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Abstract

There is widespread concern about the lack of transparency regarding standard essential patents (SEPs). This paper examines the proposal to introduce essentiality checks, a certification scheme for declared SEPs. We develop a framework that allows us to evaluate how essentiality checks would impact licensing, litigation, and incentives to innovate. In our model, an upstream innovator invests in R&D and privately learns about the likely essentiality of its patents for a standard. The innovator then licenses the patents to a downstream implementer who can contest the essentiality of the patent in court. We identify a tradeoff whereby essentiality checks can reduce litigation but also provide excessive incentives for R&D investment. Their overall welfare effect depends on the level of the "fair, reasonable, and non-discriminatory" (FRAND) royalty rate.

Keywords: standardization, R&D, patents, licensing, litigation, price caps, certification
JEL classification: D82, L15, L24, O31, O34

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1 Introduction

With the emergence of the Internet of Things (IoT), a growing number of products rely on connectivity. In smart cities, traffic lights, vehicles, and sensors are interconnected to manage the flow of traffic; in the healthcare sector, wearable devices collect and transmit health data in real-time; in industrial settings, networked sensors embedded in machinery allow for predictive maintenance and process optimization; in smart homes, lighting, speakers, thermostats, and security systems can be accessed and controlled remotely. These developments have elevated the significance of the technology standards that enable interoperability. This, in turn, has rendered the patents covering the relevant technologies—so-called standard-essential patents (SEPs)—increasingly valuable.

Yet there is widespread concern that a lack of transparency concerning essentiality is raising the transaction costs of licensing SEPs. The patents firms declare essential to standard-setting organizations (SSOs) may not always turn out to be truly essential. Several studies, using a variety of methodologies, find that only a minority of declared SEPs stand up to scrutiny (Goodman and Myers, 2005; Stitzing *et al.*, 2017; Lemley and Simcoe, 2019; Bekkers *et al.*, 2020; Brachtendorf *et al.*, 2023).[1] As a result, would-be implementers of a standard face uncertainty as to which patents they need to license or what the appropriate royalty rate for a particular SEP holder's patent portfolio is. Legal disputes concerning SEPs have been proliferating. Initially confined to the information and communication technology industries (e.g., smartphones), they have recently spread to others, such as the automotive industry, where car manufacturers and their suppliers have become embroiled in litigation with the holders of SEPs covering key wireless communications standards.[2]

[1] For example, Stitzing *et al.* (2017) report that an independent third-party evaluation found that only 35% of the patents declared essential for the 4G LTE wireless communication standard were truly essential. Similarly, in *Unwired Planet v. Huawei*, experts for the parties found essentiality rates of between 20 and 40 percent for 2G/3G/4G standards (Bekkers *et al.*, 2020).

[2] See, e.g., *Nokia v. Daimler* (Mannheim Regional Court, Germany, Case No. 2 O 34/19, decided on 18 August 2020), *Continental v. Avanci* (U.S. Court of Appeals for the Firth Circuit, 27 F.4th 326 (5th Cir. 2022), decided on 28 February 2022), *IP Bridge v. Ford* (Munich I Regional Court, Germany, Case No. 7 O 9572/21, decided on 19 May 2022).

In response, observers have advocated essentiality checks, whereby an independent entity such as a patent office would administer a certification scheme for declared SEPs (Régibeau *et al.*, 2016; Bekkers *et al.*, 2020; SEPs Expert Group, 2021). This idea has rapidly gained traction and now features prominently in a proposed regulation on SEPs recently put forward by the European Commission.[3] Proponents of essentiality checks argue that by curtailing uncertainty and information asymmetries, they would facilitate licensing and reduce litigation. These arguments, however, are not based on a formal framework that accounts for equilibrium effects. Moreover, they neglect the impact essentiality checks have on upstream innovation.

In this paper, we develop a model in which an upstream innovator invests in R&D, privately learns about the likely essentiality of its patents, and then offers a license covering these patents to a downstream implementer. The implementer sells a standard-compliant product and must decide whether to buy a license or litigate. The assumption that the upstream firm holds private information is based on the notion that innovators, who know how successful their research projects have been and are often actively involved in the process of formulating technical specifications for standards, have a better sense of whether their patents read on the standard that is adopted than potential implementers. This assumption gives rise to a signaling game where the terms of the proposed license can convey information about the likely essentiality of the innovator's patents.

We use this framework to address the following research questions. First, how do essentiality checks affect the equilibrium of the licensing and litigation game, and how does this feed back into the innovator's incentive to invest in R&D? Second, how do the answers to these questions depend on whether SSO licensing rules, particularly the requirement to license on "fair, reasonable and non-discriminatory" (FRAND) terms, are effective in constraining SEP holders in their exercise of market power? Finally, how do essentiality checks interact with FRAND requirements, i.e., how should the design of royalty caps for SEPs depend on the accuracy of essentiality

[3] Commission, "Proposal for a regulation of the European Parliament and of the Council on standard essential patents and amending Regulation (EU)2017/1001" COM (2023) 232 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2023:232:FIN.

checks?

To be specific, in the model presented below, the outcome of the R&D process depends on the innovator's R&D investment, is privately observed by the innovator, and determines the likelihood that the innovator's technology is selected into the standard. The R&D outcome can be successful or unsuccessful, and this stochastically determines the value of the standardized technology. The implementer observes the value but, due to the stochastic nature of the process, cannot perfectly infer the R&D outcome, so that the innovator has better information on whether their patents are essential. The innovator then offers a license to the implementer, who can either accept or litigate to contest the patent's essentiality in court.

We show that the resulting signaling game has a semi-separating equilibrium in which innovators whose technology is likely to be essential charge high royalty rates, while innovators whose technology is unlikely to be essential randomize between high and low royalties, where the low royalty rate is set at the implementer's litigation cost so as to prevent them from litigating. Implementers who receive an offer with a high royalty randomize between accepting and litigating. As a result, there is wasteful litigation in equilibrium.

We then use the outcome at the licensing stage, including equilibrium royalties and litigation, to derive the privately and socially optimal levels of R&D investment. The private and social incentive to invest is determined by the wedge in profits and welfare, respectively, between successful and unsuccessful R&D projects. In the absence of a royalty cap that constrains the upstream firm in its exercise of market power – perhaps because FRAND requirements are too vague to be effective, as Lerner and Tirole (2015) have argued – the private incentive to invest in R&D tends to be socially excessive. This happens both because the innovator neglects the surplus that society would receive from alternative technologies and because the innovator does not take into account the implementer's litigation costs.

We model essentiality checks as a certification mechanism. Certification is informative but imperfect: while truly standard-essential patents are always correctly certified as essential, patents that are not actually essential are sometimes incorrectly certified as well. We show that introducing essentiality checks affects welfare through two channels. First, in line with the arguments given in the policy debate, essentiality checks reduce litigation. They not only detect some non-essential patents (thus eliminating litigation over them), but can also induce the implementer to forego litigation over patents that are certified as essential. This latter effect works via an increase in the implementer's confidence that certified patents are actually essential. Second, essentiality checks tend to enhance the incentive to invest in R&D, as they increase the wedge between successful and unsuccessful R&D outcomes. (In our baseline model, essentiality checks reduce the innovator's expected licensing revenue after unsuccessful R&D outcomes.)

The welfare implications of essentiality checks depend on the relative importance of these two channels. Holding the level of R&D investment constant so that the second channel is shut down, the welfare impact of essentiality checks is positive, as their only effect is to reduce wasteful litigation. (Note that our analysis does not account for the cost of carrying out the essentiality checks.) More generally, however, the welfare impact of essentiality checks is ambiguous. The increase in investment incentives that they generate via the second channel can diminish or overturn the positive welfare impact from the first channel because, when investment incentives are socially excessive, essentiality checks exacerbate overinvestment.

We identify one particular set of circumstances in which introducing or intensifying essentiality checks is unambiguously welfare reducing. Specifically, we show that a marginal increase in the accuracy of essentiality checks reduces welfare when FRAND requirements do not place an effective cap on royalties. The reason for this result is that making essentiality checks *marginally* more accurate does not reduce litigation: in equilibrium, the enhanced detection of non-essential patents is exactly offset by an increase in the litigation rate for certified patents. This is because unsuccessful innovators whose non-essential patents go undetected respond to increased accuracy by charging high royalties more often. At the same time, without effective FRAND requirements, investment incentives are socially excessive because the innovator is able to obtain more than the incremental value of their technology. Essentiality checks then distort R&D efforts further away from the second-best level. This result provides a cautionary note about essentiality checks.

We go on to investigate how the analysis changes when essentiality checks can be combined with an effective FRAND requirement that puts a cap on royalty rates. We obtain two results. First, when essentiality checks are perfect, so that non-essential patents never go undetected, setting the FRAND rate at the level of the incremental value of the innovator's technology over the next best alternative in the event of a successful R&D outcome implements the first best: there is no litigation, and investment is efficient. Second, when essentiality checks are slightly less than perfect, the optimal FRAND rate exceeds the incremental value. This highlights the fact that the design of essentiality checks interacts with other policy instruments and that, in more complex settings that involve an R&D investment stage, the optimal FRAND rate may differ from the incremental value of a technology.

The stylized essentiality check in our model is broadly in line with the proposed regulation by the European Commission. According to the proposal, a unit to be created within the European Union Intellectual Property Office would subject a sample of registered SEPs to an essentiality check conducted by an expert examiner. The results would then be published for use in licensing negotiations and litigation, without being legally binding. This is consistent with our assumption that the check is exogenously imposed and publicly observed, but the court ruling may not always follow the certification.[4]

The paper is related to the literature on licensing and innovation in the context of standardization. The starting point is the observation that, by creating essentiality, standards confer monopoly power on the holders of standard essential patents (Shapiro, 2001; Farrell *et al.*, 2007).[5] Much of the literature has focused on remedies for the resulting distortions in pricing. Swanson and Baumol (2005) argue that prices can be held in check if SEP

[4]The proposed regulation also allows the patent holder or the implementer to nominate a patent to be checked. The patent holder's endogenous choice to get certified may affect the incentives differently (as analyzed in the literature on quality disclosure, see Dranove and Jin (2010)). This is not considered in our model.

[5]Because licensing occurs after the standard is set, this can give rise to opportunistic behavior which is sometimes referred to as "patent holdup." Note that there are also concerns about implementers engaging in "patent holdout" by dragging out the licensing negotiations through various tactics; see Llobet and Padilla (2023). Spulber (2019) derives conditions under which voting power can counterbalance market power.

holders' FRAND commitments are interpreted according to an incremental-value rule, whereby royalties cannot exceed the difference in value to the next-best technology.[6] FRAND commitments, however, are often thought to be insufficient, and alternative remedies such as ex ante agreements and price commitments have been proposed (Lerner and Tirole, 2015; Llanes and Poblete, 2014). Llanes (2019) and Larouche and Schuett (2019) study the conditions under which repeated interaction in standard setting can give FRAND commitments more bite.

