. W_d denotes total downstream surplus, while W_u denotes the surplus that innovators are extracting via royalty payments. Consequently, $W_d + W_u$ is the total surplus generated in the downstream market.

[25] This should be seen as a simplification of a demand model where the profits of the implementers are increasing in the quality of the standard. For example, this result can be derived from a demand model where the implementers are monopolists and use perfect price discrimination to extract the full value of the product from a limited number of customers. If the value of the product increases due to a higher quality of the standard, they can directly increase prices and extract the full marginal benefit of the new technology.

[26] Small knowledge spillovers for downstream firms would not alter the results qualitatively. Large knowledge spillovers for downstream firms would attract implementers to the SSO mainly for those spillovers. This would fundamentally change the model because the membership incentives specified in Eq. (4) would be dominated by knowledge-spillover gains, independent of S_j.

[27] The underlying assumption is that we only consider large implementers in set $\mathcal{M}$, who require a say in the SSO and are not interested in adopting technology without membership. If implementers were able to license the standard at the same royalty fee while not being SSO-members, in equilibrium still a share λ of them would have to join the SSO as otherwise the standard would collapse and they would all gain zero profits (see details below). This would open a new coordination game among implementers. The same argument would also hold if innovators could charge differentiated royalty fees to members of the SSO.

Finally, we make three assumptions, for tractability:

Assumption 2. R&D stock (R_i) is distributed at regular intervals with a constant distance of $\rho \in (0, \frac{\bar{R}}{n-1})$:

$$R_i = \bar{R} - (i-1)\rho$$

Assumption 3. Innovators make decisions at all stages in order of decreasing R&D stock R_i.

Assumption 4. A standard consisting only of the highest-quality innovator ($\bar{R}$) can generate a profit exceeding the fixed costs of joining the standard and becoming active such that:

$$\max_{p_u} W_u(p_u,\bar{R}) \geq F_p + F_a,$$

Imposing a simple structure on the distribution of innovators' R&D stock simplifies the analysis (Assumption 2). Assuming a specific order of decision making enables us to find a unique equilibrium (Assumption 3).[28] Assuming that a single-firm standard is feasible guarantees an equilibrium for at least some values of λ (Assumption 4). For tie-breaking purposes, assume a firm indifferent between its choices prefers (active) participation in the standard.

The game consists of three stages broadly reflecting the three stages outlined in Gupta (2014): first standardized technology is developed upstream, then standards-compliant products are developed downstream, followed by the deployment of interoperable networks. More formally, at stage one, all firms decide about their membership in the SSO. At stage two, innovators who joined the SSO decide whether to actively exert effort to include their technology in the standard, or to remain passive. At stage 3, a patent pool is formed by the firms with standard-essential patents, the royalty rate is determined, and implementers decide whether to license the standard, that is, the bundle of all standard-essential patents, or not. We solve this game for a *unique Subgame-Perfect Nash Equilibrium* in pure strategies.

4. Analysis

We solve the game by backward induction. We only consider standards with at least one active innovator. Solving for an equilibrium with an empty standard is trivial: all innovators and implementers would obtain a negative profit if they join the standard and thus not do so.

4.1. Stage 3: Patent pooling and license-fee setting

At Stage 3, upstream firms have already made their SSO-membership decisions on whether to become an active or passive member. Thus, the combined quality of the standard ($\tilde{R}$) is set and known. Downstream firms are confronted with a Take-It-Or-Leave-It (TIOLI) offer from the manager of the patent pool on behalf of the active upstream firms. Implementers decide about their SSO-membership independently and join the standard if doing so yields them a non-negative profit. For the standard to be viable $m\lambda$ implementers need to obtain a non-negative profit.

Implementer j's profit (Eq. (4)) is decreasing in the fixed cost of membership (F_d) and in the royalty rate (p_u) and increasing in their strength (S_j). Let $\hat{S}(\lambda)$ be the strength of the pivotal downstream firm at the $(1-\lambda)$ percentile of the firm distribution. If a firm of strength $\hat{S}(\lambda)$ obtains zero profits from implementing the standard, all firms with higher strength obtain positive profits and all firms with lower strength negative profits. Thus, the patent pool manager sets a royalty fee such that active innovators' profits are maximized, subject to $\hat{S}(\lambda)$ obtaining

[28] Appendix B studies the consequences of Assumption 3 and the related role of innovators' beliefs about other innovators' membership decisions in more detail and shows the robustness of the model's corresponding results.

a non-negative profit. In general, we will denote threshold values that characterize an outcome with $\hat{\cdot}$.

We assume that λ is determined during the foundation of the SSO, before the game is played, and will analyze the effects of changes in λ in Section 4.4. Therefore, from both innovators' and implementers' perspectives, λ is an exogenous parameter. So is $\hat{S}(\lambda)$. Consequently, we have to distinguish between two cases, which we will refer to as λ being *binding* and λ being *not binding*. If λ is not binding, the participation rate of implementers required by λ is lower than the profit-maximizing participation rate. Innovators would then benefit from selling to a higher share of implementers and voluntarily charge a lower royalty rate than is required from them by the SSO's statutes. We consider this an uninteresting case, however, and will only analyze it briefly. By contrast, if λ is binding, the participation rate of implementers required by λ exceeds the profit-maximizing participation rate. In this case, the standard will feature a participation rate that just equals λ, such that innovators' profits are limited by λ.

Lemma 1 (*Royalty Fee If λ Is Not Binding*). *Consider $\lambda = 0$, such that λ is not binding. Let j° be the index of the lowest-strength implementer who licenses the technology. The profit-maximizing royalty for a given level of $\tilde{R}$ is given as:*

$$p_u^\circ(\tilde{R}) = \tilde{R} - \frac{F_d}{\bar{S} - (j^\circ(\tilde{R}) - 1)\sigma}$$

where the marginal implementer's index $j^\circ(\tilde{R})$ is given by:

$$j^\circ(\tilde{R}) = \arg\max_{j \in \mathcal{M}} \left(j \left(\bar{S} - \frac{(j-1)\sigma}{2} \right) \left(\tilde{R} - \frac{F_d}{\bar{S} - (j-1)\sigma} \right) \right)$$

$p_u^\circ(\tilde{R})$ is increasing in $\tilde{R}$ and decreasing in F_d. The change to the royalty revenue caused by lowering prices to attract one more customer is declining in the number of customers.

Proof. see Appendix A.1.

In Lemma 1, j° denotes the index of the lowest-strength implementer that is profitable to be included in the standard ($\hat{S}^\circ$). The marginal profit of increasing the number of implementers is decreasing in their number, which is the discrete equivalent to saying that the royalty revenue is concave in the number of implementers it is licensed to. As the standard becomes more valuable, both the profit-maximizing royalty fee and the number of implementers who license it increases. A higher-quality standard allows the patent pool to charge a higher price, which increases the incentives to license the standard to more implementers. In contrast, higher costs of implementers lead to a lower price and a lower number of implementers being licensed to. As the costs of membership increase, the patent pool finds it more profitable to focus on the high-quality implementers, raising the royalty, and lowering the total downstream costs.

Now consider a value of $\lambda \geq \frac{j^\circ(\tilde{R})}{m}$, such that the profit-maximizing royalty rate exceeds the royalty fee implied by λ. In this case, we say that λ is *binding* for the royalty fee:

Lemma 2 (*Royalty Fee If λ Is Binding*). *If λ is binding, the optimal licensing fee for a given level of $(\tilde{R}, \lambda)$ is given as:*

$$p_u^*(\tilde{R}, \lambda) = \tilde{R} - \frac{F_d}{\hat{S}(\lambda)} \tag{8}$$

In equilibrium, all implementers with strength $S_j \geq \hat{S}(\lambda)$ adopt the technology and make non-negative profits. The firm at $\hat{S}(\lambda)$ makes zero profits. Furthermore, based on Eq. (5) we find that:

(i) Demand for the standard ($q_u^*(\lambda) = q_u(p_u^*, \tilde{R})$) is independent of $\tilde{R}$ and increasing in λ.
(ii) Total downstream profits ($W_d^*(\tilde{R}, \lambda) = q_u^*(\lambda)(\tilde{R} - p_u^*) - \tilde{m}F_d$) are increasing in λ.[29]
(iii) The total licensing revenue ($W_u^*(\tilde{R}, \lambda) = q_u^*(\lambda)p_u^*(\tilde{R}, \lambda)$) is decreasing in λ.
(iv) Furthermore, $\Delta(W_u^*(\tilde{R}, \lambda) + W_d^*(\tilde{R}, \lambda)) > 0$ and for $S_j > \hat{S}(\lambda)$: $\Delta\Pi^d(S_j, \tilde{R}) > 0$.[30]

Proof. see Appendix A.2.

Lemma 2 specifies the royalty-fee level, at which lowering the royalty rate is not profitable for the innovators while raising it is not possible because then less than a share λ of implementers break even. This critical royalty-fee level, $p_u^*(\tilde{R}, \lambda)$, is decreasing in λ: if the patent-pool manager wants to attract more implementers to license the standard, the licensing fee must shrink. Furthermore, if one of the $m\lambda$ implementers rejects the offer, the standard collapses. Lemma 2 also shows how results change with changes in governance (λ) and the standard's quality ($\tilde{R}$). First, demand for the standard is independent of $\tilde{R}$ and increasing in λ. By itself, an increase in the quality of the standard makes the standard more attractive to the implementers and would increase the demand. However, λ is binding and thus any demand increase beyond the one implied by λ leads to sub-optimal profits. Thus, the optimal response to a change in $\tilde{R}$ is an equal change to the royalty rate such that λ remains binding.[31]

Second, total downstream profits are increasing in λ. As λ increases, upstream firms need to lower the price in order to adhere to the by-laws. This benefits downstream licensees. Third, total licensing revenue is decreasing in λ: as λ is binding, any lowering of the price lowers total upstream royalty revenue. Finally, combined profits from the downstream market ($W_u^* + W_d^*$) are increasing in λ. Once the standard has been set, industry profits are decreasing in the royalty rate until the rate reaches 0, such that all implementers would then adopt the technology. As long as λ leads to a positive royalty rate, any increase in λ lowers the rate and thus leads to higher industry profits.[32]

Notably, innovators fail to extract all surplus generated on the downstream market despite their right to make a TIOLI offer for a license.[33] Instead, they limit supply of the technology to maximize their profits. Raising λ by $\frac{1}{m}$ leads to one more downstream firm implementing the technology, which increases profits on the downstream market by $p_u^*(\tilde{R}, \lambda + \frac{1}{m})\hat{S}(\lambda + \frac{1}{m}) = \tilde{R}\hat{S}(\lambda + \frac{1}{m}) - F_d$.

Comparing the cases of Lemmas 1 and 2, we are only interested in λ-values that are binding. The value of λ reflects a tension between innovators and implementers. Innovators want to set low λ to limit implementers' power when bargaining over royalty fees. A non-binding λ implies that this tension does not exist and is thus not interesting.

As a final step in the analysis of Stage 3, we show Lemma 3, which is rather technical and, hence, stated and proven in Appendix A.3. It shows that $W_u^*(\tilde{R}, \lambda)$ is the discrete equivalent of a concave function in λ: the higher λ is, the smaller is the change to the royalty rate caused by increasing λ further. The intuition for this result is that, as λ increases, the revenue charged to implementers declines while their number increases. If only a few implementers use the standardized technology, serving additional implementers while lowering the price increases profits. However, once λ is large, many implementers are charged a low royalty and thus lowering it even further while only

[29] Where $\tilde{m}$ denotes the number of implementers who implement the standard.

[30] Where $\Delta W(\lambda) \equiv W(\lambda + \frac{1}{m}) - W(\lambda)$ denotes the change to W caused by an increase in λ by one step.

[31] Typically, such an increase in $\tilde{R}$ does increase $j^\circ(\tilde{R})$, i.e., it raises the profit-maximizing demand. Thus, a large increase in $\tilde{R}$ could cause λ not to be binding anymore.

