Membership, Governance, and Lobbying in Standard-Setting Organizations*

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May 25, 2020

Abstract

Standard-setting organizations (SSOs) are collectively self-governed industry associations, formed by innovators and implementers. They are the main organizational form to agree on and manage technical standards, and form the foundation for many technological and economic sectors. Constructing a model, we study the incentives of heterogeneous innovators and implementers to join an SSO, which is endogenously formed. We also study the effect of SSO governance on membership incentives and on members' lobbying efforts to get their technologies included in the standard. We show that, depending on parameter realizations, one of four equilibrium types arises uniquely. The results can reconcile existing evidence, especially that many SSO member firms are small. We show that raising the influence of implementers within the SSO increases the standard's market coverage and lowers royalty rates but it erodes the innovators' incentives to contribute to the standard. This results shows how the incentives of both type of firms are conflicting within an SSO and need to be carefully weighted for it to be successful.

Keywords: Standard-setting organizations, associations, governance, lobbying.
JEL Classification: D71, D72, L15, O31

*We are grateful to Cedric Argenton, Jan Boone, Peter Kort, Florian Schütt, Sandro Shelegia, Bert Willems, and seminar participants at TILEC for their comments and feedback. All errors are our own.

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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. These positive welfare effects of compatibility and standardization are well documented.[1] Moreover, due to the steady growth of information and communication technologies over the last three decades and the high importance of network effects in these industries, standardization has become especially valuable as standards reduce uncertainty, facilitate interoperability, provide investment opportunities, and lower the cost of innovating (Bresnahan and Greenstein, 1999). Crucially, the successful diffusion of new technologies often depends on the emergence of a single standard and SSOs are mostly the only organizational vehicle that can reach standardization (Gandal and Regibeau, 2014).

Being industry associations, membership in SSOs is usually open to all industry participants, subject to paying a membership fee. 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. 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.[2] 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 main factor in standard selection, despite its theoretical pretense. However, large firms could just be more successful in producing the highest-quality technologies. For example, Rysman and Simcoe (2008) empirically study four major SSOs and find that the

[1] 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 industries characterized by network effects, see Gandal and Regibeau (2014).

[2] See Larrain and Prüfer (2015) for a general model of trade associations, where lobbying can have negative or positive spillovers.

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 quote explains the starting point of our paper. We aim at a better understanding of the decision-making rules of standard-setting organizations and their influence on the standard selection (*SSO governance*), which can have a profound impact on the abilities of innovators to coordinate in developing new technologies and on the incentives to innovate (Chiao et al., 2007).

Moving from governance to *membership*, in most of the theoretical literature studying SSOs,[3] there is an implicit assumption that the only motivation for innovator firms 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 fairly robust empirical result is that the disclosure of patents 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.[4]

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

[4]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

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.[5] 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 and for implementers with heterogeneous R&D-profiles 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 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 in the royalty profits. Downstream members benefit from the sale of standard-compliant products to consumers and knowledge spillovers. 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.

attending meetings in which firms that heavily invest in R&D also participate.

[5] 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.

The main result of the paper is that depending on the lobbying costs required of firms to have their technology incorporated in the standard one of four possible equilibrium types can occur: (i) If the costs of lobbying are very low, all firms join the SSO. (ii) If the costs of lobbying are at a medium level, both small firms and large upstream firms—but not upstream firms 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 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 costs of lobbying, only very large upstream firms join as they can still profitably market their technology. Small upstream firms stop participating as the benefits of learning from only a few remaining upstream firms is not sufficient to compensate them for their own costs of participation. (iv) For prohibitive high costs of lobbying, nobody joins.

Based on these results we find that the governance structure of the SSO is crucial for its outcomes. As implementers get more 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 certain thresholds of implementers’ power, the incentives of innovators to contribute their technologies decline, which lowers the standard’s quality and industry profits. Furthermore, we find that implementers who obtain a large benefit from adopting the technology have an incentive to raise the participation of low-strength implementers as this forces innovators to lower the royalty 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.

The remainder of the paper is organized as follows. Section 2 offers a literature review. In Section 3, we describe the model, which we analyze in Section 4. Section 5 contains a discussion and concluding remarks. Proofs are in Appendix A.

2 Literature

We contribute to the results regarding standard participation by modeling firms' participation in standard-setting organizations (SSO). In our model, firms profit by obtaining royalty profits from their technology and being able to implement the technology. However, firms also can passively participate in the SSO and benefit from knowledge spillovers. As the literature has shown, both aspects are important. By studying them together we find novel results on firms' participation choice and how commitments made to downstream firms can lead to positive or negative results.

The broad literature on Standard-Setting Organizations 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 technology, there is any hope that the standard is as good as technically (and economically) possible (Gandal and Regibeau, 2014). Especially important for this is that the SSO solves the hold-up associated with the standard. One important aspect is to make sure that implementers who have invested in the downstream capacity for standard-compliant products are protected from excessively high royalty rates. For this, both IP owners and downstream implementers must participate and SSO policies should be aimed at encouraging firms of both types to attend their meetings and contribute (Layne-Farrar et al., 2014).

We directly address the aspects of membership and participation by modeling innovators and implementers participation in an SSO by considering an SSO who's 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.

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). While holdup is considered an important challenge by authorities the evidence on its prevalence in reality is mixed. 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). Two empirical papers find now evidence for hold-up.(Gupta, 2013; Galetovic et al., 2015)[6] Especially consensus building in the standard-setting process, active meeting participation structure within the SSO meetings and the repeated interactions between stakeholders in the standard-setting process seem to counteract the risk of hold-up.

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. Similar to the previous literature we find that implements 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 price caps ex-ante (structured price commitments Lerner and Tirole, 2015), that firms should be allowed to form a patent pool ex-ante 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).[7] More, recently it has been shown that repeated interaction can help make FRAND rates binding such that innovators refrain from charging unreasonable 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 to the discussion of them be given an example of a mechanism leading to a FRAND license. To attract implementers innovators are limited in the royalty rate they can set. In this paper, we consider minimal limit in the sense that innovators need to make sure that implementers make zero profits. By doing so we draw attention to the benefit of ex-ante commitments aimed at tying innovators' hands in the ex-post setting of the royalty rate.

[6] Gupta (2013)refers to the case Microsoft vs. Motorola (Seattle, November 2011) where expert witnesses failed to provide evidence for hold-up when prompted to do so by the Judge. Galetovic et al. (2015) find that industries relying on SEPs exhibit the fastest quality-adjusted price decline in the U.S. economy.

[7] 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).

3 Model

In this section, we define the model used. Section 3.1 describes the general setup of the upstream market, Section 3.2 the timing of the market, Section 3.3 the downstream market in detail and Section 3.4 discusses the key modeling choices made.

3.1 Model Description

We consider a market consisting of upstream firms (innovators, $\mathcal{N} = \{1, \ldots, n\}$) and downstream firms (implementers, $\mathcal{M} = \{1, \ldots, m\}$). We discuss downstream firms' role in detail in Section 3.3.

Each upstream firm $i \in \mathcal{N}$ is characterized by an exogenous, fixed, and observable R&D stock $R_i \in [0, \bar{R}]$ that determines the potential quality of the firm's only patented technology and thus its marginal contribution to the quality of the standard. Upstream firms fall into three roles. Active members join the SSO and contribute their patent to the standard, for which they obtain a share of the royalty revenue, passive members join the standard and obtain knowledge spillovers based on the active firms, and non-members do not join the SSO. Innovators' profits are given by:

$$\Pi^u(R_i, \tilde{R}) = \begin{cases} \alpha\left(\tilde{R}_{-i} - R_i\right) - k_u + \frac{W_u(p_u, \tilde{R})}{\tilde{n}} - \bar{e} & \text{active member} \\ \alpha\left(\tilde{R}_{-i} - R_i\right) - k_u & \text{passive member} \\ 0 & \text{non} - \text{member} \end{cases} \tag{1}$$

In Equation (1), k_u gives the costs of becoming a member, p_u is the royalty rate charged for licensing the technology, $\frac{W_u(p_u, \tilde{R})}{\tilde{n}}$ gives the per-active innovator royalty revenue based on the standard which we discuss in detail in Stage 3, and $\bar{e}$ the costs of becoming active. The exogenous parameters are α, k_u, and $\bar{e}$.

