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Jan Boone, Florian Schütt and Emanuele Tarantino

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Price Commitments in Standard Setting under Asymmetric Information*

Jan Boone† Florian Schuett‡ Emanuele Tarantino§

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Abstract

Many observers have voiced concerns that standards create essentiality and thus monopoly power for the holders of standard essential patents (SEPs). To address these concerns, Lerner and Tirole (2015) advocate structured price commitments, whereby SEP holders commit to the maximum royalty they would charge were their technology included in the standard. We consider a setting in which a technology implementer holds private information about demand. In this setting, price commitments increase efficiency not only by curbing SEP holders' market power, but also by alleviating distortions in the design of the royalty scheme. In the absence of price commitments, the SEP holder distorts the implementer's output downward in the low-demand state to reduce the high-demand type's information rent. Price commitments reduce this distortion.

Keywords: standardization, standard-essential patents, price commitments, information asymmetry
JEL classification: D82, L15, L24

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†TILEC, CentER, Tilburg University. E-mail: `j.boone@uvt.nl`.

‡TILEC, CentER, Tilburg University. E-mail: `f.schuett@uvt.nl`.

§University of Mannheim and TILEC. E-mail: `etaranti@gmail.com`

1 Introduction

Many observers have voiced concerns that standards create essentiality and thus monopoly power for the holders of standard essential patents (SEPs) (Farrell *et al.*, 2007; Ganglmair *et al.*, 2012; Dewatripont and Legros, 2013; Lerner and Tirole, 2015). This is said to cause at least two inefficiencies. First, SEP holders can charge higher royalties than under hypothetical ex ante licensing. Second, anticipating such opportunistic behavior, standard setting organizations (SSOs) may select technologically inferior functionalities that are available at lower royalties, for example because there is within-functionality competition or the patents have expired.

To address these concerns, Lerner and Tirole (2015) advocate structured price commitments, whereby SEP holders commit to the maximum royalty they would charge were their technology included in the standard.[1] In Lerner and Tirole's complete-information setting, price commitments restore the competitive benchmark royalty rates and ensure that the SSO selects the efficient standard. In practice, however, there is often considerable uncertainty about the benefits of including certain functionalities in the standard. In the case of mobile telephony, for instance, it may not be clear how much consumers are willing to pay for increased transmission speeds. Such uncertainty is typically resolved only after the standard has been set. Moreover, technology contributors (SEP holders) tend to be less well informed about demand parameters than implementers of the standard (in the mobile telephony example, the handset makers).

In this paper, we investigate the effects of the kind of price commitments advocated by Lerner and Tirole (2015) in an environment with asymmetric information between upstream and downstream firms. We consider a setting in which the downstream firm holds private information about the demand for the final product incorporating the standard. In such a setting, the upstream firm will design its royalty scheme to screen the downstream firm

[1] In a similar vein, Llanes and Poblete (2014) study alternative standard-setting and patent pool-formation rules and show that welfare is maximized by ex ante agreements about participation in, and the distribution of dividends from, a patent pool for technologies selected into the standard.

and elicit its private information (Macho-Stadler and Perez-Castrillo, 1991).[2] We assume that the uncertainty about demand is resolved after the SSO sets the standard but before royalty negotiations between upstream and downstream firm take place.

In the absence of price commitments, the upstream firm screens the downstream firm by means of a non-linear royalty scheme. As usual, the optimal contract involves no distortion of the downstream firm's output in the high-demand state. In the low-demand state, output is distorted downward to make it less attractive for the high type to mimic the low type. This is done in an effort to reduce the downstream firm's information rent. Except for the information rent, the optimal contract extracts the downstream firm's entire surplus. Even though an alternative, albeit inferior, technology is available ex ante, once the standard is set the downstream firm can no longer turn to this alternative technology if it wants to comply with the standard. Because the SSO anticipates the upstream firm's behavior, it often selects the inferior alternative technology as the standard. This is especially bad for welfare if the high-demand state is very likely; that is, of the new technology is very promising.