[32] Conceptually, once the standard has been fixed, the royalty rate is a pure transfer that causes allocation inefficiencies on the downstream market unless it equals 0.

[33] Similar to Katz and Shapiro (1986), innovators have an incentive to restrict the downstream supply of the technology to improve their own profits as they cannot capture the increase in industry profits caused by an extension of the margin.

adding one additional implementer decreases revenue.[34] We also derive the value of λ for which the innovators' commitment is binding for all standards. If the commitment is not binding for a level of λ, innovators charge the profit-maximizing price and do not react to any changes in λ. Such an equilibrium is not interesting. Thus, we henceforth restrict attention to $\lambda \geq \lambda^{\circ} \equiv \frac{j^{\circ}(\bar{R})}{m}$, such that λ is binding.

4.2. Stage 2: Standard formation

At Stage 2, innovators who are SSO members decide whether to remain passive and only obtain benefits from knowledge spillovers or whether to become active, exert effort, and gain a share of the patent pool's royalty income. Innovators have already paid the membership fee and knowledge spillovers are independent of their decision. Becoming active costs effort F_a. Consequently, based on Eq. (3), an innovator R_i becomes active if, and only if:

$$\frac{W_u^*(\tilde{R},\lambda)}{\tilde{n}} \geq F_a$$

If an innovator becomes active, it increases the spillover effects for other firms, but not for itself. It also leaves the downstream market share (q_u^*) of the implementers unchanged. Thus, based on Lemma 2, becoming active increases the royalty fee $p_u(\cdot)$ and the number of innovators that get a share of the royalty fee, $\tilde{n}$.

Proposition 1 (*Active Members*). *Let R_a be the quality of the highest-quality firm that is **not** an active member of the standard. Then, in equilibrium R_a satisfies:*

$$\frac{W_u^*(\tilde{R},\lambda)}{\tilde{n}} \geq F_a > \frac{W_u^*(\tilde{R}+R_a,\lambda)}{\tilde{n}+1},$$

where, at Stage 2, all innovators with a patent quality strictly exceeding R_a exert efforts of F_a and become active members. All upstream firms with quality lower or equal to R_a remain passive members.

Proof. see Appendix A.4.

Deriving the conditions under which an innovator decides to exert effort are an important part of this paper because they show when the incentive to directly earn licensing fees from owning a Standard-Essential Patent trumps indirect benefits from receiving knowledge spillovers, despite the fact that contributing an SEP creates positive externalities (which is not attractive to firm i) but getting knowledge spillovers does not. Proposition 1 implies the following:

Corollary 1 (*Number of Active Members*). *Let $\tilde{n}$ be the equilibrium number of active upstream firms. If a parameter change does not lead to a collapse of the standard, it yields the following comparative statics:*

- *(i)* $\frac{\partial \tilde{n}}{\partial F_a} \leq 0$*: An increase in the effort cost (F_a) lowers $\tilde{n}$.*
- *(ii)* $\frac{\partial \tilde{n}}{\partial \bar{R}} \geq 0$*: An increase in the quality of all innovators ($\bar{R}$) raises $\tilde{n}$.*
- *(iii)* $\frac{\partial \tilde{n}}{\partial \rho} \leq 0$*: An increase in the spread ρ, while keeping $\bar{R}$ constant, lowers $\tilde{n}$.*
- *(iv)* $\frac{\partial \tilde{n}}{\partial \lambda} \leq 0$*: An increase in the governance parameter λ lowers $\tilde{n}$.*

Proof. see Appendix A.5.

First, the number of active innovators at Stage 2 is decreasing in the effort cost (F_a). Second, an increase in the quality of all innovators increases the value (and prospective revenues) of any standard and thus incentivizes additional innovators to become active. It also lowers the decrease in the per-innovator royalty caused by the entry of an additional firm, which makes the entry itself more attractive and lowers the discouraging effect that entry has on follow-up entry. Both effects cause active participation to increase. Third, an increase in the spread of participation (ρ), which can be interpreted as an inverse measure of competitiveness on the market for ideas, lowers the number of innovators in the standard. Additional innovators contribute less to the standard but lower the per-firm royalty nonetheless. Thus, fewer innovators join the standard. Finally, a governance structure that puts more weight on downstream firms (higher λ) leads to a lower royalty fee and, thus, lower profits of innovators at stage 3. Active participation declines in response.

4.3. Stage 1: Membership

At Stage 1, innovators decide if they join the standard, or not. Recall that $\tilde{R}_{-i}$ is the combined quality of all active innovators, excluding innovator i. Based on Eq. (3), an innovator with R&D stock R_i who joins the standard obtains profits of:

$$\Pi^u(R_i,\tilde{R}_{-i}) = \alpha\left(\tilde{R}_{-i} - R_i\right) - F_p + \max\left\{0, \frac{W_u^*(\tilde{R}_{-i}+R_i,\lambda)}{\tilde{n}} - F_a\right\}$$

Knowledge spillover effects are decreasing in R_i. A high-quality firm benefits less from other members' knowledge. This determines a first threshold value R_l such that, ceteris paribus, upstream firms with a quality of $R_i \leq R_l$ join the standard to obtain spillover effects. Besides, for a given aggregate quality of the standard, a firm's individual royalty income is independent of its technological quality. However, total royalty income is growing in $\tilde{R}$, which is decreasing if the marginal member's R_i decreases. Let R_h be the R&D-stock of the highest-quality firm that does *not* join the standard, such that all innovators with quality $R_i > R_h$ join.

Proposition 2 (*Innovators' Membership*). *The first-stage equilibrium is determined by the threshold values R_l and R_h, where $R_l \leq R_h$. An innovator of quality R_i acts as follows:*

- *For $R_i \leq R_l$, i joins the SSO and becomes a passive member.*
- *For $R_l < R_i \leq R_h$, i does not join the SSO.*
- *For $R_h < R_i$, i joins the SSO and becomes an active member.*

Proof. see Appendix A.6.

Proposition 2 establishes the central result of this paper: it determines innovators' SSO-membership and lobbying effort decisions. However, it is framed independent of the membership cost F_p. If F_p is very low, such that $\Pi^u(R_a,\tilde{R}) > 0$, all innovators join the standard as members and those with patent quality above R_a become active members. Proposition 2 still applies for $R_l = R_h = R_a$. As rising F_p discourages passive and active membership equally, Fig. 1, which visualizes Proposition 2, plots innovators' relative equilibrium profits (net of costs) for four different levels of the effort cost F_a. In each panel (a) to (d), the *solid horizontal, black* line displays all innovators' outside option to SSO membership with a profit of 0. The *vertical, black* lines show the endogenous cutoffs between different roles of innovators. The *blue, solid* line shows the profit of an active innovator of quality R_i if all innovators of higher quality join the standard and are active. It is upward sloping as an increasing number of innovators (starting at $\bar{R}$ and moving the marginal member to the left) implies a lower average quality $\frac{\tilde{R}}{\tilde{n}}$ of the standard and thus lower per-firm royalty revenues. The *orange, dashed* line shows the profit of a passive innovator of quality R_i for the equilibrium standard size, $\tilde{R}$. It is decreasing because high-quality innovators benefit less from spillovers. For a sufficiently high-quality firm, the spillovers are 0 which leads to the kink in a passive innovator's profit function.[35]

[34] This is conceptually similar to the reason why revenue in a standard linear demand function is concave in the price.

[35] By definition, spillovers cannot be negative. Thus, we observe a kink at $-F_p$, which never impacts innovators' behavior, in equilibrium.

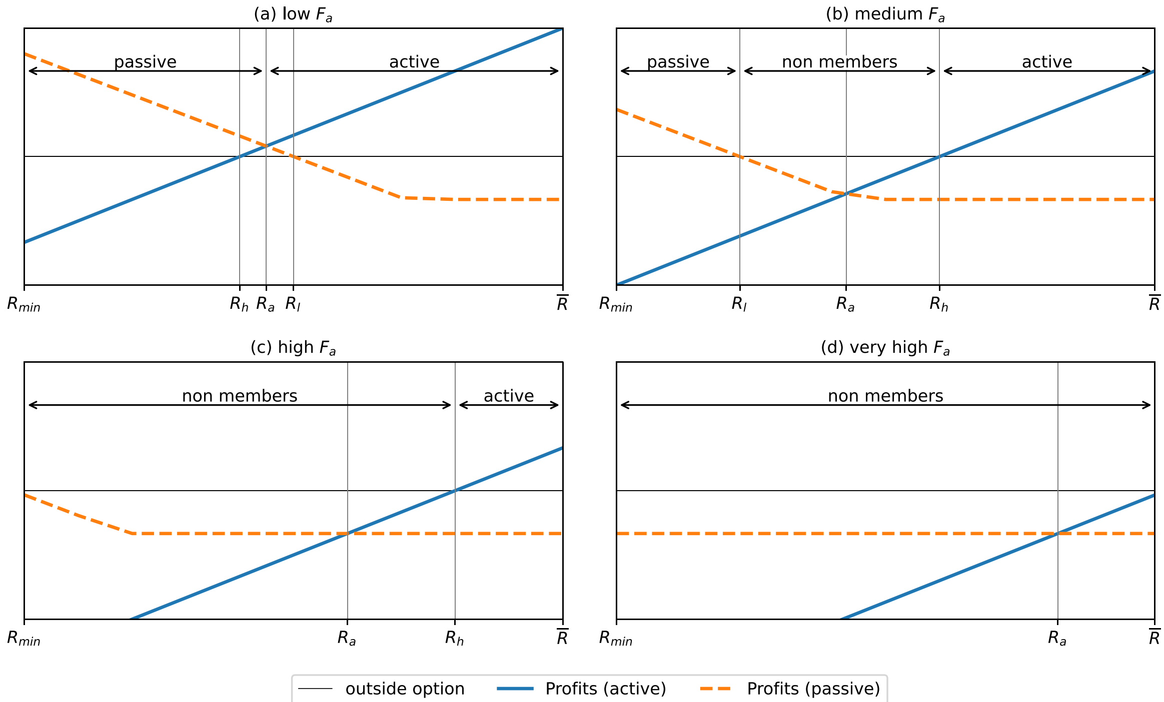

Fig. 1. Profits of innovators depending on the lobbying cost F_a. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

In each panel of Fig. 1, for each R_i, the top curve among the black, blue, and orange lines determines that innovator's payoff-maximizing choice out of being an active or passive member or not joining the standard at all. Vertical lines denote when innovators are indifferent between two choices. An upstream firm of quality $R_i = R_a$ is indifferent between being an active and passive member, and all firms with a higher (lower) quality prefer being an active (passive) member.

First, consider the overall pattern: As the strength of a given innovator increases, being a passive member becomes less attractive due to less potential to learn from knowledge spillovers. However, becoming active becomes more attractive as their contribution to the standard increases in value and so does their individual share of said contribution. Depending on the parameters we identify four exemplary ways how this can manifest itself.

In panel (a), the effort costs F_a are sufficiently low such that all upstream firms with a quality above (below) R_a become active (passive) members and no firms remain outside of the standard. As innovators' lobbying costs F_a increase, the active innovators' profits decline and fewer innovators become active members. This, in turn, lowers the profits of passive members and fewer innovators choose passive membership, too. In panel (b), the profits of a firm at $R_i = R_a$ are negative and the innovators between R_l and R_h remain outside of the standard. Increasing the lobbying cost F_a further leads to even fewer active firms, which causes the profits of the passive innovators in panel (c) to be negative: no innovators join the SSO as passive innovators. In panel (d), the lobbying costs are prohibitively high. There are no active innovators, which drives down knowledge spillover effects to zero. Hence, the SSO collapses and gets no members.