The paper is more closely related to two strands of the literature, the first of which introduces information asymmetries, the second of which studies incentives to innovate, both key ingredients of our analysis. Among the papers that consider asymmetric information, Farrell and Simcoe (2012) and Bonatti and Rantakari (2016) investigate standardization outcomes when firms have private information on certain attributes of their technologies; however, they do not consider licensing. Boone *et al.* (forthcoming) consider a setting in which, contrary to ours, it is the downstream firm that holds private information, and they analyze the effects of price commitments on output distortions and standard selection. Lerner *et al.* (2016) study innovators' decision to make generic or specific disclosures to SSOs; like us, they assume that innovators have private information about the likely essentiality of their patents.[7]

A number of papers have considered the effects of standard setting on innovation. Ganglmair *et al.* (2012) study how the courts' calculation of damages for breach of FRAND commitments affects R&D investment by SEP holders. Layne-Farrar *et al.* (2014) show that an incremental-value rule may distort both R&D investment and participation decisions. Baron *et al.* (2014) investigate whether consortia within standards can mitigate coordination failures in R&D decisions.[8] Wipusanawan (2020) adds an R&D

[6]In practice, things are likely to be more complex: Layne-Farrar and Llobet (2014) show that when technologies are multi-dimensional, it is unlikely that all users would be able to agree on the same incremental-value rule.

[7]Ganglmair and Tarantino (2014) study how private information about the existence of intellectual property rights affects the standard-setting process using a model of conversation.

[8]In an empirical study, Leiponen (2008) finds that participation in industry consortia increases firms' contributions to standard development.

investment stage to a standardization and pricing game à la Lerner and Tirole (2015) and shows that, when technologies can have both complements and substitutes, the competitive benchmark prices often do not provide efficient innovation incentives. Llanes (2022) studies R&D investment by two firms developing complementary technologies vying for inclusion in a standard and compares the effectiveness of price caps and patent pools as tools to mitigate distortions resulting from market power and double marginalization. However, none of these models involve uncertainty about whether or not patents are essential, and hence there is no scope for essentiality checks.

Two other papers theoretically study the strategic declaration of SEPs.[9] Dewatripont and Legros (2013) consider a setting in which innovators' R&D investments deterministically increase the stock of essential patents, which raise the value of the standard, but as a by-product also generate non-essential patents which the firms can "disguise" as essential at some cost. Contrary to us, they do not consider a stochastic R&D process, and they model licensing negotiations as a cooperative game that follows a dispute stage where downstream firms can contest the essentiality of a share of patents. Aoki and Arai (2018) is, to the best of our knowledge, the only other theoretical paper that examines essentiality checks. They present a model in which an innovator has an exogenously given stock of patents that differ in the probability of being essential, and can decide on the share to declare essential. Essentiality checks (ex-post assessment, in the language of Aoki and Arai), decrease the share of patents the firm declares essential. However, they do not consider R&D incentives.

Finally, the paper is also related to the literature studying the impact of certification on the incentives to invest in quality (Buehler and Schuett, 2014; Harbaugh and Rasmusen, 2018; Zapechelnyuk, 2020; Vatter, 2022), with our focus being the institutional setting pertaining to SEPs. The essentiality checks in our model can be considered an exogenous mandatory certification mechanism, with two possible quality levels.

The remainder of this paper is organized as follows. Section 2 sets out

[9] Empirical contributions include Righi and Simcoe (2023), who show how the publication of a standard affects the strategic use of continuations at the U.S. Patent and Trademark Office, and Bekkers *et al.* (2023), who analyze how SSO policies affect disclosure and litigation.

the model. Section 3 derives the equilibrium of the licensing game. Section 4 determines the equilibrium R&D investment and compares it to the second-best level. Section 5 then studies the welfare effects of essentiality checks in a setting where there is no cap on royalty rates, while Section 6 examines how the results change when essentiality checks can be combined with an effective royalty cap. Section 7 concludes.

2 Model

There is an upstream firm, or innovator, U, and a downstream firm, or implementer, D. The upstream firm develops a technology vying for inclusion in a standard whose technical specification is determined by a standard-setting organization (SSO). The downstream firm commercializes a product that implements the standard. In order to ensure interoperability with other equipment and services, the downstream firm must adhere to the standard's technical specification. The specification that the SSO adopts may be such that U's patents read on it, in which case these patents are *standard essential.* Alternatively, none of U's patents may read on the specification so that complying with the standard only requires a status-quo technology that is available royalty free. The status-quo technology captures in a simple way the idea that there is an alternative standard specification that does not read on U's patent.[10]

The upstream firm chooses its research effort $x \in [0, 1]$ at cost $c(x)$. With probability x, the research project yields an outcome of type H, while with probability $1 - x$ it yields an outcome of type L. We assume that $c(\cdot)$ is twice continuously differentiable, increasing, and convex, with $c'(0) = 0$ and $\lim_{x \to 1} c'(x) = \infty$. In what follows, we sometimes refer to a type-H outcome as the project being successful and to a type-L outcome as the project being unsuccessful.

The commercial value v of the product implementing the standard can take n values: $v \in \{v_1, \ldots, v_n\}$. The probability distribution over values depends on the outcome of U's R&D project and on the technology the

[10]More generally, the existence of an alternative technology could be made stochastic or endogenized by introducing a competing innovator. An endogenous competing technology would greatly complicate the model, however.

standard is built on. If U's R&D project is successful (type H), the probability distribution over values from building the standard on U's technology is $(p_1^H, \ldots, p_n^H)$; if the project is unsuccessful (type L), it is $(p_1^L, \ldots, p_n^L)$. With the status-quo technology, the probability distribution is $(p_1^0, \ldots, p_n^0)$. We assume that the existence of the status-quo technology and all probability distributions are common knowledge.

We make the following assumption about the expected value of technologies:

Assumption 1. $\sum_{i=1}^n p_i^H v_i > \sum_{i=1}^n p_i^0 v_i > \sum_{i=1}^n p_i^L v_i$.

This assumption says that U's technology is of higher expected value than the status-quo technology if U's R&D project succeeds, while the opposite is true if the project fails.

The SSO sets the standard after the outcome of U's R&D project is realized but before the value v is known. In practice, SSOs choose technologies based on their anticipated performance; hence, an SSO is more likely to build its standard on a technology whose expected value is higher.[11] To capture this notion in the simplest possible way, we assume in what follows that the SSO always builds the standard on the technology with the higher expected value.[12] Together with Assumption 1, this implies that the SSO specifies a standard that U's patents read on if and only if U is successful. We assume, however, that the SSO observes neither where the technology originated (i.e., from U or the status quo), nor what its expected value is; it observes merely the *ranking* of technologies in terms of their expected value, and then writes a technical specification that corresponds to (the relevant features of) the superior technology. It follows that the SSO does not have information that would allow the implementer to make inferences about essentiality.

We assume that U privately observes its R&D outcome but obtains a patent (or portfolio of patents) related to the standard regardless of whether

[11]This assumption is consistent with the evidence in Rysman and Simcoe (2008), who show that citations to patents disclosed during the standard-setting process increase following standardization. They interpret this as suggesting that SSOs identify promising technologies.

[12]More generally, standardization could be probabilistic, with higher-value technologies being more likely to be selected.

the R&D outcome is H or L. Whether (at least one of) U's patents reads on the standard is unobservable to the downstream firm, which observes only the realized commercial value of standard-compliant products. Our modeling reflects the idea that success by the innovator U makes it more likely that the SSO specifies the standard in such a way that it reads on U's patents, and it stochastically also increases the value of the standard. However, whether a particular patent is standard essential remains uncertain. This setup allows us to meaningfully study the relationship between information on essentiality, litigation, and R&D incentives.

The SSO or another third party may provide a system of essentiality checks whereby a certifier verifies and attests whether a patent is essential to the standard. Suppose that if U's patent is not essential, the certifier erroneously certifies the patent as essential with probability $1 - \beta$, while if U's patent is essential, the certifier always correctly certifies it as such.[13] The case of $\beta = 0$ is equivalent to having no essentiality checks in place (note that there is no difference between certifying no patents and certifying all patents), while $\beta = 1$ means the certifier perfectly distinguishes between essential and non-essential patents. The certification outcome is publicly observed and denoted by $s \in \{c, nc\}$, where c corresponds to the patent being certified essential and nc corresponds to the patent not being certified essential.

After the standard is set and uncertainties about commercial value and certification are resolved, U offers a license contract to D. Specifically, for a given realized commercial value v_i, U chooses a royalty rate $\alpha_i \in [0, \bar{\alpha}]$ at which D can obtain a license to its patent (or patent portfolio).[14] The royalty rate corresponds to the fraction of the value that needs to be paid to U. If D accepts the contract, it obtains $(1-\alpha_i)v_i$ while U obtains $\alpha_i v_i$. The maximum royalty $\bar{\alpha}$ represents a cap on α_i satisfying $0 < \bar{\alpha} \leq 1$. Below, we consider both the case $\bar{\alpha} = 1$, which corresponds to a situation where the

[13] Our setup thus involves false positives but no false negatives. Appendix B studies an alternative setup in which there are false negatives but no false positives: type L is never certified essential, while type H is certified with some probability and sometimes fails to receive certification. We show that the main insights from our analysis are robust to this alternative specification.

[14] If U licenses a patent portfolio, the interpretation is that, in the event of success, at least one patent is essential, and U can select that specific patent for litigation.

requirement to license SEPs on "fair, reasonable and non-discriminatory" (FRAND) terms is ineffective so that the patent holder can charge up to the implementer's willingness to pay, and the case where $\bar{\alpha} < 1$, in which FRAND requirements are effective. Note that in the latter case, the FRAND rate becomes a policy variable.

Instead of accepting the license contract, D can decide to go to court. There are two steps in the litigation process. In a first step, D can make a pre-trial motion for summary judgment; this is assumed to be costless. If the motion is granted, the case is dismissed and D can implement the standard without a license from U. If the motion is rejected, then in a second step, D decides whether to let the case proceed to trial, at cost l_i for each party.[15] The court then determines whether U's patent is essential or not. If the patent is found to be essential, U can offer a new license contract to D, in which case it will choose $\alpha_i = \bar{\alpha}$ (D cannot produce without a license). If the patent is found not to be essential, D can produce without a license. We make the following assumption about value and litigation costs:

Assumption 2. *$\bar{\alpha} v_i > l_i$ for all $i = 1, \ldots, n$.*

This assumption ensures that litigation is a credible threat when D is certain that U's patent is not essential.