In the presence of price commitments, the upstream firm can indirectly control the contract that it will offer to the downstream firm after the standard is set by appropriately choosing the royalty cap to which it commits prior to standardization. Essentially, thus, the need to ensure inclusion in the standard adds an additional constraint to the upstream firm's problem. This forces the upstream firm to leave enough rent to the downstream firm to beat out the alternative technology. We show that a side-effect of this imperative to improve on the alternative technology is to reduce – or even completely eliminate – the distortion of the low type's output. Intuitively, because the upstream firm cannot extract the downstream firm's entire surplus anymore, there is less of a need to reduce the information rent; on the contrary, giving an information rent is an efficient way of transferring some surplus to the downstream firm.

[2] Gallini and Wright (1990) address similar issues in a setting where the innovator, rather than the implementer, holds private information, so that there is signaling rather than screening.

The paper is related to the growing literature on the economics of standard setting. Within that literature, Llanes and Poblete (2014) and Lerner and Tirole (2015) share our focus on ex ante commitments. Llanes (forthcoming) studies a game of repeated standard setting and shows that commitments to license on fair, reasonable, and non-discriminatory (FRAND) terms can outperform price commitments when technologies are hard to describe ex ante. Bekkers *et al.* (2017) model the disclosure process and show that, when there is competition for inclusion in the standard, vertically integrated firms can find it optimal to commit to royalty-free licensing.

For the most part, the literature has ignored asymmetric information about the benefits and costs of technologies vying for inclusion in a standard, which is the focus of our paper. Two exceptions – though different in focus from our paper – are Farrell and Simcoe (2012) and Lerner *et al.* (2016). Farrell and Simcoe (2012) model standard setting as a war of attrition where selection occurs through delay. Lerner *et al.* (2016) study SEP holders' decision whether to make generic or specific disclosures to the SSO. Both papers assume that the quality of technologies, or the patents that cover them, is innovators' private information. By contrast, in our model it is the implementer that holds private information about the demand for a technology.

Our paper also differs from much of the rest of the literature by considering non-linear royalties. Like us, Schmidt (2014) allows for two-part tariffs and shows that, in the context of licensing complementary technologies, they eliminate royalty stacking. In our paper, royalties can be part of the optimal contract despite the fact that we allow for two-part tariffs because they are used for screening purposes.

The remainder of the paper is organized as follows. Section 2 sets out the model. Section 3 analyzes the case without price commitments, while Section 4 turns to the case in which price commitments, in the form of a royalty cap, are possible. Section 5 concludes.

2 Model

Consider the following setup. There is a single upstream firm U, a single downstream firm D, and an SSO. U owns a patent on a feature that the SSO considers for inclusion in a standard. There exists an alternative (backstop) technology that is available royalty free and generates a known (inverse) demand $P_0(q)$. The demand generated by U's technology is uncertain and governed by a demand parameter $\theta \in \{H, L\}$, such that $P_H(q) > P_L(q) > P_0(q)$. The demand parameter is initially unknown to all parties but is revealed to D prior to the implementation of the standard (in a final product). Assume $\Pr(\theta = L) = \lambda$ and $\Pr(\theta = H) = 1 - \lambda$. D has production costs $C(q)$.

The timing is as follows:

1. In the presence of price commitments, U announces the maximum royalty it will charge $\bar{R}(q)$.
2. The SSO selects between U's technology and the alternative one. Assume the SSO is "user-driven" and thus selects the technology that maximizes D's expected profit.
3. If U's technology is selected, D learns θ. Otherwise, D produces using the backstop technology and earns $\max_q P_0(q)q - C(q)$.
4. U proposes a royalty scheme $R(q)$. If a price commitment is in place, U is subject to the constraint $R(q) \leq \bar{R}(q)$.
5. D accepts or rejects. If it accepts, it chooses its output q to maximize $P_\theta(q)q - C(q) - R(q)$.

Let $\pi_0(q) \equiv P_0(q)q - C(q)$ denote the downstream firm's profit with the alternative technology. Similarly, let $\pi_\theta(q) \equiv P_\theta(q)q - C(q)$ denote the downstream firm's profit gross of royalties with U's technology when the demand parameter is $\theta = L, H$. We assume that the profit function is twice continuously differentiable, strictly concave, and has a unique maximum for any demand realization. We let q_θ^* denote the profit-maximizing output when the demand parameter is θ. In addition, we impose the following assumption:

Assumption 1. $\pi'_H(q) > \pi'_L(q)$ *for all* $q \geq 0$.

This assumption says that the change in profit resulting from a marginal expansion of output is larger in the high-demand than in the low-demand state.