4.4. Changes in governance structure

A central purpose of this paper is to analyze how different SSO-governance structures – different allocations of control between implementers and innovators – affect the results of the model. Baron and Kanevskaia Whitaker (2022) compare four different SSO-governance structures. Independent of differences, however, all four are subject to the insight of Simcoe (2014, p. 116): "As a general rule, SSOs are responsive to their members' interests, which include giving implementers enough of a voice in the standard- setting process that they choose to participate in the shared platform". Therefore, by modeling λ as a continuous variable, we take a shortcut, which is in line with actual SSO-governance practices.[36]

We now study the comparative statics of a change in λ on equilibrium decisions and payoffs: combined profits of downstream and upstream firms, referred to as *industry profits*. We model implementers as niche monopolists in a monopolistically competitive market and thus assume that all downstream firms have some market power and can extract some but not all value accruing through the additional quality of the standard from their final consumers. Thus, *industry profits* are positively correlated with total welfare and we will use industry profits and welfare interchangeable. According to Lemma 2, industry profits are increasing in λ for a given $\tilde{R}$ and a binding λ.[37] However, a higher λ decreases the number of active innovators (lower $\tilde{R}$), in equilibrium, and thus involves a trade-off.

To attract more downstream firms, it is necessary to decrease the royalty fee p_u^*. A change in the royalty fee by itself does not change the combined profits of upstream and downstream firms. However, it affects industry profits via two channels. First, it raises demand for the standard (q_u) as more downstream firms are served, which increases industry profits ($W_u^* + W_d^*$). Innovators want to restrict access to the standard to extract a higher royalty and thus lowering the royalty rate leads to a more efficient market outcome. Second, it lowers innovators' profits, thus lowering their incentives to become active members and lowering the quality of the standard ($\tilde{R}$). In the following discussion,

[36] Moreover, studying discrete governance structures of professional associations can be involving and would stretch the scope of this paper (see Larrain and Prüfer (2015) or Prüfer (2016)).

[37] For a non-binding λ, industry profits are independent of λ. As discussed earlier, however, a non-binding λ is both uninteresting and unlikely to occur because it serves no purpose in disciplining innovators. Innovators could then freely set their profit-maximizing royalty rate while satisfying the criterion imposed by λ.

we consider a discrete increase from λ to $\lambda' \equiv \lambda + \frac{1}{m}$, where the change leads to *one more downstream implementer* being required by the SSO's by-laws to accept a technology into the standard. Let Δ be the difference operator that denotes a change in a variable and denote by $'$ the quantities after the increase in λ.[38]

A sufficiently large increase in λ can cause the market to collapse such that the maximum royalty fee the patent pool can charge is not large enough to compensate innovators for the costs of active membership. In this case, the SSO has no members and all firms make zero profits. This collapse of the market lowers the profits of all firms individually and collectively and decreases welfare. In the following discussion, we assume that at least one firm remains active for the increased value of λ'.

Industry profits: Through an increase from λ to λ', downstream firms' profits are increasing (individually and collectively):

$$\Delta\Pi^d(S_j,\tilde{R}) \begin{cases} > 0 & \text{for } S_j \geq \hat{S}(\lambda) \\ = 0 & \text{for } S_j = \hat{S}(\lambda + \frac{1}{m}) \end{cases}$$

Passive innovators are either unaffected by a change in λ, if the standard quality remains unchanged ($\Delta\tilde{R} = 0$), or harmed, if it declines:

$$\Delta\Pi^u(R_i,\tilde{R}) \begin{cases} = 0 & \text{if } \Delta\tilde{R} = 0 \\ < 0 & \text{if } \Delta\tilde{R} < 0 \end{cases} \quad \text{for } R_i \leq R_l$$

Active innovators who exit the market are harmed by an increase in λ :

$$\Delta\Pi^u(R_i,\tilde{R}) < 0 \quad \text{for } R_h \leq R_i < R_h'$$

Active innovators who remain in the market are either harmed or they benefit individually but are harmed collectively.

$$\Delta\Pi^u(R_i,\tilde{R}) \begin{cases} > 0 & \text{if } \alpha\Delta\tilde{R} < \left(\frac{\Delta n}{n} - \frac{\Delta W_u^*}{W_u^*}\right)\left(\frac{W_u^*}{n+\Delta n}\right) \\ < 0 & \text{else} \end{cases} \quad \text{for } R_i \geq R_h'$$

Finally, let $W(\lambda)$ be industry profits for a given λ. There exists a $\hat{\lambda}$ such that:

$$\Delta W(\lambda) \begin{cases} > 0 \text{ if } \Delta\tilde{R} = 0 \\ > 0 \text{ if } \lambda > \hat{\lambda} \text{ and } \Delta\tilde{R} < 0 \\ < 0 \text{ if } \lambda < \hat{\lambda} \text{ and } \Delta\tilde{R} < 0 \end{cases} \tag{9}$$

These results are proven in Appendix A.7. Their intuition is as follows.

First, if the increase in the governance parameter (λ) does *not* affect the number of active innovators, the quality of the standard ($\tilde{R}$), and thus the profits of passive innovators, remain unchanged. However, a higher λ requires a higher market coverage in the downstream market, which reduces the equilibrium royalty fee. This, in turn, increases the profits of each and all downstream firms. Downstream firms with a higher strength benefit most from this because royalties are paid based on strength. The change in royalty fees comes at the cost of active innovators' profits, who collectively lose by the same amount as implementers gain. This effect leaves welfare unchanged. However, it also expands the downstream market, raising welfare.

Second, if an increase in λ *does* lead to a reduction in the number of active innovators, in addition to the positive impact of the downstream-market expansion, it causes a costly decline in the quality of the standard affecting all involved firms. The profits of the remaining active innovators may be higher or lower than before, depending on the change to their number relative to the change in royalty caused by the decline in quality. If the loss of one active innovator leads to a large decline in the quality of the standard, active innovators are harmed. Otherwise, they benefit. However, in total, the profits of active innovators do decline in λ.

Finally, downstream firms benefit individually and collectively from the increase in λ as long as the standard remains viable. Innovators need to attract additional implementers to the standard and thus need to compensate them for any decline in the quality of the standard. Note that the per-strength net-benefit to the implementers ($\tilde{R} - p_u$) is weakly increasing in λ. This implies that high-strength implementers benefit more from an expansion of other implementers' participation since this change is multiplied with the strength of the respective implementers. They also profit from increasing λ even if doing so leads to a lower-quality standard in equilibrium. Intuitively, a higher implementer participation (higher λ) requires a lower royalty rate. As the innovators cannot discriminate based on the strength of the implementers this benefits firms proportional to the total royalty fee paid by them. Since high-strength firms pay a higher total royalty fee they also benefit more. We summarize these results in the following Corollary without formal proof.

Corollary 2 (*Governance and Welfare*). *Consider an increase in λ.*

(i) If the increase does not affect the number of active innovators, the net benefit to society is positive, where downstream firms benefit and upstream firms lose out.
(ii) If the increase in λ decreases the number of active innovators, it harms passive innovators and may lead to an increase or decrease in welfare. The net impact depends on the size of the standard and is more likely to be positive for standards including many active firms.

Items (i) and (ii) follow directly from the previously obtained. The details are presented in Appendix A.7.

Fig. 2 shows this using a numerical example.[39] Note that all $\lambda < 0.65$ are not binding. Thus, all graphs to the left of the figure are flat at their $\lambda = 0.65$-levels, and are thus omitted. For $\lambda < 0.85$, the profits of implementers are increasing in λ. With a larger degree of implementer participation, innovators need to compensate the implementers. Innovators' profits are thus (weakly) decreasing in λ. Initially, the increase in λ leaves their profits nearly unchanged but any further increase leads to a decline in profits and one innovator exits the standard. This pattern continues until the increase to $\lambda = 0.85$ causes the market to collapse: upstream firms cannot obtain sufficient profits, anymore, and thus exit.[40]

5. Discussion and extensions

Exogenous vs. endogenous governance parameter λ: λ can capture different interpretations. We model it as an exogenous parameter specifying the share of implementers that are necessary to avoid a collapse of the standard. This is tantamount to viewing λ as the minimum diffusion that is necessary for the technology to generate value, for example thanks to network effects or economies generated by compatibility. However, this view is isomorphic to a model where instead of a share of λ of downstream firms a strength–weighted share of downstream firms is required. Both can be mapped into a monotone cut-off threshold of the strength of downstream implementers. Off-equilibrium, a standard fails if less than λ implementers adopt it. However, as we consider perfect information and assume that downstream firms are royalty fee-price takers, this does not impact the results of the model.[41] Modeling

[38] This trade-off is reflective of the general trade-off faced behind innovation such that granting firms the spoils from their innovations via patents causes market imperfections but is necessary to encourage innovation.

[39] The parameter values for the graph are $F_d = 0.64$, $F_a = 4.33$, $F_p = 0.7$, $\alpha = 0.1$, $R = \{0, 0.1, \ldots, 0.9\}$, $n = 10$, $S = \{0, 0.05, \ldots, 0.95\}$, $m = 20$.

[40] This pattern is repeated for other parameter values, satisfying the assumptions defined in the model section. However, not all regions necessarily exist always.

[41] This approach is related to Llanes (2019), who studies how repeated interaction in the standard-setting process can make FRAND agreements binding.

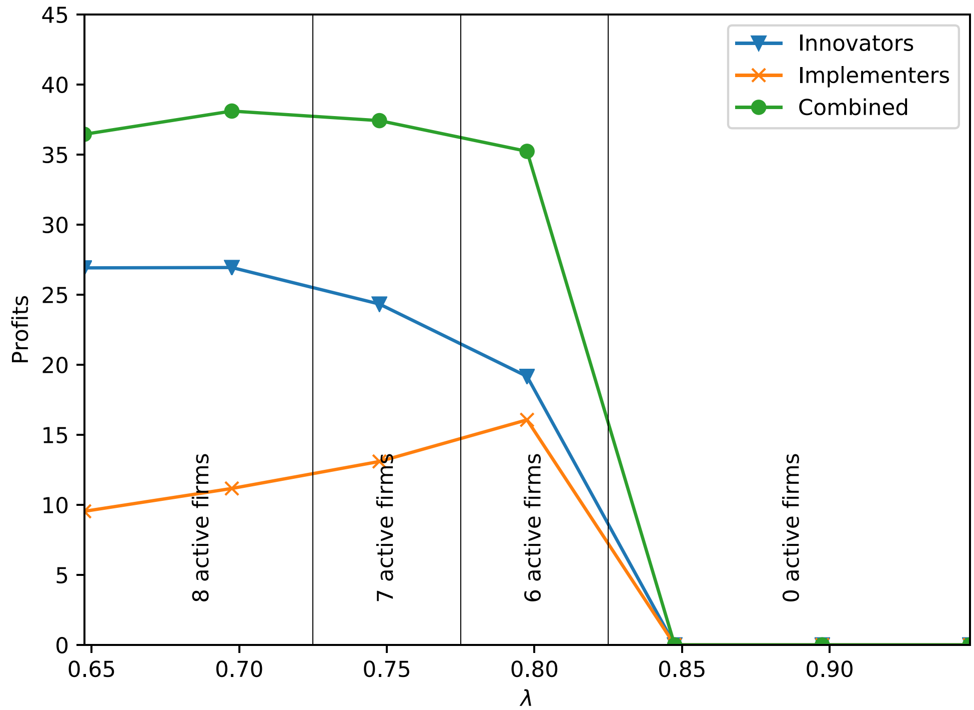

Fig. 2. Profits of firms.