Let $\mathcal{N}_a = \{k \in \mathcal{N} | e_k = \bar{e}\}$ be the set of all innovators who exert the necessary lobbying efforts. We define two qualities of the standard:[8]

$$\tilde{R} = \sum_{k \in \mathcal{N}_a} R_k \tag{2}$$
$$\tilde{R}_{-i} = \sum_{k \in \mathcal{N}_\text{a} \setminus \{i\}} R_k$$

The quality of the standard ($\tilde{R}$) is given by the combined quality of all active innovators, which gives the quality downstream firms can derive profits from. The marginal contribution of one patent to the quality of the standard is independent of the other patents in the standard such that patents are neither complements nor substitutes. The profits innovator i obtains from knowledge spillover depends on $\tilde{R}_{-i}$:

$$\Pi^u_{KS}(R_i) = \alpha \max\{\tilde{R}_{-i} - R_i, 0\}, \tag{3}$$

where $\alpha \in \mathbb{R}^+$ represents the strength of knowledge spillovers within the SSO and $\tilde{R}_{-i}$ is the knowledge stock that firm i can derive spillovers from.[9] As a firm cannot obtain spillovers from itself, $\tilde{R}_{-i}$ is independent of firm i's decision (not) to become an active member. 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.

3.2 Timing

The game consists of three stages. First, firms decide on their membership in the SSO, second innovators decide whether to contribute their technology to the standard or remain passive. Finally, a patent pool is formed, the royalty rate is determined and implementers decide on licensing the standard.

Stage 1: Membership Innovators In the first stage, an SSO is formed and firms in $\mathcal{N}$ and $\mathcal{M}$ decide whether to join or not. To join innovators have to pay a cost k_u which is exogenous to the model and may include a monetary membership fee that covers the operating costs of the SSO and the opportunity cost for the time of employees attending SSO meetings.[10].

As SSO members, innovators attend meetings and can learn from the knowledge of the active

[8] Equation (2) assumes that at least one firm joins the standard. If the set of active firms is empty the quality of the standard is given as $\tilde{R} = 0$.

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

[10] We assume the costs of joining as given and an economic loss. Specifically, we abstract from the possibility of the SSO to set membership fees to achieve its (one of its) objectives.

innovators which we refer to as *knowledge spillovers*.[11] However, only a subset of innovators actively contributes to the standard. Innovators that join the SSO without contributing their technology are called passive innovators and innovators that join the SSO and contribute their technology are called active innovators.

Membership for implementers is determined in Stage 3 after the standard has been set. However, the by-laws of the SSO specify that membership of a proportion of $\lambda \in [0, 1]$ of the implementers is required for the standard to be implemented.

Stage 2: Standard Formation In the second stage, upstream SSO members can choose to become *active* or *passive* members of the standard. Both types of firms profit from the potential of knowledge spillovers but only active members have their technology included in the standard and gain royalty revenue in Stage 3. To become active, innovators need to exert an exogenously given level of lobbying efforts $\bar{e}$. Lobbying is costly and unproductive by itself but necessary to allow voting members to add the technology to the standard.[12]

Stage 3: Patent pooling, and license-fee setting In the third stage, the active innovators bundle their patents into a patent pool of quality $\tilde{R}$ and delegate setting the royalty rate to its manager. The manager of the patent pool makes a Take-It-Or-Leave-It offer on behalf of the active upstream members to the downstream members and is bound by the governance parameter λ such that at least a proportion of λ implements join the standard-setting organization and license the technology.[13] If the SSO fails to reach a participation of λ the standard collapses all firms receive negative profits amounting to the investments taken in the past.[14]

The offer specifies a per-unit royalty fee of p_u paid by the implementers to license the patent pool. For a given royalty rate (p_u) and quality of the standard ($\tilde{R}$) the implementers' demand for the technology in the standard pool is given by $q_u(p_u, \tilde{R}) \geq 0$ and the total royalty revenue is given as $W_u(p_u, \tilde{R}) = q_u(p_u, \tilde{R})p_u$.[15] Furthermore, the maximal royalty rate the pool can

[11] These benefits can be based on learning about new technology, sharing opinions on market developments, or building business networks and relationships with other firms.

[12] Lobbying 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 and other committee work, etc. We only consider a binary modeling structure such that firms either exert efforts or not. More complicated assumptions are possible but increase the complexity.

[13] Thus, $m\lambda$ implementers 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.

[14] This can be seen as the SSO having to start from scratch with discussing the standard within its organization, a long period delay in implementation, or some other prohibitively high cost.

[15] Implementers' demand for technology refers to the usage intensity of the standard by downstream firms. While it could be linked to the demand for the implementers' products we abstract from the product market.

charge is limited by convincing $m\lambda$ downstream firms to join the SSO and adopt the standard which we discuss in detail in Section 3.3.

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 gives the requirements on the usage of the standard. 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 and thus lowers the usage of the technology. Furthermore, the 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.

The manager of the patent pool sets the royalty rate to maximize total royalty revenue W_u.[16] which is then equally split between all active innovators. However, to satisfy the requirement of the SSO, the royalty it can charge is limited by the governance parameter λ such that the maximal royalty the patent pool manager can charge is decreasing in λ for which we provide a micro-foundation in Section 3.3.

Let $\tilde{n}$ be the number of *active* innovators. After combining the royalty revenue with the knowledge spillovers from Equation (3) the profits of innovator i with patent quality R_i are given by the profit function in Equation (1). 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 in 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:*

$$\max_{p_u} W_u(p_u, \bar{R}) \geq k_u + \bar{e},$$

Imposing a simple structure on the distribution of innovators' R&D stock simplifies the

[16] 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.

analysis and allows us to study the results of standardization, assuming a specific order of decision making enables us to find a unique equilibrium and assuming that a single-firm standard is feasible guarantees an equilibrium for at least some values of governance λ. Finally, for tie-breaking purposes, a firm indifferent between its choices prefers (active) participation in the standard.

3.3 Downstream Market

The core of our results are derived from innovators' profit function, the fact that innovators' profit-maximizing royalty rate is excessive, and that λ limits the royalty rate. However, to specifically model the participation of the implementers and micro-found the assumptions made in the previous section we assume additional structure on the downstream market and implementers' objective function. Each downstream firm $j \in \mathcal{M}$ is characterized by an exogenous, fixed and observable level of strength (market share) in the downstream market $S_j \in [0, \bar{S}]$.[17] Downstream firms either adopt the technology in which case they profit from its usage but have to pay a royalty fee to the active innovators or abstain from the standard.

Similar to the upstream market, we make the simplifying assumption that strength S_j is distributed at a regular interval with step-size σ such that $S_j = \bar{S} - (j-1)\sigma$ with $\sigma \in (0, \frac{\bar{S}}{m-1})$. Each implementer decides independently if it joins the standard-setting organization and adopts the technology, or not. We assume that one downstream firm adopting the technology has no externality on other firms adopting it, that is and they cannot use a higher quality to gain market power (and thus increase S_j) i.e., implementers are monopolists on separate markets.

The product market demand[18] implementers face is simple: we assume that demand is fixed and that prices charged to consumers are a linear function of the standard quality given in Equation (2) such that for a fixed royalty fee the profits of downstream firms are linear in the quality of the standard.[19] Implementer j's profit is:

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

[17] The strength S_j can also be capture additional aspects like the strength of the brand of implementer j or their ability to incorporate the standard in their products.