To streamline the analysis, we will also assume the following:

Assumption 2. $\pi'_L(0) > (1-\lambda)\pi'_H(0)$.

This assumption ensures that the optimal contract will not involve shutdown of the low type. For λ close enough to zero it is violated because of Assumption 1. In that case, U ignores the L type and leaves the H type no rents. As a result U's technology is always rejected by the SSO in favor of the backstop technology. Price commitments can clearly improve the outcome in such a situation which happens if the technology is very promising (high-demand state is likely).[3]

3 No price commitments

Consider first the case without price commitments. We solve the model backwards, starting from stage 4.

Royalty setting stage. Suppose that the SSO has selected U's technology as the standard, so that D cannot use the alternative technology. U's problem of choosing a royalty scheme can be recast as choosing the quantities q_L and q_H and associated royalty payments R_L and R_H to solve

$$\max_{q_L, q_H, R_L, R_H} \lambda R_L + (1-\lambda) R_H \tag{1}$$

subject to individual rationality (IR) and incentive compatibility (IC) constraints,

$$\pi_L(q_L) - R_L \geq 0 \tag{2}$$

$$\pi_H(q_H) - R_H \geq 0 \tag{3}$$

$$\pi_L(q_L) - R_L \geq \pi_L(q_H) - R_H \tag{4}$$

$$\pi_H(q_H) - R_H \geq \pi_H(q_L) - R_L. \tag{5}$$

[3]Note that although price commitments will be efficiency-enhancing ex ante, they may nevertheless result in ex post inefficiency in the case where the low type is shut down.

The following proposition characterizes the solution to U's problem.

Proposition 1. *In the absence of price commitments, U chooses the royalty scheme to implement an allocation* (q_L^{NC}, q_H^{NC}) *such that* $\pi'_H(q_H^{NC}) = 0$ *and* $\pi'_L(q_L^{NC}) = (1-\lambda)\pi'_H(q_L^{NC}) > 0$, *with associated royalty payments* $R_L^{NC} = \pi_L(q_L^{NC})$ *and* $R_H^{NC} = \pi_H(q_H^{NC}) - [\pi_H(q_L^{NC}) - \pi_L(q_L^{NC})]$.

Proof. We will solve a relaxed problem, ignoring the high type's IR constraint, (3), and the low type's IC constraint, (4), and then show that the solution to the relaxed problem satisfies these constraints, so that it is also the solution to the original problem. Since the objective is increasing in R_L and R_H, the constraints (2) and (5) must be binding at the optimum. Hence we can use the constraints to substitute for R_L and R_H in the objective. The problem becomes

$$\max_{q_L, q_H} \ \lambda\pi_L(q_L) + (1-\lambda)[\pi_H(q_H) - \pi_H(q_L) + \pi_L(q_L)],$$

leading to the first-order conditions

$$\pi'_H(q_H) = 0 \tag{6}$$

$$\pi'_L(q_L) = (1-\lambda)\pi'_H(q_L). \tag{7}$$

The existence of a strictly positive solution to (7) follows from Assumptions 1 and 2 together with the assumption that π_L and π_H are continuously differentiable and have unique maximizers.

Next, we show that $\pi'_H(q_L) > 0$, a sufficient condition for which, by strict concavity of π_θ and (6), is $q_L < q_H$. Suppose otherwise, i.e., $q_L \geq q_H$. Then $\pi'_H(q_L) \leq 0$ and hence $\pi'_L(q_L) = (1-\lambda)\pi'_H(q_L) \geq \pi'_H(q_L)$, contradicting the assumption that $\pi'_H(q) > \pi'_L(q)$.

It remains to verify that the constraints that we initially ignored are indeed satisfied. Start from (5):

$$\pi_H(q_H) - R_H \geq \pi_H(q_L) - R_L \geq \pi_L(q_L) - R_L \geq 0$$

where the second inequality follows from $\pi_H(q_L) \geq \pi_L(q_L)$ (which is implied by the assumption that $P_H(q) \geq P_L(q)$ for all q) and the last inequality from (2). Hence, (3) is satisfied.