We now describe how the court makes decisions at each of the two steps of litigation. At the summary judgment stage, the court grants the downstream firm's motion if and only if the court's prior about U's patent being essential is sufficiently low: letting λ denote the court's prior, the motion is granted if $\lambda \leq \underline{\lambda}$, where $\underline{\lambda} \geq 0$ is the court's threshold for summary judgment, and rejected if $\lambda > \underline{\lambda}$. For simplicity, we set $\underline{\lambda} = 0$: a motion for summary judgment is granted only if the court is sure that the patent is not essential.[16] The assumption on summary judgment introduces a wedge between the payoffs an unsuccessful innovator (type L) receives when its

[15]The state-dependent litigation cost l_i allows for the possibility that, for example, a high-value case may be associated with higher litigation costs. We can accommodate the special case with constant litigation costs, $l_i = l$ for $i = 1, \ldots, n$, as long as Assumption 2 holds.

[16]This modeling of motion to dismiss and summary judgment is roughly consistent with how summary judgments work in Anglo-American jurisdictions. For example, the US Federal Rules of Civil Procedure state that summary judgment should be granted if "there is no genuine dispute as to any material fact and the movant is entitled to judgment

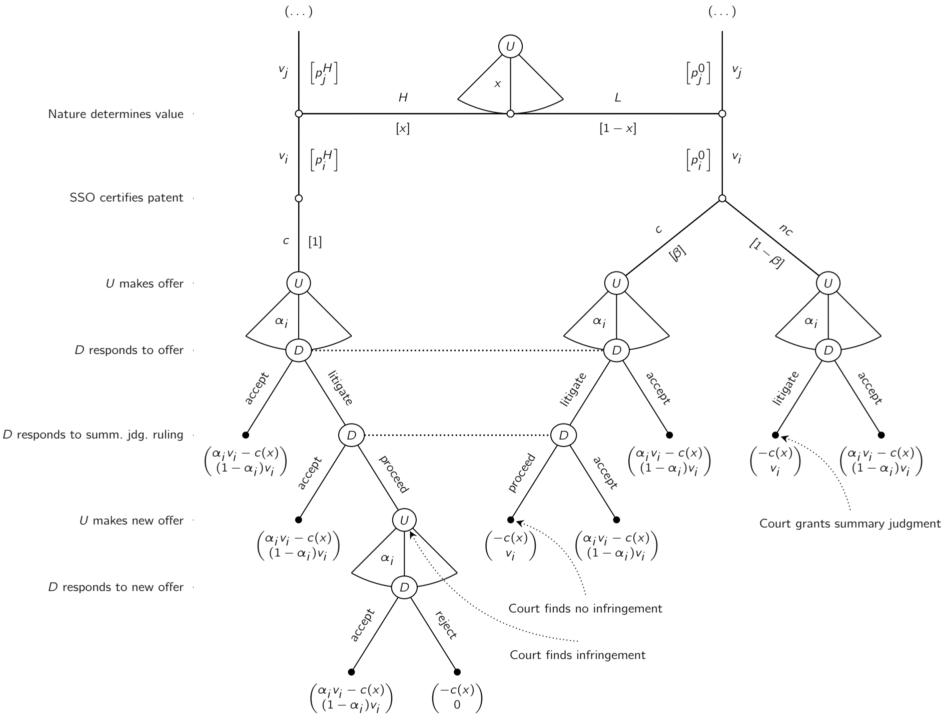

Figure 1: Partial game tree focusing on a single realized commercial value v_i. The square brackets $[\cdot]$ denote the probability of the random event.

patent is erroneously certified essential and when it is not. Without this assumption, firm D always has to incur litigation costs l_i when rejecting U's offer, regardless of whether the patent is certified essential, and thus U can always extract (at least) l_i in license fees.

At trial, the court hears evidence, which we assume is conclusive, so that the court always correctly decides the case. That is, the court will find the patent essential if and only if U's patent truly reads on the standard. Because of our assumptions about the way the SSO specifies the standard, it follows that the court will find essentiality if and only if U's R&D project was successful.

Figure 1 shows a partial game tree focusing on the branches with the

as a matter of law". To illustrate the prevalence of this process, observe that 473 out of 949 substantive decisions that US federal district courts made in patent infringement lawsuits filed in 2008 and 2009 were rulings on non-infringement summary judgment motions. Fifty-four percent of the motions were granted (Allison *et al.*, 2014). In jurisdictions where pre-trial dismissals do not exist, our model can apply if the presumption created by the certification system means the implementer can defend the case at a lower cost.

realized value of v_i. In summary, the timing is as follows:

1. U chooses an unobservable R&D effort $x \in [0, 1]$.
2. The outcome of U's R&D project (H or L) is realized and privately observed by U.
3. The SSO sets the standard. The value of the standard (v_i) is realized and observed by U and D.
4. If essentiality checks are in place, the certifier publicly announces the certification outcome $s \in \{n, nc\}$. D forms a belief λ_i^s that the patent is essential.
5. U offers a license contract to D at royalty rate α_i. D updates its belief to $\hat{\lambda}_i^s(\alpha_i)$.
6. D decides whether to accept or litigate.
7. If D litigates, the court decides on summary judgment.
8. If summary judgment is denied, D decides whether to proceed to trial or accept the contract.
9. If the case goes to trial, each party incurs litigation cost l_i, and the court decides on essentiality. If its patent is found essential, U offers a new license contract to D.

Our solution concept is Perfect Bayesian Equilibrium (PBE). This implies in particular that the beliefs λ_i^s and $\hat{\lambda}_i^s(\alpha_i)$ at stages 4 and 5 are derived from equilibrium strategies using Bayes' rule.

Discussion of key assumptions. Before proceeding, it may be useful to further discuss our key assumptions. Our model equates the patent being "essential" to it being "infringed" (if D does not take a license), meaning that a patent is either required for any implementation of the standard, or it is not needed at all. This is similar to the contention in, for example, *Unwired Planet v. Huawei*,[17] where the infringement is considered a consequence

[17] [2017] EWHC 711 (Pat).

of the patent being valid and essential (Contreras, 2017). This assumption rules out the possibility that a patent is infringed without it being *essential*, in the sense that the patent's claims might be used in an implementation of the standard, but can be worked around.[18] In this paper, we take the view that the main justification for essentiality checks is to clarify whether a patent holder's claim of infringement is legitimate (see Bekkers *et al.*, 2020).

While the matter of patent essentiality and infringement must undoubtedly be informed by a technical assessment, whether a patent is infringed is ultimately a *legal* question. We see the role of the essentiality check as providing greater legal certainty at the licensing stage, as the essentiality check does not affect the court ruling except for the decision to grant a summary judgment in our model. The assumption that the court decision is perfectly in line with the success of the R&D project (and thus the expected value of the standard) is a simplification that streamlines the analysis. More generally, the relationship between value creation and legal status can be stochastic as well.

The assumption of asymmetric information on U's patent is crucial to obtain equilibrium litigation, and thus for the model to be consistent with the extensive litigation around SEPs that is observed and is what triggered the policy debate about essentiality checks. As is well known in the law and economics literature, with symmetric information the parties would always settle the case (Bebchuk, 1984; Cooter and Rubinfeld, 1989). The information asymmetry can be due to U being privately informed about the outcomes of its R&D projects, as we have assumed, but could also be due to the patent holder's closer involvement in the standard-setting process and greater familiarity with its own patent portfolio.[19]

3 Equilibrium at the licensing stage

We start by deriving the equilibrium at the licensing stage for a given R&D effort x and certification outcome $s \in \{c, nc\}$. Later we consider U's invest-

[18] In *Fujitsu v. Tellabs* (N.D. Ill. 2012), the patent holder argues that its patents are infringed, but *not* essential, so that the FRAND commitment does not apply (Contreras, 2017).

[19] For example, with the rise of Internet of Things, telecommunication standards are now implemented in products that are not in the traditional ICT industries.

ment decision.

Recall that λ_i^c denotes D's belief that U's patent is essential when D observes value v_i and the patent is certified (but before receiving a royalty offer from U). Similarly, λ_i^{nc} denotes D's belief that the patent is essential given v_i when the patent is not certified. By Bayes' rule, we have

$$\lambda_i^c = \frac{\hat{x} p_i^H}{\hat{x} p_i^H + (1-\beta)(1-\hat{x}) p_i^0}, \tag{1}$$

where $\hat{x}$ is D's expectation about U's R&D investment. (In equilibrium, this expectation must be correct.) We also have $\lambda_i^{nc} = 0$ for all i since, for any β, only an unsuccessful U can fail the essentiality check.

Consider first the case where U's patent is not certified as essential. Then, even if the court cannot observe the realized state i (i.e., the commercial value), the court's belief about the patent being essential is zero:

$$\lambda = \sum_i \hat{p}_i \lambda_i^{nc} = 0,$$

for any weights $\hat{p}_i$ that the court may assign to states i. Since $\lambda = 0 \leq \underline{\lambda}$, if D litigates and moves for summary judgment, the court grants D's motion and dismisses the case before it gets to trial. As a result, when U fails to obtain essentiality certification, it cannot extract any licensing revenue from D.

Next, consider the case where U's patent is certified as essential. Note that this includes the case where there are no essentiality checks ($\beta = 0$), which is equivalent to all patents receiving certification. Suppose $\lambda_i^c > 0$ for some i to which the court assigns strictly positive weight, $\hat{p}_i > 0$. This will be the case in equilibrium provided $x > 0$ and $p_i^H > 0$; it implies that the court does not dismiss the case at the summary judgment stage. The following lemma derives the equilibrium at the licensing stage for a given state i.

Lemma 1. *Suppose the standard has value v_i and U's patent is certified essential. There exists an equilibrium in which a type-H U offers $\alpha_i = \bar{\alpha}$, while a type-L U offers*

$$\alpha_i = \begin{cases} \bar{\alpha} & \textit{with probability } y_i \\ l_i/v_i & \textit{with probability } 1 - y_i. \end{cases}$$

D always accepts $\alpha_i = l_i/v_i$ and rejects $\alpha_i = \bar{\alpha}$ with probability z_i. The probabilities y_i and z_i are given by

$$y_i = \begin{cases} \dfrac{\lambda_i^c}{1-\lambda_i^c} \dfrac{l_i}{\bar{\alpha} v_i - l_i} & \text{if } (1-\lambda_i^c)\bar{\alpha} v_i \geq l_i \\ 1 & \text{otherwise,} \end{cases} \tag{2}$$

$$z_i = \begin{cases} \dfrac{\bar{\alpha} v_i - l_i}{\bar{\alpha} v_i + l_i} & \text{if } (1-\lambda_i^c)\bar{\alpha} v_i \geq l_i \\ 0 & \text{otherwise.} \end{cases} \tag{3}$$

Proof. See Appendix A. □

Lemma 1 shows that there is an equilibrium of the licensing game in which the license contract takes one of two forms: it is either *pooling*, with both types of U (successful and unsuccessful) offering the maximum royalty ($\alpha_i = \bar{\alpha}$), or *hybrid*, with a successful U offering a high royalty and an unsuccessful U randomizing between a high and a low royalty.[20] Which form of equilibrium contract prevails depends on whether or not litigation is a credible threat for D when the unsuccessful type mimics the successful type. Recall that $\hat{\lambda}_i^c(\alpha_i)$ denotes D's posterior about U being successful. When the unsuccessful type plays $\alpha_i = \bar{\alpha}$ with certainty ($y_i = 1$), we have $\hat{\lambda}_i^c(\bar{\alpha}) = \lambda_i^c$. Litigation is credible if $(1-\lambda_i^c)\bar{\alpha} v_i \geq l_i$. If this condition is violated, then both types charge high royalties and D accepts. If it holds, then pooling on $\alpha_i = \bar{\alpha}$ cannot be an equilibrium as D would want to litigate, and thus the unsuccessful type would have an incentive to deviate. The equilibrium then involves mixed strategies. The unsuccessful type randomizes over the royalty, either mimicking the successful type by offering $\alpha_i = \bar{\alpha}$, or offering a low royalty $\alpha_i = l_i/v_i$ which reveals its type but makes it unattractive for D to litigate. The downstream firm randomizes over the litigation decision when offered the high royalty.