λ as an exogenous parameter underlines that, from the perspective of a single firm, the SSO's governance structure is fixed. Section 4.4 studies the effects of a change in λ, which generates different empirical predictions regarding real-world SSOs that give a lot of (very little) voice to implementers.[42]

We do not endogenize λ in the model. Nevertheless, Section 4.4 can still inform policy makers because it reveals the divergent, and often conflicting, interests of the various stakeholder groups. From the innovators' perspective, the optimal λ is the one that leads to the profit-maximizing price (see Lemma 1). In contrast, from the implementers' perspective, the ideal λ is the highest λ such that at least the highest-strength innovator enters the standard. Any λ outside of this range is uninteresting from a policy perspective. If λ is too low, innovators will just charge the profit-maximizing price and license the standard to more implementers than they are required to do. If λ is too high, no standard will be set. Total welfare follows an inverted-U shape in λ and, hence, the welfare-maximizing λ is interior. Consequently, the choice of λ is driven by three forces: innovators aiming at low λ, implementers aiming at high λ, and policy makers aiming at intermediate λ. Thus, one possible way to endogenize the choice of λ is to model λ as the bargaining outcome of those three groups. However, adding such a bargaining stage explicitly is beyond the scope of this paper and would have to be tailored to the individual characteristics of a given industry.

Outside options and order of joining the SSO: How would the model change if the outside options of implementers and innovators were dependent on S_j or R_i, respectively? First, consider implementers. The model suggests that high-strength implementers gain the most from licensing the standard's technologies. Consequently, the lowest-strength implementer is pivotal and innovators need to guarantee them a non-negative profit.

[42] For instance, in the SSO-typology of Baron and Kanevskaia Whitaker (2022) the second governance model represents global partnerships of regional SDOs, the rules of which strive to strike a balance between the interests of various private actors. 3GPP and OneM2M are different subtypes of this governance model, with a different balance of power across commercial stakeholders.

Proposition 3 (*Linear Outside Option*)**.** *Assume that the value of the outside option of implementer j is given by $S_j g$, with the outside option becoming more attractive for a higher strength S_j, s.t. $g > 0$. In this case, the equilibrium royalty rate and implementers' profits are given by:*

$$p_u'(\tilde{R}, \lambda) = \tilde{R} - \frac{F_d}{\hat{S}(\lambda)} - g = p_u^*(\tilde{R}, \lambda) - g\,\Pi^d(S_j) = S_j\left(\tilde{R} - \frac{F_d}{\hat{S}(\lambda)}\right) - F_d$$

p' denotes the royalty rate necessary in the model with the aforementioned outside option and p^* denotes the royalty rate without the outside option (or $g = 0$). All implementers with a strength $S_j \geq \hat{S}(\lambda)$ join the standard while those with $S_j < \hat{S}(\lambda)$ do not. Besides the lower overall royalty, the model does not change qualitatively.

Proof. We only discuss the essentials of the proof here: The net benefit an implementer obtains from the standard is given by:

$$\Pi^d(S_j) = S_j(\tilde{R} - p_u - g) - F_d$$

Thus an implementer adopts the standard if $\tilde{R} - \frac{F_d}{S_j} - g > p_u$. Let us consider the pivotal firm of strength $\hat{S}(\lambda)$ at the $(1-\lambda)$ percentile. If the outside option was zero for all firms, the royalty rate would be equal to $p_u^*(\tilde{R}, \lambda) = \tilde{R} - \frac{F_d}{\hat{S}(\lambda)}$. □

Intuitively, a linear outside option can be perfectly compensated by an adjustment in the royalty rate. If we normalize the outside option such that the pivotal firm for a flat outside option of 0 still has an outside option of 0, i.e., such that the outside option is equal to $S_j g - \hat{S}(\lambda)$, the model would be completely unchanged. The same would be true if the outside option is any weakly *concave* function of the implementers' strength. The next proposition will discuss the case of the outside option being any *convex* function of the implementers' strength.

Proposition 4 (*General Outside Option*)**.** *Assume that the value of implementer j's outside option is given by $g(S_j)$, with the outside option becoming disproportionally more attractive for a higher strength S_j: $g'(S_j) > 0, g''(S_j) > 0$. As $g(S_j)$ is a convex function, $S_j(\tilde{R} - p_u) - F_d - g(S_j) = 0$ has at most two roots with respect to S_j, which we define as S_{low}, S_{high}*

with $S_{high} > S_{low}$.[43] *Recall that m is the number of implementers and let $\left\|\{j : a \leq S_j \leq b\}\right\|$ be the number of implementers whose strength falls between a and b. An equilibrium in stage 3 is then defined by:*

$$\frac{\left\|\{j : S_{low}(\tilde{R}, p_u) \leq S_j \leq S_{high}(\tilde{R}, p_u)\}\right\|}{m} \geq \lambda$$

As S_{low} is decreasing in p_u and S_{high} is increasing in p_u, this expression determines a maximal royalty rate that the standard can charge.

As in the baseline model, here charging a lower royalty rate might be more profitable than charging a high rate, in which case λ would not be binding. There are three cases. (i) If $S_{\text{high}} \geq \max_j(S_j), S_{\text{low}} > \min_j(S_j)$, all implementers with a strength exceeding S_{low} adopt the technology and the model behaves essentially like the baseline model. (ii) If $S_{\text{high}} < \max_j(S_j), S_{\text{low}} \leq \min_j(S_j)$, all implementers with a strength below S_{high} join the standard and those above do not. In this case, the outside option of high-strength firms is too good for them to join the standard. (iii) If $S_{\text{high}}\langle \max_j(S_j), S_{\text{low}}\rangle \min_j(S_j)$, only firms with a strength between $S_{\text{low}}, S_{\text{high}}$ join the standard. Low-strength firms do not join the standard as they do not gain enough while high-strength firms have a better outside option.

From an innovator's perspective, all cases are equivalent, as they only care about the total revenue they can obtain from the market and on licensing their SEPs to a minimum number of implementers, which is determined by λ. However, the models all exhibit a complex relationship between the quality of the standard, the royalty rate, and a trade-off between λ and industry profits.

Second, allowing innovators' outside option to depend positively on R_i would lead to more substantial changes. In the baseline model, profits of passive members are decreasing in their own quality, anyway; see (Eq. (3)). Thus, here we focus on active members. A typical equilibrium would involve low-quality innovators as passive members, mid-quality innovators abstaining from the standard, and high-quality innovators joining the standard as active members; see Proposition 2. Allowing for the outside option to depend positively on R_i might cause the highest-quality innovators to find it unprofitable to join the standard, the consequences of which depend crucially on the sequence in which innovators make membership decisions.

In the baseline model, we use Assumption 3 to guarantee that the set of innovators joining the standard is convex in R_i: if two innovators join the standard as active members, all firms with a quality between both firms do so, too (details in Appendix B). Such an equilibrium still exists if we allow the outside option to depend on R_i. Under this new regime, such an equilibrium would take the following form: lowest-quality innovators become passive members, lower-medium quality innovators abstain, upper-medium join as active members, and highest-quality innovators abstain. The main reason why we do not allow for this in the baseline model is that allowing for an outside option that depends on R_i renders equilibria inherently unstable. A reduction in λ raises the profits of the innovators collectively and will incentivize a low-quality innovator to enter the standard. Depending on how the total profits of the standard change, it can also lead to a high-quality firm entering the standard—or dropping out. If a high-quality innovator drops out of the standard, the next highest innovator might find it unprofitable to remain. The standard may collapse by unraveling from the top. Avoiding the danger of such a collapse is mathematically difficult and eludes a simple analytical criterion. Consequently, such a more complex model would be less robust and, hence, less helpful for economic intuition and policy making.

[43] For ease of exposition, we consider the cases of 1 or 0 roots to be defined by $S_{\text{low}} = -\inf$ or $S_{\text{high}} = \inf$, or both.

Substitutive and complementary technologies: We only model innovators' technologies that are neither complements nor substitutes, such that the marginal contribution of a upstream firm to the standard is independent of member firms' types. As we will see, this does not qualitatively affect the model's results. Together with the assumption, that upstream firms join in order of decreasing patent quality, assuming complementary technologies would be no different than changing the distribution of the quality of the firms' patents. For ease of exposition, we will ignore the extent of knowledge spillovers and the choice of becoming a passive member below.

Innovator i bases its decisions to join the standard as an active member on the average revenue of the standard after it has joined. Consider that the first innovator, firm 1, has joined such that $\tilde{R} = R_1$ and that the second innovator, with R_2, is considering its choice to join the SSO. It will join if the average revenue after joining exceeds the costs of doing so, such that $W_u^*(f(R_1, R_2), \lambda)/2 > F_a$ where $f(\cdot)$ is a function that models the degree of complementarity. If patents are complements, we have that $f(x, y) > x + y$; if they are substitutes, $f(x, y) < x + y$; and if they are neither, $f(x, y) = x + y$.

Now consider $\hat{R}_2 \equiv f(R_1, R_2) - R_1$, i.e., the marginal contribution of firm 2. Clearly, this will be greater, smaller, or equal to R_2, depending on the degree of complementarity. By instead denoting the quality of firm 2 as $\hat{R}_2$, we can transcribe the model with complementarity to one without. We can repeat this process for all following firms by replacing their quality with their marginal contribution to fully transcribe the model.

This will have implications for the standard. If patents are complements, we would expect to see a larger standard and that any change that encourages an additional innovator to join the standard, e.g. after lowering λ, will have a higher potential to lead to more than one upstream firm joining. Similarly, an increase in λ has a higher potential to lead to the collapse of the standard and to render the standard less stable. For patents that are substitutes, we observe the inverse pattern, such that changing parameters will have a softened impact on the size of the standard. However, no qualitative changes will occur.[44]

Formally, allowing for more complex relationships between the quality of the patents and the quality of the standard requires replacing Proposition 1 by the following:

Proposition 5 (*Active Members, Non-Linear Standard Quality*). *Let $\mathcal{R}_a \subseteq \mathcal{R}$ be the set of all active innovators that are active in the standard and let $W_u^*(\mathcal{R}_a, \lambda)$ be the royalty revenue if $\mathcal{R}_a$ innovators join the standard. Then, in equilibrium we require:*

$$\frac{W_u^*(\mathcal{R}_a, \lambda)}{\tilde{n}} \geq F_a$$

$$\frac{W_u^*(\mathcal{R}_a \cup \{i\}, \lambda)}{\tilde{n}+1} \leq F_a \qquad \forall i \in \mathcal{R} \setminus \mathcal{R}_a$$

where, at Stage 2, all innovators in $\mathcal{R}_a$ exert efforts of F_a and become active members.

We omit the proof for the proposition above. It guarantees both that none of the innovators who are not active members of the SSO want to become active and that the active members make a positive profit. However, defining a full model would be much more involved. As discussed above, allowing for the quality of the standard to not be the sum of all patents contributed will lead to a multiplicity of equilibria. Furthermore, it would be difficult to pin down parameters that guarantee even the existence of a pure-strategy equilibrium.

[44] It should be noted that this transcription will affect the structure of the passive innovators' potential to learn as that is based on their original quality R_i, not on the transcribed $\hat{R}_i$. However, this will only lead to a minor change, where innovators become passive instead of non-members, and will not affect any other aspects of the model.

Royalty-fee structure: The model above subjects the patent pool to a simple royalty-fee structure that is linear in an implementer's strength, or market share. This leaves some implementers positive surplus from licensing (Lemma 2).

Proposition 6 (*Royalty Rate Under Two-Part Tariff*)**.** *Consider innovators being able to charge a two-part tariff consisting of a lump-sum royalty fee of $\bar{p} \in \mathbb{R}$ and a strength-dependent royalty fee of $p_u \in \mathbb{R}$. The optimal royalty fee would be independent of λ and be equal to:*

$$\bar{p} = -F_d,\ p_u = \tilde{R}$$

All implementers make 0 profits and all implementers for whom $S_j \tilde{R} > F_d$ join the standard.