To check (4), note that the left hand side equals 0. Hence, we have

$$\pi_L(q_H) - R_H \leq 0$$

which, using (5) and (2), can be written as

$$\pi_L(q_H) - \pi_L(q_L) \leq \pi_H(q_H) - \pi_H(q_L) \quad \Leftrightarrow \quad \int_{q_L}^{q_H} \pi'_L(q)dq \leq \int_{q_L}^{q_H} \pi'_H(q)dq,$$

which holds for $q_H > q_L$ by Assumption 1. $\square$

The allocation in Proposition 1 features the familiar "no distortion at the top" result – the high type produces the efficient output – and a downward distortion of the low type's output, i.e., the low type produces less than the efficient quantity (characterized by $\pi'_L(q_L) = 0$).[4] The intuition is that U can extract D's surplus through the royalty scheme $R(q)$, and thus has an interest in inducing the profit-maximizing output level. The presence of private information, however, allows D to collect an information rent in the high-demand state. To reduce this information rent, U lowers the output level in the low-demand state below the efficient level. This makes it less attractive for the high type to mimic the low type, and thus generates a first-order gain in terms of reducing the information rent in the high-demand state, while (initially) causing only second-order losses in the low-demand state.

The allocation can be implemented by means of a royalty scheme such that $R'(q_H^{NC}) = 0$ and $R(q_H^{NC}) = \pi_H(q_H^{NC}) - \pi_H(q_L^{NC}) + \pi_L(q_L^{NC})$ while $R'(q_L^{NC}) = (1-\lambda)\pi'_H(q_L^{NC})$ and $R(q_L^{NC}) = \pi_L(q_L^{NC})$. An example of such a royalty scheme is a menu of two-part tariffs consisting of a fixed fee F and a per-unit royalty r, where $(F_L, r_L) = (\pi_L(q_L^{NC}) - r_L q_L^{NC}, (1-\lambda)\pi'_H(q_L^{NC}))$ and $(F_H, r_H) = (\pi_H(q_H^{NC}) - \pi_H(q_L^{NC}) + \pi_L(q_L^{NC}), 0)$. In words, the high type receives a contract that includes only a fixed fee, while the low type receives a contract that includes both a fixed fee and a per-unit royalty.

Standard setting stage. Anticipating the outcome at the royalty-setting stage, the SSO selects U's technology if and only if it yields D a greater

[4] The term 'efficiency' here refers to the joint profits of U and D, ignoring consumers.

expected profit than the alternative technology. Letting

$$\hat{\pi}_0 \equiv \max_q \pi_0(q),$$

the condition for the SSO to select U's technology is

$$\lambda[\pi_L(q_L^{NC}) - R_L^{NC}] + (1-\lambda)[\pi_H(q_H^{NC}) - R_H^{NC}] \geq \hat{\pi}_0,$$

or

$$(1-\lambda)[\pi_H(q_L^{NC}) - \pi_L(q_L^{NC})] \geq \hat{\pi}_0. \tag{8}$$

As noted after Assumption 2, for λ close to 0, the SSO rejects U's technology and D works with the 0-technology. Similarly, if λ is close to 1, the L-state with no rents for D is so likely that D's expected profit does not exceed $\hat{\pi}_0$. Thus also in this case, U's technology is rejected. Consequently, only for intermediate values of λ will the SSO choose to work with U's technology.

There are two inefficiencies that arise in this setting. First, although U's technology is always superior to the alternative one, it will sometimes not be selected by the SSO. This inefficiency is due to U's lack of commitment power: because royalties are negotiated after the standard is set, U cannot credibly promise not to extract (most of) D's surplus after being selected as the standard.[5] Second, the contract designed by the upstream firm introduces an output distortion in the low-demand state. This second inefficiency exacerbates the first one, as it reduces the range of parameters for which the SSO adopts U's superior technology compared to a situation without output distortions.

[5]Note that a joint profit maximizing SSO would always adopt U's technology. The joint profit maximizing adoption rule (taking q_L and q_H as given) would be to select U's technology if and only if

$$\lambda\pi_L(q_L) + (1-\lambda)\pi_H(q_H) \geq \hat{\pi}_0. \tag{9}$$

To see that it is always joint-profit maximizing to adopt U's technology, notice first that since $P_L(q) > P_0(q)$, we have $\pi_L(q_L^*) > \hat{\pi}_0$. U could propose a unique contract $(q, R) = (q_L^*, \pi_L(q_L^*))$, which both types would accept. By revealed preference, if U instead proposes the contracts (q_L^{NC}, R_L^{NC}) and (q_H^{NC}, R_H^{NC}) characterized in Proposition 1, it must be that this yields a higher profit:

$$\lambda\pi_L(q_L^{NC}) + (1-\lambda)[\pi_H(q_H^{NC}) - \pi_H(q_L^{NC}) + \pi_L(q_L^{NC})] \geq \pi_L(q_L^*),$$

which, together with $\pi_L(q_L^*) > \hat{\pi}_0$, implies (9). A similar argument can be made for the case where it is optimal to shut down the low type.