[18] Not to be confused with the demand for the standard technology.

[19] Implementers have market power in the downstream market but, due to heterogeneous preferences of final consumers, demand is downward sloping such that, for increasing quality $\tilde{R}$, both the implementers' revenues and consumer surplus are increasing.

Implementer j's strength (S_j) measures its ability to market a standard of quality $\tilde{R}$ to its customers such that the revenue derived from the standard is given by $S_j\tilde{R}$. Secondly, the implementer pays a royalty rate proportional to its strength which is given by $S_j p_u$. Finally, implementation has a cost of k_d to be a member of the SSO which may include a monetary membership cost, an opportunity cost, and the cost of implementation of the standard. We rule out knowledge spillovers for downstream firms.[20]

Furthermore, we assume that implementers either become members of the SSO and license the standard or do not become a member and not license the standard. Implementers have no incentive to join the SSO without adopting the technology as they do not receive a direct benefit from being part of the SSO (they cannot profit form knowledge spillovers). Furthermore, we assume that not becoming a member of the SSO while licensing the technology is not feasible. We discuss this assumption in Section 3.4.

Let $\tilde{S}(p_u, \tilde{R})$ be the set of all implementers licensing the standard technology. Based on this, we derive downstream demand for the standard ($q_u(p_u, \tilde{R})$) as the combined strength of all implementers in $\tilde{S}$ and downstream surplus ($W_d(p_u, \tilde{R})$) as their combined profits. Finally, let $W_u = q_u p_u$ be the combined royalty payments:

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

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

$$W_d(p_u, \tilde{R}) = \sum_{j \in \tilde{S}(p_u, \tilde{R})} \Big(S_j(\tilde{R} - p_u) - k_d\Big) \tag{6}$$

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

Note, that the demand system satisfies Assumption 1 which we verify as part of the proof for Proposition 2. The value of W_d gives the downstream surplus, while the value of W_u gives the amount of surplus that innovators are extracting using royalty payments. Consequently, $W_d + W_u$ is the surplus generated in the downstream market.

In Section 4, we solve the game for a *unique Sub-game Perfect Nash Equilibrium* in pure strategies. First, however, we explain several modeling choices made above and discuss alter-

[20] Allowing for 'small' knowledge spillovers of downstream firms does not alter the results significantly. If knowledge spillovers of downstream firms are large implementer join the standard for the spillovers not for the technology which causes fundamental changes in the model.

native setups and robustness of the model.

3.4 Model Discussion

R&D-distribution and common knowledge: The assumption of common knowledge of the strength of firms simplifies the analysis and is plausible in the case of standard-setting. Firms in high-tech sectors frequently interact with each other and thus can be expected to have an accurate perception of other industry participants' qualities, in practice. Assumption 2 simplifies the analysis and guarantees the existence of a unique equilibrium, yet enables us to study different cases.

Order of innovators' choice: Assumption 3 rules out that low-quality firms become active participants, guarantee themselves a share in the royalty profits, but suppress the potential for high-quality firms to enter the standard. Such a behavior can be seen as similar to patent-trolling where firms declare low-quality patents to receive a large share of royalty revenue. Avoiding such a behavior can be seen as a core role of any SSO. At any point, the incentives to join are higher for a high-quality innovator than for a low-quality innovator. Furthermore, replacing a low-quality firm as an active member with a firm of higher-quality increases the profits of each member of the SSO (upstream and downstream) except for the low-quality firm. Thus, the SSO has a high incentive to implement policies to avoid this. Based on this we abstract away from it and assume it as a given rule.

Outside option: We assume that the outside option for both innovators and implementers is fixed at 0. In reality, firms with higher-quality technology or higher strength in the downstream market might have more valuable outside options. High-quality firms would find it more costly to join the standard. Depending on the functional form of the outside option it could have many different effects including high-quality innovators dropping out of the standard. This would require a different design of the sharing rule of the standard to compensate firms adequately.

Governance parameter λ: The SSO requires the participation of λ implementers in the body of the SSO. Thus, λ gives the influence implementers have within the SSO and can be seen as a mechanism to discipline the innovators in favor of implementers: as the SSO needs to obtain the approval of more implementers, innovators are forced to charge a lower royalty fee. Alternatively, λ can be seen as the minimal downstream market coverage required to make the standard economically viable such that the underlying functionality can only be profitably marketed if a share λ of the downstream firms are willing to implement it. However, this is isomorphic to a model where instead of a share of λ of firms a strength-weighted share of 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 firms 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.[21]

Downstream Market: We assume that implementers benefit from a higher quality of the standard: an additional innovator adding its technology to the standard increases the standard's total quality, which is appreciated by final consumers. Therefore, the quality of the standard directly increases the revenue implementers can charge. An implementer using the standard raises its price in line with higher quality but cannot gain additional consumers. Think, for instance, of a market with a dominant firm and a competitive fringe, such that the dominant firm can charge the difference in quality to the competitive fringe. However, extending the model to include a more elaborate downstream market is technically straightforward. In this case, we would expect that profits are not linearly increasing in the quality of the standard. However, this would require us to model the strategic decisions of the downstream firms as the incentive of one downstream firm to adopt the standard would depend on the other downstream firms' choice in a potentially non-monotone way. The results would be reminiscent of Katz and Shapiro (1986): innovators would have an additional incentive to under-supply technology to downstream firms.

Downstream Membership: We assume that implementers cannot adopt the technology without becoming members of the SSO. The underlying assumption is that we only consider large implementers in set $\mathcal{M}$ who require a say in the organization to adopt the technology and not interested in adopting technology without becoming a member of the SSO. If this were not the case, innovators need to make sure that for a proportion of λ membership is beneficial, e.g., by offering reduced royalty rates for SSO members and a higher royalty rate for SSO members. If implementers were able to license the standard at the same royalty while not being part of the standard the equilibrium would still see a proportion λ of them joining the SSO as otherwise the standard would fail and they would gain zero profits. The same argument would also hold if innovators can charge a differentiated royalty to members of the SSO. However, the effect

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

of λ on firms behavior becomes increasingly complicated. In this paper we are interested in how the membership of downstream firms forces innovators to lower the royalty they set. For this, the simplest assumption is to consider membership in the SSO necessary to implement the standard.

Royalty-rate structure: We model a royalty fee (p_u) that is paid by downstream firms proportional to their strength. The reason for this is that we consider the strength to reflect the market share of the firms. Replacing the royalty fee by a fixed amount would not change the model fundamentally. By contrast, allowing for a two-part tariff with a variable and a fixed part at the same time would severely change the results: The result of the downstream market is driven by the tension between the benefits of the standard that are increasing in strength and the costs which are fixed. The royalty can be seen as increasing the fixed costs (in case of a fixed fee) or lowering the variable revenue (for p_u). Thus, both methods would lead to some firms implementing the standard based on their strength.

Structured price commitments: The value of λ that is given, shares similarities with structural price commitments. In the paper, we treat λ as exogenous to the model but it can be seen as the SSO or innovators having committed to a certain number of implementers becoming part of the standard which limits their ability to extract the benefit of their technology from the implementers using an excessive royalty. As such it plays a function similar to a structured price commitment that limits the maximal royalty a firm may charge (Llanes and Poblete, 2014). However, a commitment in λ is more general and allows for (limited) adjustment based on the quality of the standard[22] without firms having to discuss prices with other innovators before the standard has been set, which might help mitigate anti-trust concerns.