For the unsuccessful type of firm U to be indifferent, both the high and the low royalty must yield the same payoff. The payoff from the low royalty

[20]The equilibrium is not unique: as is often the case with PBE, due to the leeway in specifying out-of-equilibrium beliefs, there is multiplicity. We believe, however, that this is the most interesting equilibrium and conjecture that it is the only one that survives the D1 refinement.

is l_i, while – for a given litigation rate z_i – the payoff from the high royalty is $(1-z_i)\bar{\alpha}v_i + z_i(-l_i)$. Equating both yields the expression for z_i in the top row of (3). Similarly, for firm D to be indifferent, accepting and litigating must yield the same payoff. The payoff from accepting is $(1-\bar{\alpha})v_i$, while the payoff from litigating is $(1-\hat{\lambda}_i^c(\bar{\alpha})\bar{\alpha})v_i - l_i$. Noting that

$$\hat{\lambda}_i^c(\bar{\alpha}) = \frac{\lambda_i^c}{\lambda_i^c + (1-\lambda_i^c)y_i},$$

solving for the value of y_i that equates both yields the expression in the top row of (2).

The condition $(1-\lambda_i^c)\bar{\alpha}v_i \geq l_i$ determines whether the equilibrium license contract in state i is pooling or hybrid. By (1), the belief λ_i^c depends on the expected investment $\hat{x}$, the accuracy of essentiality checks β, and the maximum royalty $\bar{\alpha}$. Let $\mathcal{H}$ denote the set of states in which the licensing equilibrium is hybrid and $\mathcal{P}$ the set of states in which the licensing equilibrium is pooling. We have that $i \in \mathcal{H}$ if and only if

$$\frac{(1-\beta)(1-\hat{x})}{\hat{x}} \geq \frac{p_i^H l_i}{p_i^0(\bar{\alpha}v_i - l_i)}. \tag{4}$$

Intuitively, the licensing equilibrium will be hybrid if D has reasons to believe that the certified patent is actually non-essential, which can be a combination of a low probability β that a non-essential patent is detected, a low probability $\hat{x}$ that U has an essential patent at all, or a low relative probability p_i^H/p_i^0 that the value v_i is realized from an H-type technology.

4 Investment

In this section, we use the results from the analysis of the licensing equilibrium in Section 3 to derive equilibrium investment. We also derive the second-best investment level that would be chosen by a social planner who controls investment but neither royalty rates nor litigation decisions. In both cases, optimal levels of investment are determined by the wedge between successful and unsuccessful R&D projects: the wedge in profits for the equilibrium investment, and the wedge in welfare for the second-best investment.

Profits. Firm U's incentive to invest in R&D depends on how licensing revenues and litigation costs differ by R&D outcome.[21] If U's research is successful, its patent will always be certified as essential, and U's expected licensing revenue (net of litigation costs) is $\bar{\alpha}v_i - z_i l_i$. In a state with a hybrid equilibrium,

$$z_i = \frac{\bar{\alpha}v_i - l_i}{\bar{\alpha}v_i + l_i} \equiv \tilde{z}_i,$$

so licensing revenue is $\bar{\alpha}v_i - \tilde{z}_i l_i$. In a state with a pooling equilibrium, $z_i = 0$ so licensing revenue is $\bar{\alpha}v_i$. It follows that U's expected revenue when it is successful is

$$\pi^H = \sum_{i \in \mathcal{H}} p_i^H \left(\bar{\alpha}v_i - \tilde{z}_i l_i\right) + \sum_{i \in \mathcal{P}} p_i^H \bar{\alpha}v_i.$$

If U's research is unsuccessful, the patent fails to receive certification with probability β, in which case U earns nothing. With probability $1-\beta$, it will be incorrectly certified as essential. In states with pooling, U's expected licensing revenue then is $\bar{\alpha}v_i$, while in states with a hybrid equilibrium, U's expected licensing revenue is l_i. This is because, in a hybrid equilibrium, type L is indifferent between the high and low royalty, so both must yield the same payoff. Overall, U's expected revenue when it is unsuccessful is

$$\pi^L = (1-\beta)\left[\sum_{i \in \mathcal{H}} p_i^0 l_i + \sum_{i \in \mathcal{P}} p_i^0 \bar{\alpha}v_i\right].$$

Firm U chooses its R&D effort to solve

$$\max_x \quad x\pi^H + (1-x)\pi^L - c(x).$$

The first-order condition characterizing the profit-maximizing research effort is

$$\sum_{i \in \mathcal{H}} p_i^H \left(\bar{\alpha}v_i - \tilde{z}_i l_i\right) + \sum_{i \in \mathcal{P}} p_i^H \bar{\alpha}v_i - (1-\beta)\left[\sum_{i \in \mathcal{H}} p_i^0 l_i + \sum_{i \in \mathcal{P}} p_i^0 \bar{\alpha}v_i\right] = c'(x). \quad (5)$$

Note that, because the choice of research effort x is unobservable for firm D, firm U takes firm D's belief $\hat{x}$, and thus the nature of the equilibrium in each state i (pooling or hybrid), as given. In equilibrium, of course, firm D's beliefs must be correct, and thus $\hat{x} = x$.

[21] Our assumption that innovators take into account expected litigation costs when making R&D investment decisions is consistent with the evidence in Mezzanotti (2021).

The equilibrium R&D effort x^* solves the first-order condition of U's profit maximization problem, (5), replacing $x = \hat{x} = x^*$. The following lemma examines how equilibrium R&D responds to a marginal change in β and will be useful for the remainder of the analysis.

Lemma 2. *Fix $\beta < 1$ and suppose that, at the resulting equilibrium research effort x^*,* (4) *does not hold with equality in any state i. A marginal increase in β raises x^*.*

Proof. Because, by assumption, (4) does not hold with equality for any i, a marginal change in β and x^* does not change the sets $\mathcal{H}$ and $\mathcal{P}$. Applying the implicit function theorem to (5), we obtain

$$\frac{\partial x^*}{\partial \beta} = \frac{\sum_{i\in\mathcal{H}} p_i^0 l_i + \sum_{i\in\mathcal{P}} p_i^0 \bar{\alpha} v_i}{c''(x^*)} > 0,$$

where the inequality is due to the convexity of c. □

Lemma 2 shows that equilibrium R&D investment increases with the accuracy of essentiality checks as long as the sets $\mathcal{H}$ and $\mathcal{P}$ are unaffected. The result follows from the fact that firm U's licensing revenue when successful is invariant to β, while its licensing revenue when unsuccessful decreases with β, as some non-essential patents that would otherwise have earned the firm some revenue are detected and no longer earn it any revenue. The revenue decline in the event of failure amplifies the firm's R&D incentives. Note that the result only considers marginal changes in β which leave $\mathcal{H}$ and $\mathcal{P}$ unaffected. We return to this issue in Section 5.[22]

[22] Note that Lemma 2 does not depend on the availability of summary judgment. To see this, suppose that the court never summarily dismisses any case even when the patent is not certified essential, so all cases go to trial and each party incurs litigation cost l_i. In this case, even when U's R&D project fails and its patent is not certified essential, U will be able to demand l_i from D. (This is similar to how D accepts $\alpha_i = l_i$ despite the posterior belief $\hat{\lambda}_i^c(l_i) = 0$.) The effect of β on U's R&D incentive is then lessened, because there is no longer a difference in the payoffs between not being certified and being certified in a hybrid state $i \in \mathcal{H}$. The first-order condition (5) becomes

$$\sum_{i\in\mathcal{H}} p_i^H (\bar{\alpha} v_i - \tilde{z}_i l_i) + \sum_{i\in\mathcal{P}} p_i^H \bar{\alpha} v_i - \sum_{i\in\mathcal{H}} p_i^0 l_i - (1-\beta) \sum_{i\in\mathcal{P}} p_i^0 \bar{\alpha} v_i - \beta \sum_{i\in\mathcal{P}} p_i^0 l_i = c'(x).$$

Using the steps in Lemma 2, a marginal increase in β raises x^* if there exist some states with the pooling outcome.

Welfare. Next, we derive the expected social surplus, which will allow us to characterize the second-best research effort. If U is successful, expected surplus in state i is $v_i - 2z_i l_i$, where once again the value of z_i depends on whether the equilibrium in state i is hybrid or pooling. It follows that expected social surplus when U is successful is

$$w^H = \sum_{i \in \mathcal{H}} p_i^H (v_i - 2\tilde{z}_i l_i) + \sum_{i \in \mathcal{P}} p_i^H v_i$$

If U is unsuccessful, expected surplus is $v_i - 2(1-\beta) y_i z_i l_i$. In states with a hybrid equilibrium,

$$y_i = \frac{x p_i^H l_i}{(1-\beta)(1-x) p_i^0 (\bar{\alpha} v_i - l_i)} \equiv \tilde{y}_i,$$

while in states with a pooling equilibrium, $y_i = 1$. Thus, expected social surplus when U is unsuccessful is

$$w^L = \sum_{i \in \mathcal{H}} p_i^0 (v_i - 2(1-\beta)\tilde{y}_i \tilde{z}_i l_i) + \sum_{i \in \mathcal{P}} p_i^0 v_i.$$

Consider a social planner who can control the research effort but can control neither royalty rates nor litigation. In addition, assume that the planner takes the nature of the equilibrium in each state i (pooling or hybrid) as given. However, except for the determination of the sets $\mathcal{H}$ and $\mathcal{P}$, the planner takes into account that firm D correctly anticipates the planner's choice of R&D effort, and hence that $\hat{x} = x$. The planner then chooses x to maximize

$$x w^H + (1-x) w^L - c(x),$$

which, substituting for $\tilde{y}_i$ and using $\hat{x} = x$, can be simplified to

$$x \left[\sum_{i \in \mathcal{H}} p_i^H \left(v_i - 2\tilde{z}_i l_i \left(\frac{\bar{\alpha} v_i}{\bar{\alpha} v_i - l_i} \right) \right) + \sum_{i \in \mathcal{P}} p_i^H v_i \right] + (1-x) \left[\sum_{i \in \mathcal{H}} p_i^0 v_i + \sum_{i \in \mathcal{P}} p_i^0 v_i \right] - c(x). \quad (6)$$