In principle, innovators can extract all implementers' surplus by setting the two-part tariff. One possible approach would be for the innovators to set the royalty rate to $\tilde{R}$ per unit of technology implemented and pay each implementer a fixed rebate of F_d (see Eq. (4)). Under such a regime, all implementers would obtain zero profits. However, this could lead to some implementers joining the standard even if it hurts welfare. To avoid this, innovators could lower the royalty rate and the rebate by a small amount. This could make sure that low-strength implementers would not join the standard while innovators can extract profits arbitrarily close to the maximum. Crucially, for this result to materialize, individualized rebates from innovators to implementers are essential, which requires that innovators have detailed information about the strength and willingness-to-pay for the standard from each individual implementer. While this is assumed in our model and possible to some degree in reality, individualized rebates are often seen as problematic from an antitrust perspective (risking being judged exploitative) (Layne-Farrar (2010)).

Related, offering different licensing terms to "similarly situated" licensees is generally viewed as discriminatory. It is therefore subject to ongoing scholarly discussion whether individualized pricing of intellectual property hurts the "ND"-part of FRAND licensing commitments (Wong-Ervin (2019)).

Leaving antitrust and FRAND-concerns aside, if innovators had the ability to charge individualized (net) royalty fees, i.e., to perfectly discriminate prices, they could extract the full surplus from all implementers. Specifically, alternatively to charging $\tilde{R}$ and paying each implementer a fixed rebate of F_d, the patent-pool manager could set the per-unit royalty fee p_u to such a low level that all implementers accept the TIOLI offer (as if $\lambda = 1$) and then charge individualized upfront payments that increase in an implementer's strength S_j. Then, however, all implementers would have the same incentive to join the SSO (expecting zero surplus). λ would not be binding and SSO-governance would not play any role for outcomes. This is clearly in contrast to existing evidence (Baron and Kanevskaia Whitaker (2021) and Baron and Kanevskaia Whitaker (2022)). We therefore hold that the linear royalty-fee structure modeled here does not lead to unrealistic results but is simpler than considering two-part-tariffs.

Monopolistically competitive downstream markets: In the baseline model, we study monopolistically organized downstream markets, where implementers do not directly compete with each other on the downstream market or for the technology itself. We belief that this assumption is essential to easily communicate the core idea behind this paper. However, this comes with limitations. Therefore, we now consider a model where the adoption of the standard by one implementer impacts the incentives of other implementers. Depending on the downstream market under observation the incentives to adopt the standard (strategic complements) or decreasing (strategic substitutes) in the number of other implementers who do so. The direction can also depend on the number of implementers.

For example, consider a market where some but not all customers are willing to pay a high premium for quality. By adopting the standard a firm can create its own niche within the market and obtain higher profits. However, as more implementers adopt the standard and thus join the high-quality segment competition increases making it less attractive to do so.

If only few implementers adopt the standard and thus sell high-quality products competition in this segment is low and they are able to profit. As more implementers adopt the standard, the high-quality segment becomes more competitive thus making it hard for firms to benefit from adopting the standard. Alternatively, if all customers value high quality equally firms are forced to adopt the standard once the majority of their competitors has done or otherwise not sell any of their inferior products.

More formally, this would imply that the implementers' profits (Π^d) for a given standard not only depend on their own choices but also the choices of other implementers. For simplicity, consider a market with only 2 implementers ($i, j \in 1, 2$), both having strength $S_i = 1$ and being otherwise symmetric. Finally we assume that joining the SSO is not incurring any costs besides beside the royalty rate for implementers such that $F_d = 0$. We define the benefit of adopting the technology without the royalty rate in the following bi-matrix with each entry showing the profits of firm i first and firm j second:

	j joins SSO	j does not join
i joins SSO	$\Pi^d_{1,1}/\Pi^d_{1,1}$	$\Pi^d_{1,0}/\Pi^d_{0,1}$
i does not join	$\Pi^d_{0,1}/\Pi^d_{1,0}$	$\Pi^d_{0,0}/\Pi^d_{0,0}$

Note that the bi-matrix shown above only includes the benefit but not the cost of adopting the standard as it excludes the royalty fee charged as the latter will be the focus of our discussion. In any market we expect that implementers benefit from adopting the technology but are harmed by their competitor adopting it such that $\Pi^d_{1,0} > \Pi^d_{1,1} > \Pi^d_{0,0} > \Pi^d_{0,1}$.

We only consider implementers who are price takers and are not able to collude. Innovators are able to extract from each firm the marginal benefit of joining the standard. If they only include one implementer, this benefit is $W_{u,1} = \Pi^d_{1,0} - \Pi^d_{0,0}$. If they include both implementers, it is $W_{u,2} = 2\left(\Pi^d_{1,1} - \Pi^d_{0,1}\right)$. We will now consider two cases depending on whether $W_{u,2} > W_{u,1}$ or $W_{u,1} > W_{u,2}$.

First, consider (strong) *Strategic Complements* such that $W_{u,2} > W_{u,1}$. In this case, adopting the standard is (substantially) more important if the implementer believes that the other firm has adopted the standard.[45] The innovators can obtain a higher profit if they include both implementers in the standard. To do so they need to set the royalty fee to be equal to $W_{u,2}/2$, i.e., the marginal benefit of adopting the standard if the implementer beliefs the other firm will do so.[46] This royalty fee is too high to convince a downstream firm to join the standard if it beliefs that the other firm will not do so. Thus, stage 3 will feature two Nash Equilibria, one in which both implementers join the standard and one where neither joins the standard.[47]

Now consider the impact λ has on this. First, for $\lambda = 0$ innovators may chose to follow the optimal strategy outlined above. Second, for $\lambda = 0.5$ such that only one firms would not change the results and innovators would still charge the optimal royalty fee of $W_{u,2}/2$ and

[45] Technically, strategic complements correspond to $\left(\Pi^d_{1,1} - \Pi^d_{0,1}\right) > \left(\Pi^d_{1,0} - \Pi^d_{0,0}\right)$. However, from the innovators perspective a market with weak strategic complements behaves identically to the market of strategic substitutes. Thus, we will refer to $W_{u,2} > W_{u,1}$ as strategic complements and to $W_{u,1} > W_{u,2}$ as strategic substitutes.

[46] Or $W_{u,1} - \varepsilon$ where ε is some infinitesimally small value in order to break any ties.

[47] Such a game is also called a Stag Hunt game. Since the equilibrium where both implementers adopt the standard is Pareto-superior, we would expect the SSO to be able to nudge its members to adopting it over the equilibrium without a standard.

cover the full market. However, setting $\lambda = 1$ such that both firms need to be part of the standard changes the results. Now both implementers are pivotal and if one of them does not adopt the technology, the standard fails. Consequently, the marginal benefit of adopting the standard for a given implement is $\Pi^d_{1,1} - \Pi^d_{0,0}$, i.e., the benefit of both firms using the standard relative to none of them. Consequently the total royalty income is $2\left(\Pi^d_{1,1} - \Pi^d_{0,0}\right)$. Interestingly, in contrast to the model used in this paper an increase in λ still increases the bargaining power of the implementers and thus leads to a lower royalty despite not changing the number of implementers who license the technology.

Second, consider *Strategic Substitutes*, where $W_{u,1} > W_{u,2}$. In this case, adopting the standard is more beneficial if the implementer believes that the other firm does not adopt. Now λ matters for the choices taken by the innovators and the number of implementers served. First, consider $\lambda = 1$ such that innovators need the support of both implementers. They need to set the royalty fee to $W_{u,2}/2$ such that stage 3 only features a unique Nash Equilibrium that has both firms joining the standard.[48] If $\lambda \leq 0.5$, such that innovators need the support of only one implementer, they can obtain a higher profit by setting the royalty fee to $W_{u,1}$. Then implementer i finds it more beneficial to join the standard only if it beliefs that its competitor does not join. This gives rise to two Nash Equilibria, both with only one implementer joining the standard.[49]

Based on this, the baseline model produces a version of the second case, where $W_{u,1} > W_{u,2}$ and where the incentives of a firm adopting the standard are decreasing or only slightly increasing with the number of other implementers that do so. In fact, the decline in the strength of the implementers that join the standard in our model has an almost identical effect to the decline of the marginal benefit of joining the standard seen here. However, in addition a model similar to the one described here would require us to make substantial assumptions on the beliefs of implementers, the order in which they make their decision, the relationship between adopting the standard and welfare, and how implementers are limited in their strategic interaction that we decided to abstract form it.

6. Conclusion

This paper started with some key empirical observations and open questions regarding standard-setting organizations. Most of the growing literature on standard setting focuses on pricing and market interactions. By contrast, we took an organizational perspective and studied the membership decisions of both innovators and implementers in the context of knowledge spillovers and endogenized innovators' efforts to get their technology into the standard in this model (and in practice, as Gupta (2017) suggests). We analyzed how these results change if the distribution of control between upstream and downstream firms, that is, SSO-governance, changes.

The model is designed to replicate the empirical observation, that standard participation is driven by active firms with high-quality technologies. However, membership also includes firms with weak patents. A lesson of the model is that innovators' SSO-membership can be driven by various different motivations (Proposition 2): a group of upstream innovators, just as assumed in most of the literature, join to get their technologies included in the standard and to reap high profits from having a *de-facto* monopoly on their component in the bundle of standard-essential patents. However, low-quality innovators have little to gain from having their patents included in the standard. Instead, we rationalize that they strive for the knowledge spillovers from larger innovators, which can boost their own R&D activities and increase future profits. This non-monotonicity in innovators' R&D intensity regarding the incentives to join an SSO can explain seemingly inconsistent findings of the empirical literature (Blind and Thumm (2004) vs. Gupta (2017)): why real-world SSOs are so large and include very heterogeneous members. The model also shows that downstream firms' SSO participation can be a powerful commitment device for innovators to lower their royalty fees to a socially superior level.

Turning to governance, the results have shown that, if an SSO requires a higher percentage of implementers to agree to a specific technology to become standard-essential, it has a series of consequences. In the short run, implementers benefit from lower licensing fees and society from higher inclusion rates of implementers. However, this comes at the cost of reduced incentives for innovators, which leads to lower-quality standards. This harms implementers, passive innovators, and potentially society as a whole. Taking a dynamic perspective, if would-be innovators understand that, for instance, because of network effects and complementarities among many component producers, an SSO would be the efficient organizational vehicle to promote their technology in case of innovation success, and if they expect the SSO to be governed largely by implementers, they may refrain from investing in R&D in the first place. This implies both for the managers of SSOs writing up their governance rules and for policymakers pondering about mandatory participation rates of implementers, that high levels of decision-making power for implementers could have negative effects for all involved groups and, hence, for total welfare. We showed that the welfare-maximizing level of λ is strictly interior, that is, optimal SSO-governance is always based on shared control by innovators and implementers. This finding is reflected by empirical studies of SSO-governance (e.g. Simcoe (2012), Baron et al. (2019) and Baron and Kanevskaia Whitaker (2022)).

Interestingly, the model shows that high-quality and low-quality innovators have conflicting incentives with respect to the inclusion of downstream firms. For high-quality innovators, raising membership too much leads to a decline in profits as it dilutes the royalty income generated by the patent pool. However, this may be counteracted by the exit of marginal active innovators, who find it non-profitable anymore to add their technology to the standard as the royalty fee declines. Especially if the market is saturated, this can be a profitable strategy. Thus, high-quality innovators might see comprehensive downstream participation as a way to discourage low-quality innovators from joining the standard and might even push for a high degree of implementer control (λ). Passive innovators, by contrast, aim for a standard that maximizes the number of active innovators because of knowledge spillovers. Therefore, they have an incentive to restrict downstream participation in the SSO.

Concerning the downstream market, we find that all implementers profit from a higher participation rate. However, as innovators need to charge a lower royalty fee to attract new implementers, the high-strength implementers profit the most from the inclusion of additional downstream firms. Surprisingly, this effect increases in the firms' strength if the inclusion of downstream firms leads to a decline in the standard's quality.