Sharing Rule: For the upstream firms, we consider an egalitarian sharing rule, where each firm obtains an equal part of the royalty revenue generated by the patent pool. It is possible to include sharing rules that are proportional to the knowledge stock of innovators. See Larrain and Prüfer (2015) for a sharing-rule that allocates more income to stronger firms than to weaker ones. Note that firms would still join the standard and would erode the incentives of other firms to do so. However, while in our model a higher-quality innovator would increase the incentives of the lower-quality firms to join, this would not necessarily follow in an extended model.[23]

[22] Thus, a higher quality of the standard leads to a higher royalty. This adjustment is not perfect compared with a complete contract but gives the standard some adjustment capacity.

[23] In practice, different sharing rules are feasible. However, given the complexity of determining the incremental value of a single patent, most patent pools prefer simple rules. According to Layne-Farrar and Lerner (2011) the

4 Analysis

In this section, we solve the game specified in Section 3 by using backward induction. For this, we only consider standards with at least one active innovator. Solving an equilibrium featuring an empty standard is trivial: All innovators and implementers make 0 profits and stay out of the standard. Sections 4.1, 4.2, and 4.3 solve the 3 stages of the game. Section 4.4 discusses the effect of changes to the governance parameter (λ) on firms' participation.

4.1 Stage 3: Patent pooling and license-fee setting

First, we solve Stage 3 using the downstream market from Section 3.3. Upstream firms have made their decisions about whether to join the standard-setting organization (SSO) and whether to become an active or passive member. Thus, the combined quality of the standard ($\tilde{R}$) is set. The downstream firms receive a take-it-or-leave-it offer from the manager of the patent pool on behalf of the active upstream firms. Implementers join the standard and implement it if doing so yields them a non-negative profit. For the standard to be viable it needs to be supported by an exogenously determined proportion λ of the implementers. Thus, we require that $m\lambda$ implementers obtain a non-negative profit.

Implementer j's profit (Equation (4)) is determined by the fixed cost of membership (k_d), is increasing in its strength (S_j) and decreasing in the royalty rate (p_u). Let $\hat{S}(\lambda)$ be the strength of the pivotal downstream firm at the $(1-\lambda)$ quantile of the firm distribution. If a firm of strength $\hat{S}(\lambda)$ obtains zero profits from implementing the standard, all firms of a higher strength obtain a positive profit, and all firms below a negative profit. Thus, the patent pool manager optimally sets a royalty fee such that active inventors' profits are maximized subject to $\hat{S}(\lambda)$ obtaining a non-negative profit, which satisfies the requirement that a λ proportion of the implementers makes a non-negative profit. We first calculate the profit-maximizing price if λ is not binding:

Lemma 1. *Consider $\lambda = 0$ such that it 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 ($\tilde{R}$)*

three common forms of sharing rules are *royalty-free licensing*, where royalty fees are 0; *numeric proportional rules*, where members receive a share of the aggregate earnings based on the number of patents they contribute to the pool; and *value-proportional rules*, where members with more valuable contributions receive a larger share of the earnings. A value proportional rule would keep most of the results unchanged, with one notable exception. In this model, we find that an increase in the quality of an active firm raises the incentives to join the standard. Under a value proportional rule, this would be partially mitigated by potential entrants not being able to appropriate part of the profits. However, as Brooks (2013) points out, royalties are typically bargained as a whole by the administrators of standard pools. Then simple rules are used to avoid transaction costs, complicated bargaining and patent thickets.

is given as:

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

Furthermore, the profit maximizing royalty is increasing in $\tilde{R}$ and decreasing in k_d. And 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 ($\hat{S}^{\circ}$). Furthermore, the lemma shows that the marginal profit of increasing the number of implementers is decreasing in the number of implementers which is the discrete equivalent of saying that the royalty revenue is concave in the number of implementers licensed to.[24] As the standard becomes more valuable the profit-maximizing royalty increases and the number of implementers licensed to increases. A higher-quality standard allows the standard pool to charge a higher price which increases the incentives to license the standard to more implementers. In contrast, a higher downstream implementers' cost leads to a lower price and a lower number of implementers being licensed too. As the costs of membership and implementation increase, the standard pool finds it more profitable to focus on the high-quality implementers, raising the royalty and lowering the total downstream costs. Now consider value of $\lambda \geq \frac{j^{\circ}(\tilde{R})}{m}$ such that λ is binding:

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

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

In equilibrium, all implementers in $\tilde{S}(\lambda) = \{j \in \mathcal{M} : \; S_j \geq \hat{S}(\lambda)\}$ adopt the technology and make non-negative profits with the firm at $\hat{S}(\lambda)$ making zero profits. Furthermore, based on Equation (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.

[24] In other words, the royalty revenue as a function of the demand for the standard is hump-shaped. It may be increasing or decreasing for all prices but becomes more decreasing for higher demand.

(ii) Total downstream profits $(W_d^*(\tilde{R},\lambda) = q_u^*(\lambda)(\tilde{R} - p_u^*) - |\tilde{S}(\lambda)|k_d)$ *are increasing in* λ.[25]

(iii) The total licensing revenue $(W_u^*(\tilde{R},\lambda) = q_u^*(\lambda)p_u^*(\tilde{R},\lambda))$ *is decreasing in* λ.

(iv) Furthermore, if $\Delta(W_u^*(\tilde{R},\lambda) + W_d^*(\tilde{R},\lambda)) > 0$ *and for* $S_j > \hat{S}(\lambda)$*:* $\Delta\Pi^d(S_j,\tilde{R}) > 0$.[26]

Proof: see Appendix A.2.

Lemma 2 gives the license fee $p_u^*(\tilde{R},\lambda)$ that maximizes the profits of active upstream firms for a given standard quality $(\tilde{R})$ and a value of λ. Setting the profits for the pivotal implementer equal to zero gives the optimal royalty. If λ is binding, lowering the royalty rate is not profitable for the innovators while raising the royalty is not possible as then more than λ proportion of the implementers makes a loss. Furthermore, if the one of the $m\lambda$ implementers rejects the offer the standard would collapse yielding them 0 profits.

Based on this we calculate how outcomes depend on λ and $\tilde{R}$. First, demand for the standard is independent of $\tilde{R}$ and increasing in λ. As λ is binding, the standard only serves as many downstream firms as it needs thus only changes with λ. Second, Total downstream profits are increasing in λ. As λ increases upstream firms are more limited in the price they can charge and thus, lower the price. This benefits the downstream firms in the standard. Third, the total licensing revenue is decreasing in λ. As λ is binding any lowering of the price lowers total royalty revenue. Finally, combined profits from the downstream market $(W_u^* + W_d^*)$ are increasing in the λ. Innovators fail to extract all the surplus generated on the downstream market.[27] Instead they limit the 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 $p_u^* = \tilde{R}\hat{S} - k_d > 0$.

Per-definition the market outcomes for $\lambda < \frac{j^\circ}{m}$ are identical to the unconstrained outcome. In Lemma 1, the marginal licensor is given as $\hat{S}^\circ$. Thus, a non-binding λ implies $\hat{S}(\lambda) < \hat{S}^\circ$ such that the royalty is higher than for any binding λ. Furthermore for a given quality of the standard $\tilde{R}$ the profits of the innovators are higher and the profits of the implementers lower if the governance parameter λ is not binding.

Lemma 3. *For a given* $\tilde{R}$ *the change to total royalty profits caused by an increase in* λ $(\Delta W_u^*(\tilde{R},\lambda) \equiv$

[25] Where $|\tilde{S}(\lambda)|$ denotes the cardinality of the set $\tilde{S}(\lambda)$, i.e., the number of implementers who are implementing the technology.

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

[27] 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.

$W_u^*(\tilde{R}, \lambda + \frac{1}{m}) - W_u^*(\tilde{R}, \lambda))$ *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 $\tilde{R} = \sum_{i \in \mathcal{N}} R_i$ *exists a* $\lambda^\circ \in [0, 1]$ *such that:*

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

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: see Appendix A.3.