4 Price commitments

We now turn to the case where the upstream firm can make price commitments at stage 1. In a first step, we will ignore the royalty setting stage and assume that U can implement any allocation it would like to through the cap $\bar{R}(q)$. Later we show that the allocation U wants to achieve can indeed be implemented through an appropriately chosen cap.

4.1 The optimal allocation

Standard setting stage. Let $(\bar{q}_L, \bar{q}_H, \bar{R}_L, \bar{R}_H)$ denote the allocation that the SSO anticipates will be implemented at the royalty setting stage if U is selected as the standard. The SSO selects U's technology if and only if

$$\lambda[\pi_L(\bar{q}_L) - \bar{R}_L] + (1-\lambda)[\pi_H(\bar{q}_H) - \bar{R}_H] \geq \hat{\pi}_0.$$

Price commitment stage. U's problem is to choose $\bar{q}_L$, $\bar{q}_H$, $\bar{R}_L$, and $\bar{R}_H$ to solve

$$\max_{\bar{q}_L, \bar{q}_H, \bar{R}_L, \bar{R}_H} \quad \lambda \bar{R}_L + (1-\lambda)\bar{R}_H$$

subject to

$$\lambda[\pi_L(\bar{q}_L) - \bar{R}_L] + (1-\lambda)[\pi_H(\bar{q}_H) - \bar{R}_H] \geq \hat{\pi}_0 \tag{10}$$

$$\pi_L(\bar{q}_L) - \bar{R}_L \geq 0 \tag{11}$$

$$\pi_H(\bar{q}_H) - \bar{R}_H \geq 0 \tag{12}$$

$$\pi_L(\bar{q}_L) - \bar{R}_L \geq \pi_L(\bar{q}_H) - \bar{R}_H \tag{13}$$

$$\pi_H(\bar{q}_H) - \bar{R}_H \geq \pi_H(\bar{q}_L) - \bar{R}_L. \tag{14}$$

Here, (10) is the constraint imposed by the SSO's selection rule.

Proposition 2. *Suppose $\hat{\pi}_0 > (1-\lambda)[\pi_H(q_L^{NC}) - \pi_L(q_L^{NC})]$. Then, U implements an allocation $(\bar{q}_L^C, \bar{q}_H^C)$ such that*

(i) $\pi'_H(\bar{q}_H^C) = 0$, and

(ii) either $\pi'_L(\bar{q}_L^C) = 0$ or $\pi_H(\bar{q}_L^C) - \pi_L(\bar{q}_L^C) = \hat{\pi}_0/(1-\lambda)$.

Proof. The assumption that $\hat{\pi}_0 > (1-\lambda)[\pi_H(q_L) - \pi_L(q_L)]$ implies that the royalty scheme chosen in the absence of price commitments does not permit

U to be selected as the standard, and hence that (10) must be binding. Since (14) and (11), together with $\pi_H(q) > \pi_L(q)$, imply that (12) must be slack, the Lagrangian of the problem can be written, using the binding constraint (10) to replace $\bar{R}_L$, as

$$\mathcal{L} = \lambda\pi_L(\bar{q}_L)+(1-\lambda)\pi_H(\bar{q}_H)-\hat{\pi}_0-\eta\left[\pi_H(\bar{q}_L) - \pi_L(\bar{q}_L) - (\pi_H(\bar{q}_H) - \bar{R}_H)\right] \\ - \mu\left[\pi_L(\bar{q}_H) - \bar{R}_H\right] - (\gamma + \mu - \eta)\left[\frac{1-\lambda}{\lambda}[\pi_H(\bar{q}_H) - \bar{R}_H] - \frac{\hat{\pi}_0}{\lambda}\right], \quad (15)$$

where γ, μ, and η are the multipliers associated with constraints (11), (13), and (14), respectively. Differentiating (15) with respect to $\bar{q}_L$, $\bar{q}_H$, and $\bar{R}_H$, respectively, yields the first-order conditions