Two things are noteworthy about the expression for second-best welfare in (6). First, because $1-\beta$ appears (multiplicatively) in the denominator of $\tilde{y}_i$, it cancels out from w^L; hence, the accuracy of essentiality checks, β, has no direct effect on welfare.[23] The intuition is that an increase in β makes it more likely that a patent certified as essential is actually essential, thus strengthening firm U's reputation when it obtains certification. This, in turn, raises the frequency at which an unsuccessful firm U must charge the high royalty rate in order to keep firm D indifferent between accepting and litigating. Even though a higher fraction of unsuccessful innovators fail to receive certification so that their cases are dismissed at summary judgment, the rate at which the remaining fraction proceeds to trial increases by exactly the same factor, so that the total amount of litigation stays the same.[24]

Second, everything is as if there is no litigation when U is unsuccessful, and instead litigation when U is successful is expanded: litigation costs have disappeared from the terms in the second line of (6), while those in the first line have been multiplied by a factor $\bar{\alpha}v_i/(\bar{\alpha}v_i - l_i) > 1$. This is because the incidence of litigation when U is unsuccessful is governed, among other things, by $\tilde{y}_i$, which is chosen by firm U to make firm D indifferent over litigation and thus has the probability of the patent being essential (xp_i^H) in the numerator and the probability of the patent being non-essential ($(1-\beta)(1-x)p_i^0$) in the denominator. As a result, the incidence of litigation goes up with xp_i^H and is invariant to $(1-\beta)(1-x)p_i^0$.

The first-order condition characterizing the second-best research effort is

$$\sum_{i \in \mathcal{H}} p_i^H \left(v_i - 2\tilde{z}_i l_i \left(\frac{\bar{\alpha}v_i}{\bar{\alpha}v_i - l_i} \right) \right) + \sum_{i \in \mathcal{P}} p_i^H v_i - \left[\sum_{i \in \mathcal{H}} p_i^0 v_i + \sum_{i \in \mathcal{P}} p_i^0 v_i \right] = c'(x). \tag{7}$$

5 Essentiality checks in the absence of effective FRAND commitments

In this section, we analyze essentiality checks in a setting where the upstream firm is unconstrained by FRAND commitments, so that $\bar{\alpha} = 1$. This

[23] When the planner cannot control U's research effort, β does affect welfare via its *indirect* effect on equilibrium investment; see below.

[24] Since the payoff that D receives when accepting $\alpha_i = \bar{\alpha}$ is constant and does not depend on β, the firm's expected payoff when rejecting must also remain the same if the equilibrium remains hybrid. This means the posterior probability $\hat{\lambda}_i^i(c)$ that U who has offered $\alpha_i = \bar{\alpha}$ is of type H must remain the same as well. Since $\tilde{z}_i$ also does not depend on β, the probability of litigation remains unchanged.

serves as a benchmark but may also be relevant when FRAND commitments are present but, as many observers fear, do not effectively constrain SEP holders in their exercise of market power. In Section 6, we introduce effective FRAND commitments and examine how they interact with essentiality checks.

The following lemma will be useful for the analysis that ensues. It compares the privately optimal investment level with the second-best level when $\bar{\alpha} = 1$.

Lemma 3. *Suppose FRAND requirements are ineffective: $\bar{\alpha} = 1$. Fixing the sets $\mathcal{H}$ and $\mathcal{P}$, the private incentive to invest in R&D is socially excessive.*

Proof. To establish the claim we show that the left-hand side of (5) exceeds the left-hand side of (7) when $\bar{\alpha} = 1$. We have

$$\sum_{i\in\mathcal{H}} p_i^H (v_i - \tilde{z}_i l_i) + \sum_{i\in\mathcal{P}} p_i^H v_i - (1-\beta)\left[\sum_{i\in\mathcal{H}} p_i^0 l_i + \sum_{i\in\mathcal{P}} p_i^0 v_i\right] \geq$$

$$\sum_{i\in\mathcal{H}} p_i^H \left(v_i - 2\tilde{z}_i l_i \left(\frac{v_i}{v_i - l_i}\right)\right) + \sum_{i\in\mathcal{P}} p_i^H v_i - \left[\sum_{i\in\mathcal{H}} p_i^0 v_i + \sum_{i\in\mathcal{P}} p_i^0 v_i\right]$$

$$\Leftrightarrow \quad \sum_{i\in\mathcal{H}} p_i^H \tilde{z}_i l_i \left(\frac{2v_i}{v_i - l_i} - 1\right) + \sum_{i\in\mathcal{H}} p_i^0 (v_i - (1-\beta) l_i) + \beta \sum_{i\in\mathcal{P}} p_i^0 v_i \geq 0.$$

Since all of the terms are positive, the result follows. □

There are two reasons why the private and social gains from R&D diverge. First, when U is unsuccessful, the surplus society obtains from the status-quo technology in state i, v_i, exceeds the surplus that firm U can appropriate, which is zero with probability β (if its patent is not certified) and either $l_i < v_i$ (in a hybrid equilibrium) or v_i (in a pooling equilibrium) with probability $1-\beta$ (if the patent is certified). In terms of investment incentives, U being under-rewarded when unsuccessful is equivalent to being over-rewarded when successful.[25] Second, the planner takes into account the litigation costs for both firms (as well as the increase in litigation costs due to a greater probability of high royalties resulting from an increase in x), whereas firm U only takes into account its own litigation costs. Both of these

[25] This is the patent holdup effect that justifies the incremental value interpretation of FRAND (Swanson and Baumol, 2005), but with stochastic values.

effects push the private incentive to invest in R&D above the second-best optimal level.

To interpret this result, it is worth pointing out that our model abstracts from a variety of other forces that affect the comparison between private and social returns to innovation. We do not model the demand side and therefore implicitly assume that, when successful, the private returns captured by the innovator are exactly equal to the social returns. Limited appropriability (due to spillovers or the inability to implement first-degree price discrimination, for example) would depress private returns below social returns, thereby muddying the conclusions from Lemma 3. On the other hand, business-stealing effects (such as those identified in the patent-race literature) would raise private returns above social returns and thus strengthen the result.

The following proposition considers a small increase in the accuracy of essentiality checks which does not affect the form of the equilibrium (hybrid or pooling) in any state i and shows that its welfare effect is negative.

Proposition 1. *Suppose $\bar{\alpha} = 1$. Fix $\beta < 1$ and assume the resulting equilibrium research effort x^* is such that* (4) *does not hold with equality in any state i. Then, a marginal increase in the accuracy of essentiality checks reduces welfare.*

Proof. For $\bar{\alpha} = 1$, welfare evaluated at x^* is

$$w^* = x^* \left[\sum_{i \in \mathcal{H}} p_i^H \left(v_i - 2\tilde{z}_i l_i \left(\frac{v_i}{v_i - l_i} \right) \right) + \sum_{i \in \mathcal{P}} p_i^H v_i \right] + (1 - x^*) \left[\sum_{i \in \mathcal{H}} p_i^0 v_i + \sum_{i \in \mathcal{P}} p_i^0 v_i \right] - c(x^*).$$

Because, by assumption, (4) does not hold with equality for any i, a marginal change in β and x^* does not change the sets $\mathcal{H}$ and $\mathcal{P}$. We thus have

$$\frac{\partial w^*}{\partial \beta} = \frac{\partial x^*}{\partial \beta} \left[\sum_{i \in \mathcal{H}} p_i^H \left(v_i - 2\tilde{z}_i l_i \left(\frac{v_i}{v_i - l_i} \right) \right) + \sum_{i \in \mathcal{P}} p_i^H v_i - \left[\sum_{i \in \mathcal{H}} p_i^0 v_i + \sum_{i \in \mathcal{P}} p_i^0 v_i \right] - c'(x^*) \right].$$

We can use the first-order condition of U's maximization problem, (5), to replace $c'(x^*)$. It then follows from Lemma 3 that the expression in square brackets is negative. By Lemma 2, $\partial x^*/\partial \beta > 0$. Combining both facts implies $\partial w^*/\partial \beta \leq 0$. $\square$

This proposition provides a cautionary note about essentiality checks. It shows that, in the absence of effective FRAND requirements, introducing or intensifying such checks can backfire by exacerbating overinvestment in standard-related technologies. As Lemma 3 established, overinvestment is likely to occur because innovators do not sufficiently take into account the surplus from alternative technologies that could be standardized if their research efforts fail, and because they do not internalize the full cost of litigation. The proposition considers a small increase in β, in the sense that it does not shift the equilibrium in any state i. Such an increase in the accuracy of essentiality checks has no direct effect on welfare: the reduction in litigation of non-essential patents detected by the checks is exactly offset by an increase in litigation for non-essential patents that go undetected and whose holders, due to a strengthening of their reputation, ask for litigation-inducing high royalties more often.[26] However, it has an indirect effect on welfare by raising equilibrium R&D investment. Because investment was already excessive from a social point of view, this effect is negative.