The first part of Lemma 3 is the discrete equivalent of $W_u^*(\tilde{R}, \lambda)$ being a concave function of λ such that the higher λ the smaller the change to the royalty rate caused by increasing λ further.[28] The intuition for this is that as λ increases the revenue derived from implementers using the technology declines, while their number increases. If only a few implementers use the technology the second effect dominates and revenue increases with λ. If many implementers use the technology the first effect dominates and an increase in λ lowers the revenue.

The second part gives that for the highest quality standard a threshold λ° exists such that royalty revenue is increasing in λ for $\lambda < \lambda^\circ$ and increasing for $\lambda \geq \lambda^\circ$ such that for a standard containing all innovators λ° maximizes profits. This follows immediately from the first part of the lemma. [29]

By the same argument such a profit-maximizing λ exists for all values of $\tilde{R}$. As $\Delta W_u^*(\tilde{R}, \lambda)$ is increasing in $\tilde{R}$, this profit-maximizing λ is increasing in $\tilde{R}$ such that any standard of a lower quality than the full standard has a lower profit-maximizing λ than λ°. Thus, if $\lambda \geq \lambda^\circ$ the commitment of λ is binding for all standards.

The proof follows from the assumptions made concerning the downstream market. The value of λ° gives the value of λ for which the innovators' commitment is binding for all standards. If the commitment is not binding for a λ the innovators charge the profit-maximizing price and do not react to any changes in λ. From a policy point of view, such an equilibrium is not interesting. Thus we assume $\lambda \geq \lambda^\circ$.

[28] Which is equivalent to the corresponding statement in Lemma 1.

[29] If $\Delta W_u^* \left(\sum_{i \in \mathcal{N}} R_i, 0 \right) \leq 0$ ($\Delta W_u^* \left(\sum_{i \in \mathcal{N}} R_i, 1 \right) \geq 0$) the royalty revenue is decreasing (increasing) for all values of λ and λ° is given by 0 (1), respectively.

As a final remark, note that as we will see an increase in λ may lead to a decrease in $\tilde{R}$. We have established that a decrease in $\tilde{R}$ lowers the λ that is binding. Thus, an increase in λ that causes λ to be binding also does so once we consider Stage 1 and Stage 2.

4.2 Stage 2: Standard Formation

In Stage 2, innovators who are part of the SSO decide on whether to remain a passive member and only to obtain the benefits of spillover effects or whether to become active members and to gain, additional to spillovers, a share of the patent pool's royalty income.

Innovators have paid the membership fee and their individual choice to become active or stay passive does not affect their own knowledge spillovers it can receive. Thus, firm i considers the membership fee and the knowledge spillover as given. To become active firm i needs to exert lobbying efforts $\bar{e}$. If it does, its technology is included in the standard and it gains a share of the royalty income W_u^*. Based on Equation (1), an innovator R_i becomes active if, and only if:

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

As a firm becomes an active member, it increases the spillover effects for other firms but not 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 firms that have to share the royalty fee, $\tilde{n}$.

Proposition 1. *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:*

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

where in Stage 2, all innovators with a patent quality strictly exceeding R_a exert efforts of $\bar{e}$ and become active members. All firms with quality lower or equal to R_a remain passive members of the standard.

Proof: see Appendix A.4. The proposition follows directly from firms' incentives to become active members and Assumption 3.

Corollary 1. *Let $\tilde{n}$ be the equilibrium number of active upstream firms. If a change in the parameters does not lead to a collapse of the standard it has the following impacts:*

(i) $\frac{\partial \tilde{n}}{\partial \bar{e}} \leq 0$*: An increase in the costs of becoming active* ($\bar{e}$) *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.

Using a uniform spread of the innovators' qualities allows us to describe the equilibrium in Stage 2 by the number of innovators active. For this, we start with expression R_a from Proposition 1 and show how changes in the parameters impact firms' incentives to become active. A change that lowers the number of firms who are active can also lead to a collapse of the market in which case $R_a = \bar{R}$ and $\tilde{n} = 0$.

The number of active firms in Stage 2 is decreasing in the level of efforts needed to be active ($\bar{e}$). A higher lobbying requirement leads to fewer firms becoming active. An increase in the quality of all innovators leads to a higher number of innovators being active. As patent quality increases the royalty for a given standard increases which attracts additional firms. Furthermore, additional firms in the standard reduce the per-firm royalty less if they are of a higher quality. Both effects cause active participation to increase. An increase in the spread of participation (ρ) lowers the number of firms in the standard. Additional firms contribute less to the standard but lower the per-firm royalty none-the-less. Thus, fewer firms join the standard. Finally, an increase in the governance of the standard (λ) lowers the number of firms. Higher participation of downstream firms (higher λ) implies a lower royalty and thus lower profits for innovators. Active participation declines in response.

4.3 Stage 1: Membership

In Stage 1, innovators decide if they join the standard, or not. In case they do join, they benefit from spillover effects. Additionally, they receive profits from royalty fees if they invest in lobbying and get their technology included in the standard in Stage 2. Recall that $\tilde{R}_{-i}$ is the combined quality of all active innovators, excluding innovator i. Based on Equation (1) an innovator of quality R_i joining the standard obtains profits of:

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

First, spillover effects are decreasing in R_i. A higher-quality firm benefits less from other members' knowledge. This determines the first threshold value R_l such that, ceteris paribus, firms with a quality of $R_i \leq R_l$ join the standard to obtain spillover effects. Second, 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***

(i) 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.*

(ii) The quality of the standard is given by $\tilde{R} = \sum_{R_i \geq R_h} R_i$. The licensing fee is set as specified in Proposition 1 and downstream firms license the standard technology if doing so gives them a non-negative profit.

Proof: see Appendix A.6.

Proposition 2 forms our central result as it determines the innovators' SSO-membership and lobbying decisions. However, it is framed independently of the membership cost k_u. If k_u is very low such that $\Pi^u(R_a, \tilde{R}) > 0$, all innovators with a patent quality join the standard as members and all innovators with a patent quality between $(R_a, \bar{R})$ become active members. There would be no firms outside of the standard. Proposition 2 still applies with $R_l = R_h = R_a$. As the costs of k_u discourage passive and active membership, Figure 1 instead focuses on the effect of the lobbying costs $\bar{e}$ and shows innovators' relative profits (net of costs) in equilibrium. The horizontal, black line shows the outside option at a profit of 0 for all firms and the vertical, black lines show the cutoffs between different roles of firms.

First, the blue, dashed line shows the profit of an active innovator of quality R_i if all firms of a higher quality actively join the standard. It is upwards sloping as a higher number of firms implies a lower average quality $\frac{\tilde{R}}{\tilde{n}}$ of the standard and thus lower per firm royalty revenue.