These results highlight several mechanisms that policymakers may want to consider to maximize welfare. First, downstream participation is beneficial as it limits the hold-up problem through upstream firms' ability to restrict supply to maximize their royalty revenue. This has to be weighed against the undermining of upstream investors' participation incentives. Moreover, in both groups, large firms push for broad inclusion of implementers. Both high-quality innovators and high-strength implementers strive to include additional implementers in the standard to obtain higher profits. This move, however, is to the detriment of smaller innovators and implementers. If policy makers are aware of such contradictory incentives, they should thus be cautious to let technology markets be self-governed by SSOs that are dominated by large firms. It might be better for standard-setting organizations to pay attention to the objectives of small implementers when determining to what extent implementers should participate in the standard-setting process.

48 The game follows a Prisoner's dilemma.

49 Such a game is called a Chicken game.

Regarding industry profits, we find an inverted U-shape in the participation of implementers in SSO control. As downstream participation becomes broader, industry profits first increase, as implementers join and the market benefits from a wider coverage. However, the more implementers join the standard, the lower becomes the potential for innovators to charge a high royalty rate and, hence, to make profits. As participation increases, the second effect becomes relatively more important and dominates at one point. Thus, for sufficiently large participation, industry profits are declining in downstream participation (or downstream impact on SSO-governance). As we are studying monopolistically competitive markets, consumer surplus qualitatively follows industry profits. Hence, so does welfare.

Looking forward, the model in this paper is based on several simplifying assumptions. Relaxing them, one by one, would generate helpful intuitions for researchers and policy makers alike. To make a start, in Section 5, we discuss robustness of our results to several important modeling changes, including endogeneity of the implementers' SSO control, more realistic outside options of firms, complementarities among standard-essential patents, royalty rates with a two-part tariff structure, and downstream market structure. Appendices B and C offer model extensions regarding the order of decision-making of innovators and the role of their beliefs, as well as cases where innovators and implementers are vertically integrated. Most notably, by focusing on the organizational structure of SSOs, we ruled out product-market competition between upstream or between downstream firms. In practice, the views of both industrial organization and organizational economics will be interwoven, which might generate strategic incentives for firms that go beyond the scope of this paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

Appendix A. Proofs

A.1. Proof of Lemma 1

Proof. Without being limited by λ the patent-pool manager sets the royalty rate to maximize total royalty revenue for the given quality of the standard. Based on Eq. (4), for a given royalty rate p_u and standard with quality $\tilde{R}$, the profits of the downstream firms are increasing in their strength. Thus, if a downstream firm of strength S_i is indifferent between joining and not joining, all firms with a strength exceeding it strictly prefer joining the standard. Furthermore, the downstream firms' profits are decreasing in p_u. Thus, for a given $\tilde{R}$, the profit-maximizing royalty rate leaves one implementer with zero profits after joining the standard (the pivotal firm) and all implementers with a higher strength with positive profits.

Recall that the total royalty revenue for a given royalty rate and standard quality is:

$$W_u(p_u, \tilde{R}) = \sum_{j \in \tilde{S}(p_u, \tilde{R})} S_j p_u$$

Let $\hat{S}$ be the strength of the pivotal implementer and $\hat{j}$ their index. Furthermore, recall that strength S_j is distributed at a regular interval with step-size σ such that $S_j = \bar{S} - (j-1)\sigma$ with $\sigma \in (0, \frac{\bar{S}}{m-1})$. The optimal royalty rate can be written based on the pivotal firm it induces: $p_u = \tilde{R} - \frac{F_d}{\hat{S}}$. The royalty revenue is given by:

$$\begin{aligned} W_u(p_u, \tilde{R}) &= \hat{j} \frac{\bar{S} + \hat{S}}{2} \left(\tilde{R} - \frac{F_d}{\hat{S}} \right) \\ &= \hat{j} \left(\bar{S} - \frac{(\hat{j}-1)\sigma}{2} \right) \left(\tilde{R} - \frac{F_d}{\bar{S} - (\hat{j}-1)\sigma} \right) \end{aligned}$$

Thus, the profit-maximizing price can be found as:

$$\begin{aligned} j^\circ(\tilde{R}) &= \arg\max_{j \in \mathcal{M}} \left(j \left(\bar{S} - \frac{(j-1)\sigma}{2} \right) \left(\tilde{R} - \frac{F_d}{\bar{S} - (j-1)\sigma} \right) \right) \\ p_u^\circ(\tilde{R}) &= \tilde{R} - \frac{F_d}{\bar{S} - (\hat{j}(\tilde{R}) - 1)\sigma} \\ &= \arg\max_{p_u} W_u(p_u, \tilde{R}) \end{aligned}$$

p_u° is increasing in $\tilde{R}$. To see this, consider an increase in $\tilde{R}$ and p_u by the same amount, such that in the above equation only $\tilde{R}$ changes. The optimal royalty rate would grow.

Consider a decrease to the royalty rate by Δp_u such that exactly one additional implementer licenses the standard. This increases $\hat{j}$ by one (one more implementer adopts the standard) and decreases $\hat{S}$ by σ (the quality of the lowest strength implementer declines). For ease of notation we define the total downstream demand before the expansion of the standard as $q_u = \frac{\bar{S}+\hat{S}}{2}\hat{j}$. Consider the change this induces to $\Delta W_u(p_u, \tilde{R})$:

$$\begin{aligned} \Delta W_u(p_u, \tilde{R}) &= \frac{\bar{S} + \hat{S} - \sigma}{2} (\hat{j} + 1) \left(\tilde{R} - \frac{F_d}{\hat{S} - \sigma} \right) - \frac{\bar{S} + \hat{S}}{2} \hat{j} \left(\tilde{R} - \frac{F_d}{\hat{S}} \right) \\ &= \left(q_u + \hat{S} - \sigma \right) \left(\tilde{R} - \frac{F_d}{\hat{S} - \sigma} \right) - q_u \left(\tilde{R} - \frac{F_d}{\hat{S}} \right) \\ &= (\hat{S} - \sigma)\tilde{R} - \frac{q_u + \hat{S} - \sigma}{\hat{S} - \sigma} F_d + \frac{q_u}{\hat{S}} F_d \\ &= (\hat{S} - \sigma)\tilde{R} - F_d \left(1 + \frac{\sigma q_u}{\hat{S}(\hat{S} - \sigma)} \right) \end{aligned}$$

By assumption, $S_{\hat{j}-1} = \hat{S} - \sigma > 0$. The first part ($(\hat{S} - \sigma)\tilde{R} > 0$) gives the additional profits as the technology can be marketed to more implementers. It is positive and declining in $\hat{S}$. As more implementers join the strength of the marginal implementer and thus their ability to make use of the technology decreases. For the second part, note that $\hat{S} - \sigma > 0$. Otherwise, the strength of the next firm was negative. Consequently, the second factor is negative.

Secondly, as the number of implementers licensing the product increases, so does q_u (by $\hat{S} - \sigma$), while $\hat{S}$ declines. Thus, $1 + \sigma \frac{q_u}{\hat{S}(\hat{S}-\sigma)}$ is increasing in the number of implementers. Hence, $\Delta W_u(p_u, \tilde{R})$ is declining in the number of implementers or, equivalently, the change to profits caused by attracting one more implementer is decreasing in the number of implementers in standard. This is the discrete equivalent of saying that $W_u(p_u, \tilde{R})$ is a concave function of the royalty p_u. □

A.2. Proof of Lemma 2

Proof. Recall the royalty as defined in Lemma 2:

$$\begin{aligned} p_u^*(\tilde{R}, \lambda) &= \tilde{R} - \frac{F_d}{\hat{S}(\lambda)} \\ \Pi^d(S_j, \tilde{R}) &= S_j \left(\tilde{R} - p_u \right) - F_d \end{aligned}$$

The innovators are committed to serve at least a proportion λ of the implementers. Per assumption, the profit-maximizing royalty rate p_u° is not compatible with this λ. Furthermore as we have seen in the proof of Lemma 1, the profits are concave in the royalty rate.[50]

[50] Technically, this is only true for its convex hull, i.e., the tips of the teeth of the sawtooth pattern. For ease of exposure we will abuse the notation in this section to only talk about the convex hull.

Consequently the profits of the implementers are given by:

$$\Pi^d(S_j, \tilde{R}) = \frac{S_j - \hat{S}(\lambda)}{\hat{S}(\lambda)} F_d$$
$$\Pi^d(\hat{S}(\lambda), \tilde{R}) = 0$$

In equilibrium $\Pi^d(S_j, \tilde{R})$ is strictly positive for $S_j \geq \hat{S}(\lambda)$. Thus all firms with $S_j \geq \hat{S}(\lambda)$ join the standard. The demand for the standard only depends on λ at least for small changes to the parameters. Note that large changes can lead to either the profit-maximizing rate being lower than the one implied by λ. In this case, λ does not become binding. Alternatively, an increase in λ leads to an additional implementer being included in the standard. The profit of the new implementer is 0. For the new implementer to join the standard, the royalty rate needs to decrease, while $\tilde{R}$ remains unchanged. Thus, all active implementers profit from the lower royalty rate and total downstream profits increase.

Furthermore, consider a change to λ, that exactly one additional implementer of strength, $\hat{S}(\lambda) - \sigma$, adopts the technology. The change in industry profits caused by this is given as:

$$\Delta W(\lambda) = (\hat{S}(\lambda) - \sigma)\tilde{R} - F_d = (\hat{S}(\lambda) - \sigma) p_u(\tilde{R}, \lambda')$$

For $(\hat{S}(\lambda) - \sigma)\tilde{R} > F_d$, the change $\Delta W(\lambda)$ is positive. If $(\hat{S}(\lambda) - \sigma)\tilde{R} < F_d$, the price is required to be negative as the implementer of strength $\hat{S}(\lambda) - \sigma$ cannot profitably market the technology. In this case, the market collapses such that the equilibrium quality of the standard is zero. Innovators set the royalty to exactly extract all the surplus generated by the lowest-strength implementer. Thus, if the royalty remains positive, increasing the number of implementers raises joint industry profits. □

A.3. Lemma 3

Lemma 3 (*Declining Marginal Royalty Revenue*). *For a given $\tilde{R}$, the change in total royalty profits caused by an increase in λ ($\Delta W_u^*(\tilde{R}, \lambda) \equiv W_u^*(\tilde{R}, \lambda + \frac{1}{m}) - W_u^*(\tilde{R}, \lambda)$) is decreasing in λ, such that:*

$$\Delta W_u^*(\tilde{R}, \lambda + \tfrac{1}{m}) - \Delta W_u^*(\tilde{R}, \lambda) \leq 0$$

Furthermore, for the highest quality standard possible such that all innovators join the standard and $\tilde{R} = \sum_{i \in \mathcal{N}} R_i$ total upstream profits $W_u^*\left(\sum_{i \in \mathcal{N}} R_i, \lambda\right)$ are quasi-concave in λ. Thus, the innovator profit maximizing $\lambda^\circ \in (0, 1]$ satisfies:

$$\Delta W_u^*\left(\textstyle\sum_{i \in \mathcal{N}} R_i, \lambda\right) \begin{cases} \leq 0 & \text{for } \lambda \geq \lambda^\circ \\ \geq 0 & \text{for } \lambda < \lambda^\circ \end{cases}$$

Consequently, for any quality of the standard $\tilde{R} \leq \sum_{i \in \mathcal{N}} R_i$ and any $\lambda \geq \lambda^\circ$, royalty revenue is declining in λ, such that $\Delta W_u^*(\tilde{R}, \lambda) \leq 0$.