Proposition 1 looks at the effect of a small increase in β which keeps the nature of the equilibrium constant in all states i. We now consider a larger increase in β with the potential to push the equilibrium from hybrid to pooling, or the other way around, in some states. Suppose the accuracy of essentiality checks increases from β_0 to $\beta_1 > \beta_0$. We first show that, in general, the effect of this change on equilibrium investment is ambiguous. Let x_0^* and x_1^* denote equilibrium investment when accuracy is β_0 and β_1, respectively, and suppose that

$$\frac{(1-\beta_0)(1-x_0^*)}{x_0^*} > \frac{(1-\beta_1)(1-x_1^*)}{x_1^*}, \tag{8}$$

so that the left-hand side of (4), evaluated at $\hat{x} = x^*$, decreases as a result of the increase in β, implying that any change in equilibrium must be from

[26]See the discussion following (6) in Section 4.

hybrid to pooling. Note that $x_1^* \geq x_0^*$ is a sufficient but not a necessary condition for (8) to hold. Let $\mathcal{S}$ denote the set of states i such that

$$\frac{(1-\beta_0)(1-x_0^*)}{x_0^*} \geq \frac{p_i^H l_i}{p_i^0(v_i - l_i)} > \frac{(1-\beta_1)(1-x_1^*)}{x_1^*}.$$

That is, $\mathcal{S}$ is the set of states where the increase in β leads the equilibrium to change from hybrid to pooling, i.e., $\mathcal{S} = \mathcal{P}_1 \cap \mathcal{H}_0$, where $\mathcal{P}_1$ denotes the set of states that are pooling after the change, and similarly, $\mathcal{H}_0$ denotes the set of states that are hybrid before the change. Notice that

$$\mathcal{S} = \mathcal{H}_0 \setminus \mathcal{H}_1 = \mathcal{P}_1 \setminus \mathcal{P}_0.$$

Let Ψ denote the left-hand side of the first-order condition of U's profit maximization problem, evaluated at $\hat{x} = x^*$:

$$\Psi \equiv \sum_{i\in\mathcal{H}} p_i^H (v_i - \tilde{z}_i l_i) + \sum_{i\in\mathcal{P}} p_i^H v_i - (1-\beta)\left[\sum_{i\in\mathcal{H}} p_i^0 l_i + \sum_{i\in\mathcal{P}} p_i^0 v_i\right].$$

The effect of an increase in β on equilibrium investment depends on $\Psi_1 - \Psi_0$, given by

$$\underbrace{\sum_{i\in\mathcal{H}_1} p_i^H (v_i - \tilde{z}_i l_i) - \sum_{i\in\mathcal{H}_0} p_i^H (v_i - \tilde{z}_i l_i)}_{=-\sum_{i\in\mathcal{S}} p_i^H (v_i - \tilde{z}_i l_i)} + \underbrace{\sum_{i\in\mathcal{P}_1} p_i^H v_i - \sum_{i\in\mathcal{P}_0} p_i^H v_i}_{=\sum_{i\in\mathcal{S}} p_i^H v_i}$$
$$\underbrace{-(1-\beta_1)\sum_{i\in\mathcal{H}_1} p_i^0 l_i + (1-\beta_0)\sum_{i\in\mathcal{H}_0} p_i^0 l_i}_{=\Delta\beta \sum_{i\in\mathcal{H}_0} p_i^0 l_i + (1-\beta_1)\sum_{i\in\mathcal{S}} p_i^0 l_i} \underbrace{-(1-\beta_1)\sum_{i\in\mathcal{P}_1} p_i^0 v_i + (1-\beta_0)\sum_{i\in\mathcal{P}_0} p_i^0 v_i}_{=\Delta\beta \sum_{i\in\mathcal{P}_0} p_i^0 v_i - (1-\beta_1)\sum_{i\in\mathcal{S}} p_i^0 v_i}$$
$$= \Delta\beta\left[\sum_{i\in\mathcal{H}_0} p_i^0 l_i + \sum_{i\in\mathcal{P}_0} p_i^0 v_i\right] + \sum_{i\in\mathcal{S}} p_i^H \tilde{z}_i l_i - (1-\beta_1)\sum_{i\in\mathcal{S}} p_i^0 (v_i - l_i),$$

where $\Delta\beta \equiv \beta_1 - \beta_0$. As this expression reveals, under condition (8), an increase in β has three effects on U's investment incentives: first, a direct positive effect from reducing licensing revenue when the research project fails; second, an indirect positive effect from eliminating litigation when the project succeeds; third, an indirect negative effect from eliminating litigation when the project fails and the essentiality check erroneously certifies the patent as essential. The indirect effects work by moving the equilibrium from hybrid to pooling in states $i \in \mathcal{S}$. The overall effect is ambiguous.

The next proposition considers the welfare effect of an increase in β holding investment constant.

Proposition 2. *Fixing x^*, the welfare effect of an increase in the accuracy of essentiality checks is positive.*

Proof. Let w_0^* and w_1^* denote expected welfare when the accuracy of essentiality checks is β_0 and β_1, respectively, while investment is held fixed at x^*. Similarly, let $\mathcal{H}_0$ and $\mathcal{H}_1$ denote the set of states for which the equilibrium is hybrid when accuracy is β_0 and β_1, respectively, while investment is held fixed at x^*, and analogously for $\mathcal{P}_0$ and $\mathcal{P}_1$. Using (6), we have

$$w_0^* = x^* \left[\sum_{i \in \mathcal{H}_0} p_i^H \left(v_i - \frac{2\tilde{z}_i l_i v_i}{v_i - l_i} \right) + \sum_{i \in \mathcal{P}_0} p_i^H v_i \right] + (1 - x^*) \sum_{i=1}^{n} p_i^0 v_i - c(x^*)$$

$$w_1^* = x^* \left[\sum_{i \in \mathcal{H}_1} p_i^H \left(v_i - \frac{2\tilde{z}_i l_i v_i}{v_i - l_i} \right) + \sum_{i \in \mathcal{P}_1} p_i^H v_i \right] + (1 - x^*) \sum_{i=1}^{n} p_i^0 v_i - c(x^*).$$

Hence,

$$w_1^* - w_0^* = 2x^* \sum_{i \in \mathcal{S}} \frac{\tilde{z}_i l_i v_i}{v_i - l_i} \geq 0.$$

□

According to this proposition, if one abstracts from investment effects, then raising the accuracy of essentiality checks is necessarily welfare-enhancing. The intuition is that more accurate essentiality checks detect more non-essential patents and move the equilibrium from hybrid to pooling in some states, both of which reduce wasteful litigation.

When interpreting this result, it is important to keep in mind that investment is held constant. Note also that the analysis underlying the result does not take into account the *cost* of carrying out the essentiality checks, which could be substantial.

6 Essentiality checks in the presence of effective FRAND commitments

We now consider the case where $\bar{\alpha} < 1$. In this setting, which corresponds to a situation in which FRAND commitments are effective in constraining SEP holders, we investigate how the conclusions from the previous section change when policy makers can combine both essentiality checks and a FRAND rule which puts a cap on royalties.

Both $\bar{\alpha}$ and β are now policy variables. Consider the social planner's problem of choosing the royalty cap $\bar{\alpha}^*$ that maximizes expected social welfare for a given β, taking into account how the choice of $\bar{\alpha}$ affects equilibrium R&D investment and litigation decisions:

$$\max_{\bar{\alpha}} x^* \left[\sum_{i=1}^{n} p_i v_i - \sum_{i \in \mathcal{H}} p_i^H \frac{2 l_i \bar{\alpha} v_i}{\bar{\alpha} v_i + l_i} \right] + (1 - x^*) \sum_{i=1}^{n} p_i^0 v_i - c(x^*)$$

Characterizing how the solution to this problem, $\bar{\alpha}^*$, depends on β turns out to be difficult in general. To make the analysis tractable, we first derive the optimal royalty cap when essentiality checks are perfect and then study how it changes as the accuracy of essentiality checks decreases.

Suppose essentiality checks are perfect, $\beta = 1$. In this case, for all realizations of v_i, we have $\lambda_i^c = 1$ and hence $(1 - \lambda_i^c)\bar{\alpha} v_i < l_i$ for all i. The equilibrium is trivially "pooling" in all states, since only successful types can be certified essential. Thus, litigation does not happen in equilibrium. The first-best R&D effort is then the effort x that maximizes

$$x \sum_{i=1}^{n} p_i^H v_i + (1 - x) \sum_{i=1}^{n} p_i^0 v_i - c(x). \tag{9}$$

The following proposition characterizes the royalty cap $\bar{\alpha}$ that maximizes the expected welfare in this ideal scenario.

Proposition 3. *Suppose $\beta = 1$. Setting the royalty cap*

$$\bar{\alpha}^* = \frac{\sum_{i=1}^{n} (p_i^H - p_i^0) v_i}{\sum_{i=1}^{n} p_i^H v_i} \tag{10}$$

maximizes the expected welfare.

Proof. The first-best R&D effort solving (9) satisfies

$$\sum_{i=1}^{n} (p_i^H - p_i^0) v_i = c'(x).$$

With $\beta = 1$, the profit-maximizing condition (5) simplifies to

$$\bar{\alpha} \sum_{i=1}^{n} p_i^H v_i = c'(x).$$

Setting $\bar{\alpha}$ according to (10) aligns the profit-maximizing condition with the welfare-maximizing condition. Given that each condition yields a unique solution x, the equilibrium effort will be the welfare-maximizing effort. $\square$

Previously, Lemma 3 states that there will be overinvestment by U without the FRAND royalty cap ($\bar{\alpha} = 1$), as U does not take into account the surplus from the status-quo technology and the full social costs of litigation. In the case of $\beta = 1$, without any litigation, a successful U can reap the entire expected value of the standard rather than the expected incremental value over the status-quo technology, which is $\sum_i (p_i^H - p_i^0) v_i$. The royalty cap given by (10) brings down U's expected revenue to the expected incremental value. This is a version of the incremental-value interpretation of FRAND, according to which the FRAND rate should reflect the difference in value between the technology chosen as the standard and the next-best competing alternative (Swanson and Baumol, 2005).[27]

Next, we examine how a marginal decrease in β affects the optimal royalty cap.

Proposition 4. *Suppose $\beta = 1$. A marginal decrease in the accuracy of essentiality checks increases the optimal royalty cap $\bar{\alpha}^*$.*

Proof. See Appendix A. $\square$

The intuition of Proposition 4 is as follows. With near-perfect certification, D is willing to accept the certification status at face value and not litigate. Without any welfare loss from litigation, the R&D effort that the social planner wants to induce will be the same as the first-best effort. According to Lemma 2, the equilibrium R&D effort x^* is increasing in β. To induce the same (first-best) effort, a decrease in β has to be compensated by an increase in $\bar{\alpha}$. This is because the inaccuracy increases the probability that U is paid when its R&D project fails, thus reducing the marginal gain from R&D success. The result shows how a royalty cap should optimally be adjusted when there is some uncertainty about essentiality that results from imperfect essentiality checks.

[27] However, in this stochastic setting, the incremental value rule cannot be defined using the realized value in a particular state but must be defined in terms of expected value.

7 Conclusion

Essentiality checks have been proposed as a way to streamline the licensing of standard-essential patents (SEPs). Their proponents argue that essentiality checks would reduce uncertainty, thus facilitating license negotiations and curtailing litigation. Their effect on innovation incentives has so far been neglected. We develop a model in which an upstream innovator invests in R&D and subsequently obtains private information on the likely essentiality of their patents for a standard. The innovator then licenses the patents to a downstream implementer who can contest the essentiality of the patent in court. In equilibrium, there is wasteful litigation.

We show that introducing essentiality checks has two effects. First, in line with the arguments given in the policy debate, essentiality checks reduce litigation by eliminating information asymmetries. Second, they raise the incentive to innovate by decreasing the rewards for unsuccessful R&D outcomes. Their overall welfare effect depends on the level of the "fair, reasonable, and non-discriminatory" (FRAND) royalty rate. In the absence of effective FRAND requirements, which constrain SEP holders in their exercise of market power, introducing or intensifying essentiality checks can backfire by exacerbating overinvestment in standard-related technologies. At the same time, essentiality checks can be an attractive tool when used in combination with a well-designed FRAND rule that is effective in capping the royalty rate SEP holders can charge.