Second, the orange, dot-dashed line shows the profit of a passive innovator of quality R_i for the equilibrium standard size $\tilde{R}$. It is decreasing as high-quality firms profit less from spillovers. For a sufficiently high-quality firm, the spillovers are 0 which leads to the kink in the passive

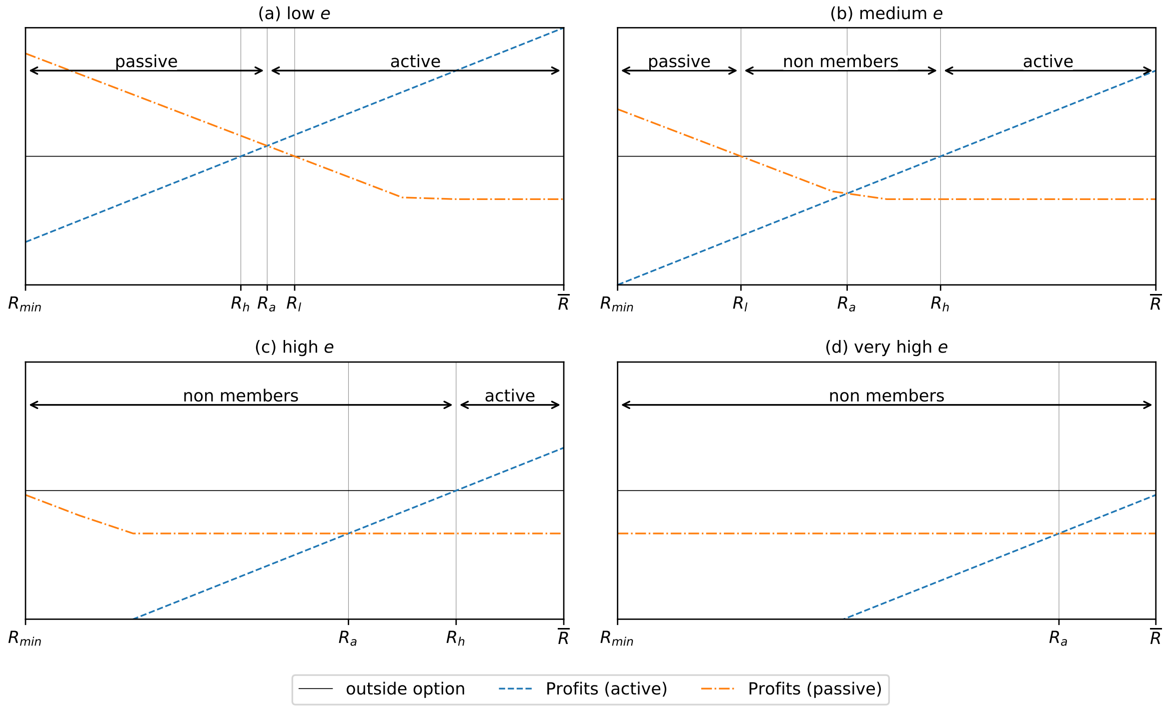

Figure 1: Profits of Innovators

profits.[30]

A 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. In Figure 1, panel (a) the costs are sufficiently low such all firms with a quality above (below) R_a become active (passive) members and now firms remain outside of the standard.

As innovators' costs of becoming active increase, the active firms' profits decline and fewer firms become active members. This, in turn, lowers the profits of passive members and fewer firms chose to do so. In the case of panel (b) the profits of a firm at $R_i = R_a$ are now negative and the firms between R_l and R_h remain outside of the standard.

Increasing the costs of the firms further leads to fewer active firm which causes the profits of the passive firms in panel (c) to be negative, thus no firms become passive firms. Finally, in panel (d) the costs of becoming an active innovator are so high that it is not profitable for any active firms to exists which causes the spillover effects to vanish. In this case, all firms remain outside of the SSO.

[30] By definition spillovers cannot be negative thus we observer a kink at $-k_u$, which never impacts firms' behavior.

4.4 Changes in Governance Structure

A central purpose of this paper is to analyze how different SSO-governance structures, that is, a different allocation of power between implementers and innovators, affects the results of the model. Therefore, we now study the impact of a change in the parameter λ on equilibrium decisions and payoffs: combined profits of downstream and upstream firms, referred to as *industry profits*.[31] According to Lemma 2, industry profits are increasing in λ for a given $\tilde{R}$. However, a higher λ leads to fewer innovators becoming active (lower $\tilde{R}$) and thus involves a trade-off.

Parameter λ specifies the number of implementers that need to support the technology. To attract more downstream firms, it is necessary to lower the royalty fee charged. The change in royalty itself does not change the combined profits of upstream and downstream firms. However, it impacts industry profits via two channels. First, it raises the demand for the standard (q_u) as more downstream firms are served, which increases industry profits ($W_u^*+W_d^*$). Second, it lowers the innovators' profits, thus lowering their incentives to become active members and lowering the quality of the standard ($\tilde{R}$). In the following discussion, we consider an increase from λ to $\lambda' \equiv \lambda + \frac{1}{m}$, where the change leads to one more downstream implementer being required. Let Δ be the difference operator that denotes a change in a variable and $'$ the quantities after the increase in λ.

A sufficiently large increase in λ can cause the market to collapse such that the maximum royalty rate the patent pool can charge cannot compensate innovators for the costs of their active membership. In this case, no firm becomes a member of the SSO 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 active firm remains for the increased value of λ'.

Industry Profits We now consider the effect that an increase in λ by $\frac{1}{m}$ has on firm equilibrium profits. Downstream firms' profits (individually and collectively) are increasing in λ, such that:

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

[31] We 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.

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

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

Active innovators who exit the market are harmed:

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

Active innovators who remain in the market are either harmed or 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 the industry profits for a given λ. There exists a $\hat{\lambda}$ such that:

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

The derivation of these results is given in Appendix A.7. In the following paragraphs we discuss the intuition behind the results.

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 royalty fee. This, in turn, increases the profits of each and all downstream firms. Firms with a higher strength benefit most from this as 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. However, this effect leaves welfare unchanged. However, it also expands the downstream market, which raises welfare.

Second, if an increase in λ *does* lead to a reduction in the number of active firms, 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 firms 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 firm leads to a large decline in the quality of the standard, active firms are harmed. Otherwise, they benefit. However, in total, the profits of active firms do decline in λ. The profits of the downstream firms decline as the quality of the standard and thus the level of spillover effects decline.

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. Interestingly, as the per-strength net-benefit to the implementers ($\tilde{R}-p_u$) is weakly increasing in λ, it is the high-strength implementers who profit most from an expansion of other implementers' participation even if doing so leads to a lower quality standard in equilibrium. 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.*

Figure 2 shows this using a numerical example.[32] For $\lambda < 0.85$, the profits of implementers are increasing in λ. As the standard requires a larger degree of implementer participation innovators need to compensate the implementers. Innovators' profits are (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 exiting the standard. This pattern continues until the last increase to $\lambda = 0.85$ causes the market to collapse. Upstream firms cannot obtain a sufficient profit and thus exit. Innovators' profits turn negative such that Assumption 4 is violated, and the market collapses. Then all firms involved make zero profits as none can use the standard.[33]

[32] The parameter values for the graph are $k_d = 0.64$, $k^a = 4.33$, $k^y = 0.7$, $\alpha = 0.1$, $R = \{0, 0.1, \ldots, 0.9\}$, $n = 10$, $S = \{0, 0.05, \ldots, 0.95\}$, $m = 20$.

[33] This pattern is repeated for other parameter values, satisfying the assumptions defined in Section 3.1. However, not all regions necessarily exist there.