Proof. The royalty rate is given by:

$$W_u^*(\tilde{R}, \lambda) = q_u^*(\lambda)\tilde{R} - \frac{q_u^*(\lambda)}{\hat{S}(\lambda)} F_d$$

Raising λ by $\frac{1}{m}$ leads to a change in W_u^* such that:

$$\begin{aligned}\Delta W_u^*(\tilde{R}, \lambda) \equiv W_u^*(\tilde{R}, \lambda + \tfrac{1}{m}) - W_u^*(\tilde{R}, \lambda) &= \hat{S}(\lambda)\tilde{R} - \frac{q_u^*(\lambda + \frac{1}{m})}{\hat{S} - \sigma} F_d \\ &\quad + \frac{q_u^*(\lambda)}{\hat{S}(\lambda)} F_d \\ &= \hat{S}(\lambda)\tilde{R} - \frac{q_u^*(\lambda) + \hat{S}(\lambda)}{\hat{S}(\lambda) - \sigma} F_d \\ &\quad + \frac{q_u^*(\lambda)}{\hat{S}(\lambda)} F_d \\ &= \hat{S}(\lambda)\tilde{R} - \frac{\hat{S}(\lambda)^2 + q_u^*\sigma}{\hat{S}(\lambda)^2 - \hat{S}(\lambda)\sigma} F_d\end{aligned}$$

First, note that $\hat{S}(\lambda)\tilde{R}$ is declining in λ. Second, $\frac{\hat{S}(\lambda)^2 + q_u^*\sigma}{\hat{S}(\lambda)^2 - \hat{S}(\lambda)\sigma} > 1$ with $\hat{S}(\lambda)$ decreasing by σ and q_u^* increasing by $\hat{S}(\lambda) > \sigma$. Furthermore, as the expression $\frac{a+(1+\gamma)x}{a-x}$ is increasing in x for $\gamma > 1$ so is, $\frac{\hat{S}(\lambda)^2 + q_u^*\sigma}{\hat{S}(\lambda)^2 - \hat{S}(\lambda)\sigma} F_d$ is increasing in λ. Thus, $\Delta W_u^*(\tilde{R}, \lambda) = W_u^*(\tilde{R}, \lambda + \frac{1}{m}) - W_u^*(\tilde{R}, \lambda)$ is decreasing in λ. The expression $\Delta W_u^*(\tilde{R}, \lambda)$ is the equivalent of the first derivative. The fact that it is decreasing is equivalent to the second derivative being negative. While λ is discrete, $\Delta W_u^*(\tilde{R}, \lambda)$ being declining is the equivalent of the profit function being concave in λ. Furthermore, for a given λ the derivative $W_u^*(\tilde{R}, \lambda + \frac{1}{m}) - W_u^*(\tilde{R}, \lambda)$ is increasing in $\tilde{R}$. Thus, as more firms join the standard, the profit-maximizing price decreases.

The profit-maximizing λ can be found by maximizing $W_u^*(\tilde{R}, \lambda)$, which, in turn, yields the profit-maximizing royalty rate p_u^*. For each λ below the profit-maximizing level, the outcome of the market is identical to the outcome for the profit-maximizing λ. □

A.4. Proof of Proposition 1

Proof. Lemma 2 gives the optimal royalty fee for each quality of the standard $\tilde{R}$:

$$p_u^*(\tilde{R}, \lambda) = \tilde{R} - \frac{F_d}{\hat{S}(\lambda)}$$

Consider a standard of quality $\tilde{R}$ and let R_a be the quality of the highest-quality innovator who is *not* part of the standard. If R_a does not join the standard, the per-firm royalty needs to exceed the costs of joining the standard. Otherwise, firms in the standard find it not profitable to be active. Thus, $\frac{W_u^*(\tilde{R},\lambda)}{\tilde{n}} \geq F_a$. Secondly, if after joining the per-firm royalty still exceeds the costs of doing so, firm R_a would join the standard and no equilibrium would be reached. Thus, $F_a > \frac{W_u^*(\tilde{R}+R_a,\lambda)}{\tilde{n}+1}$.

Ceteris paribus $\frac{W_u^*(\tilde{R},\lambda)}{\tilde{n}}$ is increasing in $\tilde{R}$. Thus, if the per-firm royalty revenue is less than F_a for innovator R_a, it also is for any innovator of quality $R_i < R_a$. If the per-firm royalty revenue exceeds F_a for innovator R_a so it does for any other innovator with $R_i > R_a$. □

A.5. Proof of Corollary 1

Proof. We start with the expression implicitly defining R_a in Proposition 1:

$$\frac{W_u^*(\tilde{R}, \lambda)}{\tilde{n}} \geq F_a > \frac{W_u^*(\tilde{R} + R_a, \lambda)}{\tilde{n} + 1},$$

(i) An increase in F_a implies that a greater $\frac{W_u^*(\tilde{R},\lambda)}{\tilde{n}}$ is required for the inequality to be satisfied. Thus, fewer innovators need to be part of the standard to raise the royalty per firm.
(ii) An increase in $\tilde{R}$ raises the quality of all innovators, which raises $\frac{W_u^*(\tilde{R},\lambda)}{\tilde{n}}$ and $\frac{W_u^*(\tilde{R}+R_a,\lambda)}{\tilde{n}+1}$. Consequently, a higher number of firms is required for the inequality to be fulfilled.
(iii) An increase in ρ lowers $\frac{W_u^*(\tilde{R},\lambda)}{\tilde{n}}$ as the quality of all but the best innovator's quality declines and lowers $\frac{W_u^*(\tilde{R}+R_a,\lambda)}{\tilde{n}+1}$, thus lowering $\tilde{n}$.
(iv) An increase in λ lowers $\frac{W_u^*(\tilde{R},\lambda)}{\tilde{n}}$ and $\frac{W_u^*(\tilde{R}+R_a,\lambda)}{\tilde{n}+1}$ thus lowering $\tilde{n}$. □

A.6. Proof of Proposition 2

This proof follows directly from Lemma 2, Proposition 1, and Assumption 4. The results follow from the profit of the indifferent innovator, between active and passive innovators, generates within the standard.

Proof. Lemma 2 states the optimal licensing fee for each strength of the standard. Based on this, Proposition 1 states the equilibrium in stage 2, where all firms behave optimally. Thus, we only need to show that the thresholds R_l and R_h exist and that behavior in stage 1 is optimal.

First, by Assumption 4 the highest-quality innovator finds it profitable to join an empty standard. Hence, we can rule out an equilibrium where $\tilde{R} = 0$. Based on Proposition 1, there exists a cut-off R_a such that firms with quality above R_a become active members if they join the SSO at all. We distinguish two cases:

Case 1: $\Pi^u(R_a, \tilde{R}) < 0$. In this case, the innovator at the cut-off makes a negative profit in the standard. Thus we find that some innovators in the intermediate range do not join the standard. Let $\tilde{R}$ be the equilibrium quality of the standard. Then R_h is found by solving the following inequality:

$$\alpha\left(\tilde{R} - R_h - \rho\right) + \frac{W_u^*(\tilde{R}, \lambda)}{\tilde{n}} \geq F_a + F_p > \alpha\left(\tilde{R} - R_h\right) + \frac{W_u^*(\tilde{R} + R_h, \lambda)}{\tilde{n} + 1}$$

This expression specifies that the lowest-quality innovator with a quality above R_h makes a positive profit, while the innovator with quality R_h makes a loss. Thus, all innovators with quality exceeding R_h join the standard. Similarly, we require that:

$$\alpha\left(\tilde{R} - R_l + \rho\right) \geq F_p > \alpha\left(\tilde{R} - R_l\right)$$
$$\tilde{R} + \rho - \frac{F_p}{\alpha} \geq R_l > \tilde{R} - \frac{F_p}{\alpha}$$

Then all firms below R_l and above R_h join the standard. Firms above R_h become active members.

Case 2: $\Pi^u(R_a, \tilde{R}) > 0$. In this case all innovators become members of the standard, with the innovators above R_a being active members. In this case, only one cut-off is reached. We define $R_l = R_h = R_a$ to simplify notation. □

It is possible that $R_l < \min_{i \in \mathcal{N}}\{R_i\}$. Then, firms refuse to become passive members.

A.7. Effect of λ governance on industry profits

Proof. Assume that $\tilde{R} > 0$ such that at least one innovator remains active in the standard. Then the profits of downstream firms are given as:

$$\Pi^d(S_j, \tilde{R}) = S_j\left(\tilde{R} - p_u\right) - F_d$$
$$\Pi^d(\hat{S}(\lambda), \tilde{R}) = S_j\left(\tilde{R} - p_u\right) - F_d = 0$$
$$\Rightarrow \tilde{R} - p_u = \frac{F_d}{\hat{S}(\lambda)}$$

An increase in λ requires the royalty to be lowered such that implementer $\hat{S}(\lambda) - \sigma$ is making zero profits. Consequently, for an implementers of strength $S_j > \hat{S} - \sigma$ we find that:

$$\Delta\Pi^d(S_j, \tilde{R}) = \left(S_j\frac{F_d}{\hat{S} - \sigma} - F_d\right) - \left(S_j\frac{F_d}{\hat{S}(\lambda)} - F_d\right)$$
$$= F_d S_j\left(\frac{1}{\hat{S} - \sigma} - \frac{1}{\hat{S}(\lambda)}\right) > 0$$

Thus, the profits of downstream implementers are increasing in λ except for the new marginal downstream firm, with strength $\hat{S} - \sigma$, which makes zero profits. It is trivial to show that passive innovators are harmed if $\Delta\tilde{R} < 0$ and are unaffected if $\Delta\tilde{R} = 0$. An active innovator who decides to stop being active is also harmed as profits before the change were positive. Finally, for active innovators who remain active, we find that, if $\Delta\tilde{R} = 0$, their profits decline. If $\Delta\tilde{R} < 0$, profits can be increasing or decreasing.

$$\Delta\Pi^u(R_i, \tilde{R}) = \underbrace{\alpha\Delta\tilde{R}}_{<0} + \Delta\left(\frac{W_u^*(\tilde{R}, \lambda)}{n}\right) \qquad \text{for } R_i \geq R_h$$

$$\Delta\Pi^u(R_i, \tilde{R})\begin{cases} > 0 & \text{if } \alpha\Delta\tilde{R} + \left(\frac{\Delta W_u}{W_u} - \frac{\Delta n}{n}\right)\left(\frac{W_u}{n+\Delta n}\right) > 0 \\ < 0 & \text{else} \end{cases}$$

As $\lambda < \lambda°$, innovators as a whole are harmed by an increase in λ.

For simplicity, assume $\alpha = 0$. Then the sign of the effect purely depends on the relative change to the royalty revenue compared with the number of active firms $\left(\frac{\Delta W_u}{W_u} - \frac{\Delta n}{n}\right)$. Consider an upstream market, where the lowest-quality active innovator has (nearly) zero patent quality and is almost indifferent between being active, or not. In this case, a reduction in the royalty revenue caused by λ causes this firm to not join the standard, which leaves $\tilde{R}$ unchanged while lowering the number of firms between whom the profits need to be shared. Thus, innovators' individual profits increase. In contrast, if the quality of the highest-quality innovator is relatively high, then a reduction lowers profits. The sign of the effect depends on the discreteness of the upstream market. Combined profits are given as:

$$\Pi^u_{\text{active}} = \alpha(n-1)\tilde{R} + W_u - \left(e + F_p\right)n$$

$$\sum\Delta\Pi^u_{\text{active}} = \overbrace{\alpha}^{\equiv 0}\underbrace{\left((n-1)\Delta\tilde{R} + \tilde{R}\Delta n\right)}_{<0} + \underbrace{\Delta\left(W_u\right)}_{<0} - \underbrace{\left(e + F_p\right)\Delta n}_{>0}$$

Let R_h be the quality of the one innovator who leaves in response to the increase in λ. Per assumption, if they would not leave, the profits of being active are negative, such that $\frac{W_u}{\tilde{n}} < F_a + F_d$. Furthermore, after the firm leaves, the standard is more profitable such that $R_h q_u > F_a + F_d$, where $R_h q_u$ is the change in total revenues caused by firm R_h leaving the standard. This shows that if we ignore the change to p_u caused by the increase in λ, innovators benefit from having one fewer firm in the standard. However, the net impact of the innovators individually is the combination of the benefit from losing a low-quality innovator and the cost of having to charge a lower royalty rate to attract one more implementer. Consider the change in profits for an innovator who is active both before and after the change in λ. The innovator's change in profits is then given as:

$$\Delta\left(\frac{W_u}{n}\right) = \frac{W_u + \Delta W_u}{n - \Delta n} - \frac{W_u}{n} = \frac{n\Delta W_u - W_u\Delta n}{n(n + \Delta n)}$$

Thus, profits are increasing if:

$$\frac{n\Delta W_u - W_u\Delta n}{n(n + \Delta n)} < 0$$
$$\Leftrightarrow \frac{\Delta W_u}{W_u} - \frac{\Delta n}{n} < 0$$

Profits of innovators are increasing if the change to the combined profits is small and the number of firms is large. Then, an increase in λ causes low-quality innovators to drop out of the active segment which leaves royalties unchanged but lowers the number of firms that share the royalty.