$$\pi'_L(\bar{q}_L)(\lambda + \eta) - \eta\pi'_H(\bar{q}_L) = 0 \quad (16)$$

$$\frac{\pi'_H(\bar{q}_H)}{\lambda}[(1-\lambda)(\lambda - \gamma - \mu) + \eta] - \mu\pi'_L(\bar{q}_H) = 0 \quad (17)$$

$$\frac{1}{\lambda}[(1-\lambda)\gamma + \mu - \eta] = 0. \quad (18)$$

From (18), we obtain

$$(1-\lambda)\gamma = \eta - \mu. \quad (19)$$

We now show that (13) and (14) cannot simultaneously be binding, so that either $\mu = 0$ or $\eta = 0$. Suppose, by contradiction, that both (13) and (14) hold with equality. Solving both equations for $\bar{R}_H - \bar{R}_L$ then implies

$$\pi_L(\bar{q}_H) - \pi_L(\bar{q}_L) = \pi_H(\bar{q}_H) - \pi_H(\bar{q}_L). \quad (20)$$

But since, for $\theta = L, H$,

$$\pi_\theta(\bar{q}_H) - \pi_\theta(\bar{q}_L) = \int_{\bar{q}_L}^{\bar{q}_H} \pi'_\theta(q)dq,$$

Assumption 1 rules out (20) for any $\bar{q}_L \neq \bar{q}_H$. (Having $\bar{q}_L = \bar{q}_H$ is clearly suboptimal for U.)

Thus, either $\mu = 0$ or $\eta = 0$, which leaves only two possibilities that are compatible with (19):

(a) $\mu = 0$, $(1-\lambda)\gamma = \eta > 0$: that is, (13) is slack while (11) and (14) are binding;

(b) because $\eta = 0$ is not compatible with $\mu > 0$, we have $\gamma = \mu = \eta = 0$: that is, (13), (11), and (14) are all slack.

In case (a), we have $\bar{R}_L = \pi_L(\bar{q}_L)$ and $\bar{R}_H = \pi_H(\bar{q}_H) - (\pi_H(\bar{q}_L) - \pi_L(\bar{q}_L))$. Then, by (10),

$$(1-\lambda)[\pi_H(\bar{q}_L) - \pi_L(\bar{q}_L)] = \hat{\pi}_0,$$

which pins down $\bar{q}_L^C$. Solving

$$\max_{\bar{q}_H} \ \lambda \pi_L(\bar{q}_L) + (1-\lambda)[\pi_H(\bar{q}_H) - (\pi_H(\bar{q}_L) - \pi_L(\bar{q}_L))]$$

yields $\pi'_H(\bar{q}_H) = 0$. In case (b), the first-order conditions (16) and (17) imply $\pi'_L(\bar{q}_L) = \pi'_H(\bar{q}_H) = 0$. □

By assuming that $\hat{\pi}_0 > (1-\lambda)[\pi_H(q_L^{NC}) - \pi_L(q_L^{NC})]$, Proposition 2 focuses on the case where, in the absence of price commitments, U's technology would not be selected as the standard. Price commitments allow U to credibly promise lower royalties and thereby ensure the selection of its technology. As U's technology is superior to the backstop, this increases efficiency.[6]

The proposition also shows that, while the quantity in the high-demand state is unaffected and continues to be set at the efficient level ($\bar{q}_H^C = q_H^{NC} = q_H^*$), the quantity in the low-demand state is set differently than in the absence of price commitments. The following corollary spells out how.

Corollary. *Price commitments reduce the output distortion in the low-demand state: $\bar{q}_L^C > q_L^{NC}$.*

The result is trivial in the case where $\bar{q}_L^C = q_L^*$. The more interesting case is when $\bar{q}_L^C$ solves $(1-\lambda)[\pi_H(\bar{q}_L^C) - \pi_L(\bar{q}_L^C)] = \hat{\pi}_0$. In that case, the result in the corollary follows from the fact that, by assumption, $(1-\lambda)[\pi_H(q_L^{NC}) - \pi_L(q_L^{NC})] < \hat{\pi}_0$, and that $\pi_H(q) - \pi_L(q)$ is strictly increasing in q due to Assumption 1.

Thus, price commitments alleviate the output distortions caused by information asymmetries. The intuition for this result is that the imperative to ensure selection by the SSO forces U to leave rents to D. As a result, U has less of an incentive to lower the high type's information rent by distorting the low type's output.