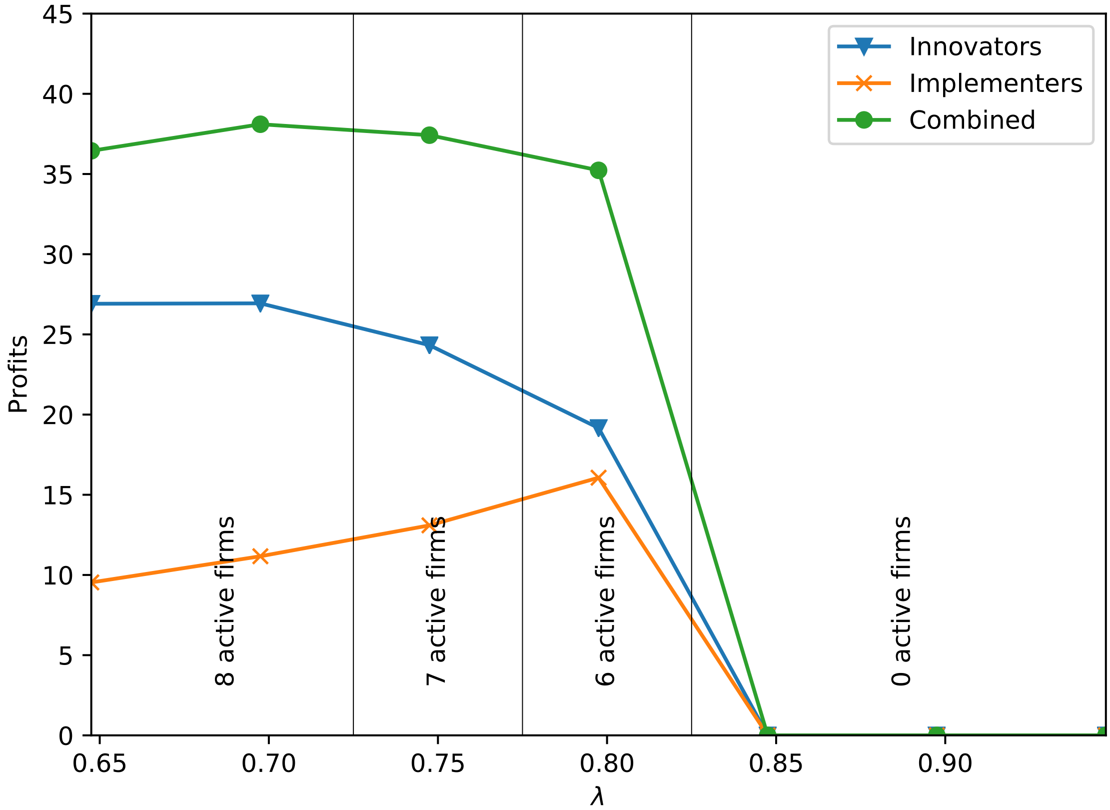

Figure 2: Profits of firms

5 Conclusion & Discussion

We started with some key empirical observations on SSOs, which could not be fully explained by existing theoretical research. 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' lobbying efforts, which are the necessary grease to get one's technology into a standard in this model (and in practice, as Gupta (2017) suggests). Next, we analyzed how these results change if the distribution of power 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. The main lesson of the model is that innovators' SSO-membership decisions can stem from different motivations (Proposition 2). A subgroup 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.[34]. However, some firms, especially if they are of a low-quality type, have little to gain from having their patents included in the standard. Instead, 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 could explain seemingly inconsistent findings in the empirical literature (Blind and Thumm (2004) vs. Gupta (2017)).

Finally, the model suggests that downstream firms' participation in a standard can be a powerful commitment device for innovators to lower the royalty rate charged to a socially superior level without having to jointly set prices or quality levels. Together all aspects explain why real-world SSOs are so large and include very heterogeneous members, including those who have no chance to get their technologies into the standard.

Turning back to governance, we showed that if an SSO requires a higher percentage of implementers to agree to a specific technology to become standard-essential, this 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 harming 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 into 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.

Interestingly, in the model high-quality and low-quality innovators have conflicting incentives with respect to the inclusion of downstream firms. For high-quality innovators, raising membership beyond the profit-maximizing level 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 active innovators who find it non-profitable to add their technology to the standard as the royalty declines. Especially if the market is saturated, this can be a profitable strategy. Thus, high-quality firms might see downstream participation as a way to discourage low-quality in-

[34] Per Assumption this subgroup is limited to only firms of a high type. However, high-quality innovators have the highest incentives to join and innovators have an incentive to set-up the standard in such a way that high-types are preferred in the joining decision.

novators from joining the standard and might even push for a high degree of downstream governance (λ). However, passive innovators aim for the largest standard possible to obtain 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 to attract new implementers, the high-strength implementers profit the most from the inclusion of additional downstream firms. Interestingly, this effect increases in the firms' strength if the inclusion of downstream firms leads to a decline in the standard's quality.

These results have wide-reaching relevance. 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. Finally, in both groups, large firms prefer to push for a broad inclusion of implementers. Both the high-quality innovators and the high-strength implementers find it profitable to include additional firms into the standard to obtain higher profits.

We find an inverted U-shape between the participation of implementers and industry profits. 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 of 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).

Based on these results, we find that upstream firms may want to restrict the supply of their technology to implementers. However, an increase in participation rates of downstream firms can mitigate this at the costs of innovation. A more worrisome finding is that high-strength implementers have a strong incentive to increase downstream participation, especially when doing so lowers the quality of the standard. Thus, if participation is determined by key implementers, standards might become too big and lead to lower innovation. Thus, it might be better for Standard Setting organizations to pay attention to small implementers when determining to what extent implementers should participate in the standard-setting process.

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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. The royalty for a given price is:

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

As the downstream profit is decreasing in p_u and increasing in the strength. We find that the patent pool managers only considers prices that leave one downstream firm indifferent. Then the pivotal downstream firm ($\hat{S}$) and all downstream firms with a higher strength license the standard. Let $\hat{j}$ be index of the lowest strength implementer who licenses the technology then the royalty revenue is given by:

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

Thus, the profit maximizing price can be found as:

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

Consider a change to the royalty $\Delta W_u(p_u, \tilde{R})$ such that the price declines and 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). Thus, we find:

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

The first part ($(\hat{S}-\sigma)\tilde{R}>0$) gives the additional profits as the technology can be marketed to more implementers. It is declining in $\hat{S}$. As more implementers join the benefit the marginal implementer obtains from the technology decreases. For the second part, note that ($\hat{S}-\sigma>0$ otherwise the strength of the next firm was negative. Consequential, the second part is negative.

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

A.2 Proof of Lemma 2

Proof. Recall the royalty as defined in Lemma 2:

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

Consequently the profits of the implementers are given as:

$$\begin{aligned}\Pi^d(S_j,\tilde{R}) &= \frac{S_j-\hat{S}(\lambda)}{\hat{S}(\lambda)}k_d\\ \Pi^d(\hat{S}(\lambda),\tilde{R}) &= 0\end{aligned}$$

Thus, in equilibrium $\Pi^d(S_j,\tilde{R})$ is positive for $S_j>\hat{S}(\lambda)$. Furthermore, as $\frac{\partial\hat{S}(\lambda)}{\partial\lambda}<0$, we find that $\frac{\partial}{\partial\lambda}\frac{S_j-\hat{S}(\lambda)}{\hat{S}(\lambda)}\geq 0$ with the inequality being strict for $S_j>\hat{S}$. Consequently, implementers profit from an increase in λ. Furthermore, consider a change to λ that exactly one additional implementer of strength $\hat{S}(\lambda)'$ adopts the technology. The change in industry profits caused by this is given as:

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

For $\hat{S}(\lambda)'\tilde{R} > k_d$ the change $\Delta W(\lambda)$ is positive. If $\hat{S}(\lambda)'\tilde{R} < k_d$ the price is required to be negative as the implementer of strength $\hat{S}(\lambda)'$ 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 Proof of Lemma 3

Proof. The royalty rate is given as:

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

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

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

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, $\frac{\hat{S}(\lambda)^2 + q_u^* \sigma}{\hat{S}(\lambda)^2 - \hat{S}(\lambda)\sigma)} k_d$ 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 and the fact that its 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 gives the profit-maximizing royalty rate p_u. For each λ below the profit-maximizing one 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 licensing fee for each quality of the standard $\tilde{R}$:

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

Consider a standard of quality $\tilde{R}$ and let R_a be the quality of the highest quality innovator not part of the standard. We compare the royalty revenue of $W_u = p_u q_u$ for a standard including firm R_a:

$$\begin{aligned}
\frac{p_u^*(\tilde{R} + R_a, \lambda) q_u(\lambda)}{\tilde{n} + 1} &\geq \frac{p_u^*(\tilde{R}, \lambda) q_u(\lambda)}{\tilde{n}} \\
\Leftrightarrow \tilde{n} p_u^*(\tilde{R} + R_a, \lambda) &\geq (\tilde{n} + 1) p_u^*(\tilde{R}, \lambda) \\
\Leftrightarrow \tilde{n} \left(\tilde{R} + R_a - \frac{k_d}{\hat{S}(\lambda)} \right) &\geq (\tilde{n} + 1) \left(\tilde{R} - \frac{k_d}{\hat{S}(\lambda)} \right) \\
\Leftrightarrow \frac{\tilde{R}}{\tilde{n}} - R_a &\leq \frac{k_d}{\tilde{n} \hat{S}(\lambda)} \\
\Leftrightarrow \frac{\bar{R} - R_a}{2} &\leq \frac{k_d}{\tilde{n} \hat{S}(\lambda)}
\end{aligned}$$

Thus, it is possible that the per-firm royalty revenue is increasing in the number of firms if the royalty revenue is low and the quality of the additional firm is high. This can be the case if the downstream firms' participation is costly (high k_d) such that the standard requires a minimum quality to be viable. However, $\frac{\bar{R} - R_a}{2}$ is increasing in R_a and $\frac{k_d}{\tilde{n} \hat{S}(\lambda)}$ is declining in $\tilde{n}$. Thus, if the per-firm royalty rate is declining with a firm of quality R_a joining it declines for each consequent firm becoming active.

If an additional innovator's entry raises the per-firm royalty it is profitable for all firms and the equilibrium R_a consequently always implies that per-firm royalty declines with the entry of an additional firm. □

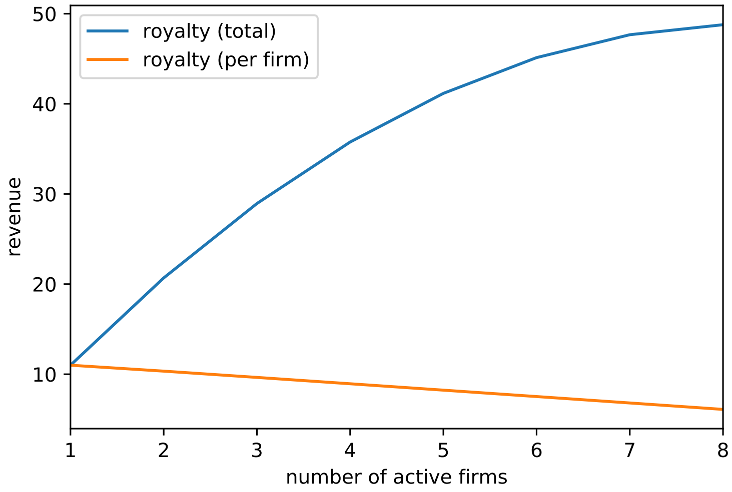

Figure 3: Royalty Revenue

A.5 Proof of Corollary 1

Proof. We start with the expression implicitly defining R_a:

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

First, an increase in $\bar{e}$ implies that a greater $\frac{W_u^*(\tilde{R},\lambda)}{\tilde{n}}$ is required for the inequality to be satisfied, thus fewer firms need to be part of the standard to raise the royalty per firm.

Second, an increase in $\bar{R}$ 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.

Third, 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 $\tilde{n}$.

Finally, 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

The proof for this proposition follows directly from Lemma 2, Proposition 1, and Assumption 4. The results follow from the profit the innovator on the threshold between active and passive innovators generates within the standard.

Proof. Lemma 2 gives the optimal licensing fee for each strength of the standard. Based on this

Proposition 1 gives 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 the behavior in stage 1 is optimal.

First, by Assumption 4 the highest quality innovator finds it profitable to join an empty standard and we thus 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 conditional on them joining the standard. We distinguish two cases:

Case 1: $\Pi^u(R_a, \tilde{R}) < 0$. In this case, the firm at the cut-off makes a negative profit in the standard. Thus we find that some firms 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:

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

This expression gives that the lowest quality firm with a quality above R_h makes a positive profit, while the innovator with quality R_h makes a loss. Thus, all firms with quality exceeding R_h join the standard. Similiarly, we require that:

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

Then all firms below R_l and above R_h join the standard with the firms above R_h becoming active members.

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

It is possible that $R_l < \min_{i \in \mathcal{N}}\{R_i\}$. In such a case firms do not find it profitable to become passive members.

A.7 Effect of λ 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:

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

An increase in λ requires the royalty to be lowered such that implementer $\hat{S}(\lambda + \frac{1}{m})$ is making zero profits. Consequently, for an implementers of strength $S_j > \hat{S}(\lambda + \frac{1}{m})$ we find that:

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

Thus, the profits of downstream implementers are increasing in λ except for the new marginal firm with strength $\hat{S}(\lambda + \frac{1}{m})$, 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 where positive. Finally, for active innovator who remain active we find that if $\Delta\tilde{R} = 0$ their profits decline. If $\Delta\tilde{R} < 0$ profits can be either increasing or decreasing.

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

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

For simplicity, assume $\alpha = 0$, then the sign of the effect depends purely 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 a upstream market where the royalty revenue is nearly exhausted such that upstream firms make nearly zero profits. In this case a small decrease in the profits changes total revenue only marginally, while forcing one firm to exit. Thus profits increase. In contrast if the profits are sufficiently high such that the firms make nearly $k_d + e$ profits, then a reduction lowers profits.

Combined profits are given as:

$$\begin{aligned}\Pi^u_{\text{active}} &= \alpha(n-1)\tilde{R} + W_u - (e+k_u)\,n \\ \sum \Delta\Pi^u_{\text{active}} &= \underbrace{\alpha\left((n-1)\Delta\tilde{R} + \tilde{R}\Delta n\right)}_{<0} + \underbrace{\Delta\,(W_u)}_{<0} \underbrace{-\,(e+k_u)\,\Delta n}_{>0}\end{aligned}$$

Consider $\alpha = 0$. Note that innovator R_h becoming in the standard cannot increase royalty revenue by more than $(e + k_u)$. Otherwise the firm at R_h would enter the market and increase the joint royalty rate by more than its own costs. Joint royalty revenue without it exceeded joint costs ($W_u \geq (e + k_u)n$) otherwise all firms would make a loss. Thus, after firm enters, all firms, including R_h would still obtain a profit. Note, that this is for the case of $\Delta\tilde{n} = 1$, but the proof for $\Delta n > 1$ uses the same argument but for Δn firms jointly. Consequently, the combined profits of active innovators are decreasing for $\alpha = 0$. For $\alpha > 0$ the reaction of the profits is more negative combined profits of active innovators are decreasing for any α.

Consequently, innovators as a whole are harmed by an increase in λ. However, the innovators who remain active may be better off depending on the initial profits. Consider the change in profits for an innovator who is active both before and after the change in λ. For simplicity consider the case of $\alpha = 0$. 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:

$$\begin{aligned}\frac{n\Delta W_u - W_u\Delta n}{n(n+\Delta n)} &< 0 \\ \Leftrightarrow \frac{\Delta W_u}{W_u} - \frac{\Delta n}{n} &< 0\end{aligned}$$

Profits of innovators are increasing if the change to the combined profits is small and the number of firms is large. In this case, 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 we consider the combined profits of upstream and downstream firms. Holding $\tilde{R}$ constant, we find that the change to industry profits is given as:

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

This expression is positive if 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:

$$W_d^* + W_u^* = q_u^*(\lambda)\tilde{R} - \underbrace{|\tilde{S}(\lambda)|k_d}_{\text{increasing}} - \underbrace{\tilde{n}\,(k_u + e)}_{\text{decreasing}}$$

First, and increase in λ raises the 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 all directions. Additional to this the passive innovators are harmed as their knowledge spillovers decline.

The marginal downstream firm's strength decreases as λ increases. Consequently, the financial benefit of market expansion declines. □