Now consider the combined profits of upstream and downstream firms. Holding $\tilde{R}$ constant, we find that the change to industry profits is given by:

$$\Delta W(\lambda) = \tilde{R}\Delta q_u - F_d > 0$$

This expression is positive because in equilibrium the royalty rate is positive. Thus, industry profits are increasing if the change in λ leaves the number of active innovators unchanged. Now consider a change that causes at least one innovator to leave the active part of the standard such that $\Delta\tilde{R} < 0$. As established, implementers' combined downstream profits (W_d^*) are increasing in λ and innovators' combined profits (W_u^*) are decreasing in λ. Thus, the net effect on industry profits depends on the relative strength of both effects. Industry profits are given by:

$$W_d^* + W_u^* = q_u^*(\lambda)\tilde{R} - \underbrace{|\tilde{S}(\lambda)|F_d}_{\text{increasing}} - \underbrace{\tilde{n}\left(F_p + e\right)}_{\text{decreasing}}$$

First, an increase in λ raises total costs of the downstream market as the number of implementers increases and lowers the costs on the upstream market as the number of innovators declines. Secondly, it changes the value generated on the downstream market as more implementers license a worse standard. The net effect can go in both directions. Additionally, passive innovators are harmed as their knowledge spillovers decline. □

Appendix B. Discussing Assumption 3: order of membership decisions

In the main section, we restricted innovators to join in order of decreasing patent quality. The purpose behind this assumption is twofold. First, from a technical point of view, it reduces the number of possible equilibria. Relaxing would require considering all possible groupings of innovators into active, passive, and non-members as candidate equilibria. Second, from an economic point of view, it rules out equilibria which are "nearly" Pareto-inferior, in the sense that replacing one of the active innovators with a different firm improves the profits of each innovator except for the removed active innovator while leaving the profits of all other firms unchanged. In this section, we discuss this in detail.

To streamline the discussion, consider the sets of active innovators (N_a), passive innovators (N_p) and non-members (N_n). By definition, we have that $N_a \cup N_p \cup N_n = N$ and that $N_a, N_p, N_n \in 2^{\mathcal{N}}$. The quality of the standard is given by the combined quality of all active innovators such that $\tilde{R} = \sum_{i \in N_a} R_i$. Furthermore, conditional on $\tilde{R}$ the downstream market is indifferent about the composition of the standard and how it came to be. Thus, we focus this discussion on the incentives of the upstream innovators.

For (N_a, N_p, N_n) to induce a stable equilibrium we require that each innovator takes the best response to their belief on the other innovators' choices. Such a belief can be sufficiently described by their belief on $\tilde{R}$ and on $\tilde{n}$, i.e., their belief of the quality of the standard (determining the potential for spillovers and the total royalty revenue) and the number of innovators in the standard (determining the share of the royalty revenue the firm can appropriate).

First, consider the choice between becoming passive and staying outside of the standard. Based on Eq. (3), the additional profits of becoming passive instead of abstaining from the standard are given by:

$$\alpha\left(\tilde{R}_{-i} - R_i\right) - F_p$$

An innovator finds it more profitable to be passive than not to be in the standard if $\tilde{R}_{-i}\frac{F_p}{\alpha} > R_i$. Since in equilibrium only R_i varies between firms, we can determine a threshold patent quality such that all firms with a quality below the threshold prefer being a passive member over a non-member. The threshold depends on the firms' belief about $\tilde{R}_{-i}$, i.e., the quality of the standard without the contribution of firm i. If firms belief that a higher-quality standard will be formed, more firms will become passive members instead of not joining.

Second, consider the choice between becoming an active member and a passive member. The additional profit an innovator makes if it becomes active instead of passive is given by:

$$\frac{W_u(p_u, \tilde{R}_{-i} + R_i)}{\tilde{n}} - F_a$$

Therefore, we require that for innovators active in the standard $\frac{W_u(p_u, \tilde{R})}{\tilde{n}} > F_a$ and for firms who are passive members $\frac{W_u(p_u, \tilde{R}) + R_i}{\tilde{n}+1} < F_a$. There are many different beliefs on sets of innovators for which both equations are satisfied for the active and passive members, respectively. For example, a standard combining high-strength and low-strength innovators may be as stable as one combining medium-strength innovators. In contrast, the second inequality depends on the strength of the passive innovator under consideration. As the left-hand side is increasing in R_i, we can conclude that the equilibrium is stable if the highest-strength passive innovator finds it unprofitable to become an active member.

Finally, consider the choice between being active and not being in the standard. We require that based on their beliefs about $\tilde{R}_{-i}$ and $\tilde{n}$:

$$\alpha\left(\tilde{R}_{-i} - R_i\right) - F_p + \frac{W_u(p_u, \tilde{R})}{\tilde{n}} - F_a > 0 \mid \forall R_i \in R_a$$

$$\alpha\left(\tilde{R}_{-i} - R_i\right) - F_p + \frac{W_u(p_u, \tilde{R} + R_i)}{\tilde{n}+1} - F_a < 0 \mid \forall R_i \in N_n$$

In equilibrium, $\frac{W_u(p_u, \tilde{R})}{\tilde{n}} - F_a > 0$. If this were not the case, active innovators would find it more profitable to be passive members. Consequently, the left-hand side of the first inequality is decreasing in R_i such that, if the highest-strength active innovator finds it profitable to be an active firm, so do all other active firms. Furthermore, if we consider λ and thus q_u^* fixed, the royalty and thus the benefit from being active instead of not a member is linear in the quality $\tilde{R}$. Hence, we require that the highest-quality innovator prefers being active over not participating and the lowest-quality active innovator prefers being active over being passive.

To summarize, without Assumption 3, multiple equilibria exist that are induced by innovators' beliefs on $\tilde{R}$ and $\tilde{n}$ and their actions, such that:

- For the highest-quality active innovator: $\alpha\left(\tilde{R}_{-i} - R_i\right) - F_p + \frac{W_u(p_u, \tilde{R})}{\tilde{n}} - F_a > 0$
- For the lowest-quality active innovator: $\frac{W_u(p_u, \tilde{R})}{\tilde{n}} > F_a$
- All firms below a quality of $R_i < \tilde{R}_{-i}\frac{F_p}{\alpha}$ become passive members.

This still leaves a large set of possible equilibria that may exist. To reduce this, we force innovators to make their decisions in order of decreasing strength. This, in turn, enforces the set of active members to be convex in the sense that, if two innovators with quality R_a and R_b respectively are active members, so must all firms with a quality between R_a and R_b. Together with Assumption 4 this implies that, if a firm of quality R_a is active, so are all firms with a quality exceeding it.

Without this assumption, a possible equilibrium could be formed by some of the highest-quality firms joining the standard, followed by the lowest quality firms. This would lower the potential gains from joining such that firms of intermediate patent quality abstain from the standard completely. This can be seen as a form of patent trolling by low-quality firms.

Clearly, from a welfare perspective, this can be improved upon. Consider an equilibrium in which firm R_a is an active member of the standard while R_b is not, with $R_b > R_a$. Replacing R_a with R_b raises the quality of the standard and the royalty. From the implementers' perspective, everything remains unchanged. For them the quality of the standard and the royalty rate increase by the same amount such that their net profits remain unchanged. In contrast, each innovator gains $q_u^*(R_b - R_a)/\tilde{n}$ in royalty revenue. The notable exceptions are R_a, who loses the royalty it used to obtain, and firm R_b, who gains the new, higher royalty. In total, welfare is increased by $q_u^*(R_b - R_a)$. Based on this, we see a role for a SSO to steer beliefs in a way to avoid such suboptimal standards.

Appendix C. Vertically integrated implementers

Throughout the paper, we assumed independence of implementers and innovators. However, in reality, it is not uncommon that firms contributing their technology to a standard are also active in its implementation. In this section, we discuss how the model would change if we allow for vertically integrated implementers. As we will see, relaxing this assumption has no qualitative consequences for the model.

Consider an innovator of type R_l and an implementer of type S_k. We consider how the model changes if, instead, both entities are vertically integrated in the sense that they share the same owner and maximize joint profits. Vertically integrated innovators would consider the royalty paid as less costly because part of it would be returned to them via the patent pool. After the standard has been set, their objective function is (cf. Eq. (4)):

$$\Pi^d(S_j, \tilde{R}) = \begin{cases} S_j \left(\tilde{R} - p_u \frac{\tilde{n}-1}{\tilde{n}} \right) - F_d & \text{member of SSO} \\ 0 & \text{outside option} \end{cases} \tag{C.1}$$

First, we consider the effect this has on the downstream market. The royalty rate is determined by λ, as in Eq. (8). Recall that $\hat{S}(\lambda)$ denotes the pivotal firm whose participation constraint determines the royalty rate. In equilibrium, the pivotal implementer obtains 0 profits while all implementers with a higher strength obtain positive profits. Based on this, we consider three possible cases.

First, consider that the vertically integrated firm is a high-strength implementer with $S_k > \hat{S}(\lambda)$. In this case, the equilibrium would remain fully unchanged. The participation constraint of the integrated implementer is relaxed, but the constraint was not binding, to begin with.

Second, consider the case where the vertically integrated implementer was pivotal. Then, the royalty rate would raise. The implementer's participation constraint would be relaxed, thus innovators could charge a higher royalty rate. The new royalty rate would change as compared to Eq. (8), from p_u to $p_u \frac{\tilde{n}}{\tilde{n}-1}$, where p_u denotes the royalty rate under no integration. If the increase in the royalty rate was such that the implementer's participation constraint with the second-lowest strength becomes binding, the new royalty rate would be determined by them instead and lie between p_u and $p_u \frac{\tilde{n}}{\tilde{n}-1}$. In both cases, innovators would gain profits while implementers would suffer. The increase in profits may be sufficient for additional innovators to join the standard. Then, the quality of the standard would also increase.

Third, consider the case that the vertically integrated implementer is of low strength, such that $S_k < \hat{S}(\lambda)$. This would relax the participation constraint for this firm. If this effect is small, such that the royalty rate this firm is willing to pay is still lower than the pivotal implementer, the equilibrium remains unchanged. If the effect is large, the royalty rate this firm is willing to pay exceeds the formerly pivotal firm, such that it replaces it and a higher royalty is charged in equilibrium. As in the case of the pivotal firm being integrated, this leads to higher profits for innovators, lower profits for implementers, and potentially additional innovators joining the standard.

In contrast, being vertically integrated does not change the decision of the innovators. This is because the implementer's profits are, in equilibrium, independent of the quality of the standard. An increase in the quality of the standard leads to an increase in the royalty rate by the same amount, such that the net benefit is unchanged—even for high-strength implementers making a profit in equilibrium.

To conclude, relative to the baseline model, allowing for vertical integration may change the participation constraint of the pivotal implementer such that the royalty rate increases, implementers' profits decline, and innovators' profits increase. This, in turn, may lead to additional innovators joining the standard, which leads to a higher quality. However, all previously discussed mechanisms remain in place. Intuitively, allowing for vertical integration is therefore qualitatively not different from increasing the strength of the pivotal firm.

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