[6]See footnote 5 for a formal argument showing that a joint-profit maximizing SSO would always adopt U even in the absence of price commitments.

4.2 Implementing the allocation through the royalty cap

We now show that U can implement the allocation derived in Proposition 2 by means of an appropriately chosen royalty cap $\bar{R}(q)$. At the royalty setting stage (stage 4), the upstream firm's problem can be written as

$$\max_{q_L, q_H, R_L, R_H} \lambda R_L + (1-\lambda) R_H \tag{21}$$

subject to the following constraints:

$$R_L \leq \bar{R}(q_L) \tag{22}$$

$$R_H \leq \bar{R}(q_H) \tag{23}$$

$$\pi_L(q_L) - R_L \geq 0 \tag{24}$$

$$\pi_H(q_H) - R_H \geq 0 \tag{25}$$

$$\pi_L(q_L) - R_L \geq \pi_L(q_H) - R_H \tag{26}$$

$$\pi_H(q_H) - R_H \geq \pi_H(q_L) - R_L. \tag{27}$$

Without loss of generality, we will assume in what follows that $\bar{R}(q)$ is almost everywhere differentiable. The following lemma shows how the optimal allocation can be implemented.

Lemma 1. *The allocation* $(\bar{q}_L, \bar{q}_H)$ *can be implemented by choosing* $\bar{R}(q)$ *such that* (22) *is binding,* (25) *is slack, and* $\bar{R}'(\bar{q}_L^C) = \psi$*, where* $\psi \in \{0, (1-\lambda)\pi'_H(\bar{q}_H^C)\}$.

Proof. Suppose $R_L \leq \bar{R}(q_L)$ is binding and $R_H \leq \bar{R}(q_H)$ is slack. If (25) is binding, U solves

$$\max_{q_L, q_H} \lambda \bar{R}(q_L) + (1-\lambda)\pi_H(q_H),$$

the first-order conditions of which are

$$\bar{R}'(q_L) = 0$$

$$\pi'_H(q_H) = 0.$$

Thus, designing $\bar{R}'$ such that $\bar{R}'(\bar{q}_L^C) = 0$ leads U to choose $q_L = \bar{q}_L^C$ and $q_H = \bar{q}_H^C = q_H^*$.

If instead (27) is binding, U solves

$$\max_{q_L, q_H} \lambda \bar{R}(q_L) + (1-\lambda)[\pi_H(q_H) - \pi_H(q_L) + \bar{R}(q_L)],$$

the first-order conditions of which are

$$\bar{R}'(q_L) = (1-\lambda)\pi'_H(q_L)$$
$$\pi'_H(q_H) = 0.$$

Thus, designing $\bar{R}'$ such that $\bar{R}'(\bar{q}_L^C) = (1-\lambda)\pi'_H(\bar{q}_L^C)$ leads U to choose $q_L = \bar{q}_L^C$ and $q_H = \bar{q}_H^C = q_H^*$. $\square$

By appropriately choosing $\bar{R}(q)$ at stage 1, the upstream firm can indirectly control the quantity q_L that it will implement at stage 4, while q_H will be set at the profit-maximizing level.

5 Conclusion

This paper analyzes the role of price commitments in the standard-setting process when there is asymmetric information between upstream and downstream firms. Specifically, we assume that the downstream firm is privately informed about the demand for the upstream firm's technology. In the absence of price commitments, the upstream firm designs its royalty scheme to elicit the downstream firm's private information. To reduce the downstream firm's information rent, the upstream firm distorts output away from the efficient level in the low-demand state. Moreover, because royalties are negotiated after the standard has been set, the upstream firm cannot commit to leave the downstream firm better off than with an inferior alternative technology that is available royalty free. Anticipating this opportunistic behavior, a user-friendly SSO often refrains from selecting the upstream firm's technology despite its technological superiority.

Price commitments allow the upstream firm to commit not to behave opportunistically after being selected as the standard. An interesting side-effect of this is that it curbs the incentive for the upstream firm to distort the downstream firm's output. In fact, convincing the SSO to select the upstream firm's technology requires leaving enough surplus to the downstream firm, and giving information rents to the high type is a relatively cheap way of doing so. As a result, price commitments reduce output distortions and ensure that the superior technology is selected as the standard.

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