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APPENDIX

A Omitted proofs

Proof of Lemma 1. Let $\theta \in \{H, L\}$ denote whether firm U's R&D was successful (H) or not (L). Given v_i, a pure strategy for firm U specifies which royalty rate α_i to propose to firm D for each possible realization of the R&D outcome θ. Formally, $s_U : \{H, L\} \to [0, \bar{\alpha}]$. A pure strategy for firm D specifies for each possible proposed royalty rate whether to accept or reject, and, conditional on rejecting, whether or not to litigate. Formally, $s_D : [0, \bar{\alpha}] \to \{0, 1\}^2$. The set of mixed strategies for each player is the set of probability distributions over pure strategies. A system of beliefs for firm D specifies, for each possible proposed royalty rate, the probability D assigns to firm U having been successful (given that the patent is certified essential), which we denote by $\hat{\lambda}_i^c(\alpha_i) \equiv \Pr(H|v_i, c, \alpha_i)$. Since, for any $\bar{\alpha} \leq 1$, D's payoff from accepting ($(1 - \alpha_i)v_i$) is weakly greater than the payoff from rejecting without litigating (0), without loss of generality we restrict attention to strategies whereby firm D always litigates after rejecting. We denote by $\zeta_i(\alpha_i) \in [0, 1]$ the probability that firm D rejects and litigates (so $1 - \zeta_i(\alpha_i)$ is the probability of accepting).

Let q^θ denote firm U's probability of winning at trial when its type is θ. (By assumption, $q^H = 1$ and $q^L = 0$.) The payoffs of firms U and D when U is of type θ and proposes royalty α_i while D litigates with probability z_i are

$$\pi_U(\theta, \alpha_i, z_i) = (1 - z_i)\alpha_i v_i + z_i(q^\theta \bar{\alpha} v_i - l_i)$$
$$\pi_D(\theta, \alpha_i, z_i) = (1 - z_i)(1 - \alpha_i)v_i + z_i((1 - q^\theta \bar{\alpha})v_i - l_i).$$

Firm D's best-response correspondence is thus

$$\zeta_i(\alpha_i) = \begin{cases} 0 & \text{for } (1 - \alpha_i)v_i > (1 - \hat{\lambda}_i^c(\alpha_i)\bar{\alpha})v_i - l_i \\ [0, 1] & \text{for } (1 - \alpha_i)v_i = (1 - \hat{\lambda}_i^c(\alpha_i)\bar{\alpha})v_i - l_i \\ 1 & \text{for } (1 - \alpha_i)v_i < (1 - \hat{\lambda}_i^c(\alpha_i)\bar{\alpha})v_i - l_i. \end{cases}$$

Consider the candidate equilibrium in which type H plays $\alpha_i = \bar{\alpha}$ and type L plays

$$\alpha_i = \begin{cases} \bar{\alpha} & \text{with probability } y_i \\ l_i/v_i & \text{with probability } 1 - y_i. \end{cases}$$

By Bayes' rule, we have $\hat{\lambda}_i^c(l_i/v_i) = 0$ and

$$\hat{\lambda}_i^c(\bar{\alpha}) = \frac{\lambda_i^c}{\lambda_i^c + (1-\lambda_i^c)y_i}.$$

The out-of-equilibrium belief that makes it easiest to support the candidate equilibrium is $\hat{\lambda}_i^c(\alpha_i) = 0$ for any $\alpha_i \notin \{l_i/v_i, \bar{\alpha}\}$.

For $\alpha_i = l_i/v_i$, always accepting ($z_i = 0$) is a best response for D as $0 \in \zeta_i(l_i/v_i) = [0,1]$. For $\alpha_i = \bar{\alpha}$, always accepting ($z_i = 0$) is a best response for any $y_i \in [0,1]$ if $(1-\lambda_i^c)\bar{\alpha}v_i \le l_i$. If instead $(1-\lambda_i^c)\bar{\alpha}v_i > l_i$, $z_i < 1$ is a best response only if

$$(1-\alpha_i)v_i = (1-\hat{\lambda}_i^c(\bar{\alpha})\bar{\alpha})v_i - l_i \quad \Leftrightarrow \quad y_i = \frac{\lambda_i^c l_i}{(1-\lambda_i^c)(\bar{\alpha}v_i - l_i)}.$$

Finally, we show that neither type of firm U has an incentive to deviate. For $(1-\lambda_i^c)\bar{\alpha}v_i \le l_i$, both types get their most preferred outcome, $\pi^*(L) = \pi^*(H) = \bar{\alpha}v_i$, so neither has an incentive to deviate. For $(1-\lambda_i^c)\bar{\alpha}v_i > l_i$, type L is indifferent between $\alpha_i = l_i/v_i$ and $\alpha_i = \bar{\alpha}$ if and only if

$$l_i = (1-z_i)\bar{\alpha}v_i + z_i(-l_i) \quad \Leftrightarrow \quad z_i = \frac{\bar{\alpha}v_i - l_i}{\bar{\alpha}v_i + l_i}.$$

Since type L is indifferent, type H strictly prefers $\alpha_i = \bar{\alpha}$. Any other α_i would lead to $z_i = 1$ and thus lower payoffs. □

Proof of Proposition 4. For $l_i > 0$, a marginal decrease in β at $\beta = 1$ does not change the licensing outcome away from pooling because, by continuity, the inequality $(1-\lambda_i^c)\bar{\alpha}v_i < l_i$ still holds.

If welfare is not discontinuous at the optimal royalty cap (a condition which is satisfied for $\beta = 1$), the optimal cap satisfies the first-order condition

$$\frac{\partial x^*}{\partial \bar{\alpha}}\left[\sum_{i=1}^{n}(p_i^H - p_i^0)v_i - \sum_{i\in\mathcal{H}} p_i^H \frac{l_i(\bar{\alpha}v_i - 2l_i)}{\bar{\alpha}v_i + l_i} - c'(x^*)\right] - x^* \sum_{i\in\mathcal{H}} p_i^H \frac{2v_i l_i^2}{(\bar{\alpha}v_i + l_i)^2} = 0$$

where x^* is the solution to (5) with belief $\hat{x}$ fixed at x^*.

With $\beta = 1$, there is no litigation in any states regardless of the belief $\hat{x}$, i.e. $\mathcal{H} = \emptyset$ for any $\hat{x}$. By the implicit function theorem,

$$\left.\frac{\partial \bar{\alpha}^*}{\partial \beta}\right|_{\beta=1} = -\left.\frac{\frac{\partial^2 x^*}{\partial\bar{\alpha}\partial\beta}\left[\sum_i (p_i^H - p_i^0)v_i - c'(x^*)\right] - \frac{\partial x^*}{\partial \bar{\alpha}}\frac{\partial x^*}{\partial \beta}c''(x^*)}{\frac{\partial^2 x^*}{\partial \bar{\alpha}^2}\left[\sum_i (p_i^H - p_i^0)v_i - c'(x^*)\right] - \left(\frac{\partial x^*}{\partial \bar{\alpha}}\right)^2 c''(x^*)}\right|_{\beta=1}.$$

From Proposition 3, the first-best x^* when $\beta = 1$ is implicitly defined by $\sum_i (p_i^H - p_i^0) v_i - c'(x^*) = 0$; hence, the term in square brackets is zero. We can derive $\partial x^*/\partial\bar{\alpha}$ by applying the implicit function theorem to (5):

$$\frac{\partial x^*}{\partial \bar{\alpha}} = \frac{1}{c''(x)}\left[\sum_{i=1}^{n}\left(p_i^H - (1-\beta)p_i^0\right)\bar{\alpha}v_i \right.$$
$$\left. - \sum_{i\in\mathcal{H}(x,\beta)} p_i^H \left(\frac{\bar{\alpha}v_i - l_i}{\bar{\alpha}v_i + l_i}\right) l_i + (1-\beta)\sum_{i\in\mathcal{H}(x,\beta)} p_i^0(\bar{\alpha}v_i - l_i)\right].$$

Evaluated at $\beta = 1$, the above expression collapses to $\sum_i p_i^H \bar{\alpha} v_i / c''(x^*) > 0$. Therefore, we can simplify

$$\left.\frac{\partial \bar{\alpha}^*}{\partial \beta}\right|_{\beta=1} = -\left.\frac{\partial x^*/\partial \beta}{\partial x^*/\partial \bar{\alpha}}\right|_{\beta=1} < 0,$$

where the inequality follows from the fact that, by Lemma 2, $\partial x^*/\partial \beta > 0$. $\square$

B Alternative specification of essentiality checks

Consider the model described in Section 2 with one difference: the certifier always correctly identifies non-essential patents as such, but only correctly certifies essential patents with probability γ. As before, the case of $\gamma = 0$ is equivalent to having no essentiality checks (no patents are certified) and $\gamma = 1$ means the certifier perfectly distinguishes between essential and non-essential patents.

Recall that λ_i^s denotes D's belief that U's patent is essential after observing the value v_i and the certification outcome s, but before observing the contract offer. If the patent is certified essential, D believes with certainty that the patent is essential, $\lambda_i^c = 1$. If the patent is not certified essential, D believes that U's patent is essential with probability λ_i^{nc} given by

$$\lambda_i^{nc} = \frac{(1-\gamma)\hat{x}p_i^H}{(1-\gamma)\hat{x}p_i^H + (1-\hat{x})p_i^0}.$$

In contrast with the main text, here the belief that a non-certified patent is essential never drops to zero unless essentiality checks are perfect, $\gamma = 1$. Thus, there is no role for summary judgment in this setting, as courts are willing to dismiss cases at the summary judgment stage only if they are certain that the case has no merit.

At the licensing stage, if the patent is certified essential, U offers $\alpha = \bar{\alpha}$ and D always accepts the offer. If the patent is not certified, we have $\lambda_i^{nc} > 0$ in equilibrium if $x > 0$, $p_i^H > 0$, and $\gamma < 1$; we have $\lambda_i^{nc} = 0$ if $x = 0$, $p_i^H = 0$, or $\gamma = 1$. The following lemma reproduces Lemma 1 under this setting. The difference is that here, the lemma pertains to non-certified patents, whereas Lemma 1 pertains to certified patents.

Lemma 4. *Suppose the standard has value v_i and U's patent is not certified essential. There exists an equilibrium in which a type-H U offers $\alpha_i = \bar{\alpha}$, while a type-L U offers*

$$\alpha_i = \begin{cases} \bar{\alpha} & \textit{with probability } y_i \\ l_i/v_i & \textit{with probability } 1 - y_i. \end{cases}$$

D always accepts $\alpha_i = l_i/v_i$; it rejects $\alpha_i = \bar{\alpha}$ with probability z_i. The probabilities y_i and z_i are given by

$$y_i = \begin{cases} \dfrac{\lambda_i^{nc}}{1 - \lambda_i^{nc}} \dfrac{l_i}{\bar{\alpha} v_i - l_i} & \textit{if } (1 - \lambda_i^{nc}) \bar{\alpha} v_i \geq l_i \\ \\ 1 & \textit{otherwise,} \end{cases}$$

$$z_i = \begin{cases} \dfrac{\bar{\alpha} v_i - l_i}{\bar{\alpha} v_i + l_i} & \textit{if } (1 - \lambda_i^{nc}) \bar{\alpha} v_i \geq l_i \\ \\ 0 & \textit{otherwise.} \end{cases}$$

The proof is the same as for Lemma 1 and is therefore omitted.

As Lemma 4 shows, the licensing outcome for non-certified patents is hybrid if $(1 - \lambda_i^{nc}) \bar{\alpha} v_i \geq l_i$ and pooling otherwise. Substituting λ_i^{nc} and rearranging the inequality yields

$$\frac{p_i^0 (\bar{\alpha} v_i - l_i)}{p_i^H l_i} \geq \frac{(1 - \gamma) \hat{x}}{1 - \hat{x}}. \tag{11}$$

Note that in this case, if the accuracy γ increases, the licensing outcome in state i can switch from pooling to hybrid given a fixed $\hat{x}$. With greater accuracy of the essentiality checks, the patents that are actually essential are more likely to be certified, so upon observing a non-certified patent, D's posterior belief that the patent is essential is lower compared to the case with lower accuracy.

If U's research is successful, U's patent fails to be certified with probability $1-\gamma$. In a state with a hybrid equilibrium, a non-certified patent faces litigation with probability $\tilde{z}_i = (\bar{\alpha}v_i - l_i)/(\bar{\alpha}v_i + l_i)$. The expected revenue (net of litigation costs) when U's research is successful is

$$\begin{aligned}\pi^H &= \gamma \sum_{i=1}^{n} p_i^H \bar{\alpha} v_i + (1-\gamma)\left[\sum_{i\in\mathcal{H}} p_i^H \left(\bar{\alpha}v_i - \tilde{z}_i l_i\right) + \sum_{i\in\mathcal{P}} p_i^H \bar{\alpha} v_i\right] \\ &= \sum_{i\in\mathcal{H}} p_i^H \left[\bar{\alpha}v_i - (1-\gamma)\tilde{z}_i l_i\right] + \sum_{i\in\mathcal{P}} p_i^H \bar{\alpha} v_i.\end{aligned}$$

If U's research is unsuccessful, U's patent is never certified. In this case, U receives an expected revenue of l_i in a state with a hybrid equilibrium and $\bar{\alpha}v_i$ in a state with a pooling equilibrium. The expected revenue when U is unsuccessful is then

$$\pi^L = \sum_{i\in\mathcal{H}} p_i^0 l_i + \sum_{i\in\mathcal{P}} p_i^0 \bar{\alpha} v_i.$$

Firm U chooses the R&D effort x to solve

$$\max_x \quad x\pi^H + (1-x)\pi^L - c(x),$$

and the equilibrium R&D effort is the x^* that solves the first-order condition

$$\sum_{i\in\mathcal{H}} p_i^H \left[\bar{\alpha}v_i - (1-\gamma)\tilde{z}_i l_i\right] + \sum_{i\in\mathcal{P}} p_i^H \bar{\alpha} v_i - \left[\sum_{i\in\mathcal{H}} p_i^0 l_i + \sum_{i\in\mathcal{P}} p_i^0 \bar{\alpha} v_i\right] = c'(x). \quad (12)$$

Similarly to Lemma 2, we can derive the effect of a marginal change in the accuracy γ on the equilibrium effort x^* using the implicit function theorem:

$$\frac{\partial x^*}{\partial \gamma} = \frac{\sum_{i\in\mathcal{H}} p_i^H \tilde{z}_i l_i}{c''(x^*)} \geq 0.$$

If there exists a state with a hybrid equilibrium, then a marginal increase in γ raises x^*. The following lemma summarizes this discussion.

Lemma 5. *Fix $\gamma < 1$ and suppose that, at the resulting equilibrium research effort x^*,* (11) *does not hold with equality in any state i. A marginal increase in γ raises x^* if at least one state i has a hybrid equilibrium.*

Welfare. As in Section 4 and Section 6, we consider the expected social surplus given the licensing outcome. If U's research is successful, the expected surplus is

$$w^H = \gamma \sum_{i=1}^{n} p_i^H v_i + (1-\gamma)\left(\sum_{i\in\mathcal{H}} p_i^H (v_i - 2\tilde{z}_i l_i) + \sum_{i\in\mathcal{P}} p_i^H v_i\right)$$

whereas the expected surplus if U is unsuccessful is

$$w^L = \sum_{i\in\mathcal{H}} p_i^0 (v_i - 2\tilde{y}_i \tilde{z}_i l_i) + \sum_{i\in\mathcal{P}} p_i^0 v_i$$

A social planner who can control the research effort but not royalties or litigation chooses the effort x to maximize

$$xw^H + (1-x)w^L - c(x),$$

which, substituting $\tilde{y}_i$, λ_i^{nc}, and $\hat{x} = x$, can be simplified to

$$x\left[\sum_{i=1}^{n} p_i^H v_i - (1-\gamma)\sum_{i\in\mathcal{H}} p_i^H 2\tilde{z}_i l_i \left(\frac{\bar{\alpha} v_i}{\bar{\alpha} v_i - l_i}\right)\right] + (1-x)\sum_{i=1}^{n} p_i^0 v_i - c(x).$$

In contrast to the model in the main text, welfare, given a fixed x, is marginally increasing in γ, assuming that $\mathcal{H}$ and $\mathcal{P}$ are unchanged. This is because increasing the accuracy of essentiality checks directly reduces litigation here: litigation is avoided if the H-type patent is certified, and the L-type patent holder is less likely to mimic the H-type in a hybrid equilibrium as the belief λ_i^{nc} is lower.

The first-order condition of the welfare-maximization problem taking the outcome at the licensing stage as given is

$$\sum_{i=1}^{n} p_i^H v_i - (1-\gamma)\sum_{i\in\mathcal{H}} p_i^H 2\tilde{z}_i l_i \left(\frac{\bar{\alpha} v_i}{\bar{\alpha} v_i - l_i}\right) - \sum_{i=1}^{n} p_i^0 v_i = c'(x). \tag{13}$$

As we do in Lemma 3, we can establish that when $\bar{\alpha} = 1$, the private incentive to invest in R&D is excessive.

Proposition 5. *Suppose FRAND requirements are ineffective: $\bar{\alpha} = 1$. Fixing the sets $\mathcal{H}$ and $\mathcal{P}$, the private incentive to invest in R&D is socially excessive.*

Proof. It suffices to show that the left-hand side of (12) exceeds the left-hand side of (13):

$$\sum_{i\in\mathcal{H}} p_i^H \left[v_i - (1-\gamma)\tilde{z}_i l_i\right] + \sum_{i\in\mathcal{P}} p_i^H v_i - \left[\sum_{i\in\mathcal{H}} p_i^0 l_i + \sum_{i\in\mathcal{P}} p_i^0 v_i\right] \geq$$
$$\sum_{i=1}^n p_i^H v_i - (1-\gamma)\sum_{i\in\mathcal{H}} p_i^H 2\tilde{z}_i l_i \left(\frac{v_i}{v_i - l_i}\right) - \sum_{i=1}^n p_i^0 v_i$$
$$\Leftrightarrow (1-\gamma)\sum_{i\in\mathcal{H}} p_i^H \tilde{z}_i l_i \left(\frac{v_i + l_i}{v_i - l_i}\right) + \sum_{i=1}^n p_i^0 v_i \geq 0.$$

□

The key insight from the main text, that increasing the accuracy of essentiality checks involves a tradeoff between litigation and efficient investment, carries over to this setting. On the one hand, higher accuracy can reduce litigation, on the other hand, Lemma 5 and Proposition 5 imply that when $\bar{\alpha} = 1$ (or more generally, when FRAND requirements are not very effective), a marginal increase in γ exacerbates overinvestment.

However, the welfare effect of an increase in γ is ambiguous in this setting even in the two situations where the effect is unambiguous in the setting of the main text: (a) when considering a marginal change in γ that holds the nature of the equilibrium in each state constant (pooling or hybrid), (b) when holding the investment x^* fixed. To understand (a), recall that, as explained above, a marginal change in γ has an effect on litigation in the setting considered in this appendix whereas it does not in the main text. This means that, unlike in Proposition 1, the effect of essentiality checks operating through investment cannot be isolated here.

To understand (b), suppose that the accuracy increases from γ_0 to $\gamma_1 > \gamma_0$, and let w_0^* and w_1^* denote the respective expected welfare when the investment x^* is held fixed. With the investment x^* held fixed, we have

$$\frac{(1-\gamma_0)x^*}{1-x^*} > \frac{(1-\gamma_1)x^*}{1-x^*},$$

meaning that an increase in γ can only push the licensing equlibrium from pooling to hybrid, not the other way round. Letting $\mathcal{H}_0$ and $\mathcal{H}_1$ denote the set of states with hybrid equilibrium when the accuracy is γ_0 and γ_1, respectively, and $\mathcal{T} = \mathcal{H}_1 \setminus \mathcal{H}_0$, we have

$$w_1^* - w_0^* = 2x^* \left[(\gamma_1 - \gamma_0) \sum_{i \in \mathcal{H}_0} p_i^H \tilde{z}_i l_i \left(\frac{v_i}{v_i - l_i} \right) - (1 - \gamma_1) \sum_{i \in \mathcal{T}} p_i^H \tilde{z}_i l_i \left(\frac{v_i}{v_i - l_i} \right) \right].$$

An increase in γ has two effects on welfare when x^* is held fixed. First, it increases the probability that the patent is (correctly) certified essential, which in this case means the patent is not litigated. Second, it may shift the licensing equilibrium in some states from pooling to hybrid (the states in $\mathcal{T}$), triggering litigation in those states.

If there is a perfect essentiality check, $\gamma = 1$, then a non-certified patent is certainly non-essential ($\lambda^{nc} = 0$). In equilibrium, the court will summarily dismiss the case with a non-certified patent so U cannot extract any revenue from D when its R&D fails. As a result, there is no litigation when $\gamma = 1$ and Proposition 3 on the first-best royalty cap continues to apply also in the setting of this appendix.

However, Proposition 4 cannot be reproduced using the same argument. The reason is that accuracy affects litigation even in the vicinity of $\gamma = 1$. In the presence of summary judgments, although there is no litigation when essentiality checks are perfect, there is a discontinuity at $\gamma = 1$, as the court never summarily dismisses a case when $\gamma < 1$. This implies that even a marginal reduction in γ can trigger a discontinuous increase in litigation. Even in the absence of summary judgments, since the licensing equilibrium is hybrid in every state of the world at $\gamma = 1$ (with $y_i = 0$), a marginal decrease in γ increases the probability that there is litigation in equilibrium. Hence, in choosing the optimal royalty cap $\bar{\alpha}$, the planner has to take into account how it affects not only investment but also litigation.