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No-Challenge Clauses in Patent Licensing - Blessing or Curse?

Benno Buehler[*], Matthias Hunold[†], and Frank Schlütter[‡]

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Abstract

We analyze the effects of no-challenge clauses that prevent licensees from challenging the validity of patents. Contrary to popular arguments, we show that banning these clauses does not necessarily improve the frequency of successful patent challenges. Depending on the patent strength, patent holders may profitably offer license contracts that incentivize licensees to not challenge the patent. Even worse, such a strategy can lead to higher running royalties and lower consumer surplus compared to contracts with no-challenge clauses. We demonstrate that measures that aim at improving the prospects of patent challenges, such as prohibiting termination-upon-challenge clauses, can cause additional detrimental effects.

Keywords: no-challenge clause, probabilistic patents, license contracts

JEL: K11, K41, L24, L42

[*]Charles River Associates, 143 Avenue Louise, B-1050 Brussels, Belgium; e-mail: bbuehler@crai.com. *The views expressed are those of the author and cannot be regarded as stating an official position of CRA.*

[†]University of Siegen, Unteres Schloß 3, 57068 Siegen, Germany; e-mail: matthias.hunold@uni-siegen.de.;

[‡]CORE/LIDAM, Université Catholique de Louvain; e-mail: frank.schluetter@uclouvain.be.

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1 Introduction

License agreements commonly contain obligations on the licensee to not challenge the validity of the intellectual property rights of the patent holder. The inclusion of these provisions (henceforth referred to as no-challenge clauses) into technology licensing agreements has been treated rather unfavorably in a number of court decisions, both in the US and in the EU. The US Supreme Court held in *Lear, Inc. vs. Adkins* that a licensee is free to challenge the validity of a patent, and expressed that licensees can play an important role in identifying and challenging invalid patents:

> "Licensees may often be the only individuals with enough economic incentive to challenge the patentability of an inventor's discovery." (*Lear, Inc. vs. Adkins*, 395 US 653 at 670.)[1]

The Second Circuit of Appeals consequently held in *Rates Technology, Inc. vs. Speakeasy, Inc.* that a no-challenge clause reduces the likelihood of weak patents being challenged and is contrary to the public interest of permitting the free use of technologies that are part of the public domain.[2] Similarly, European courts held in *Windsurfing International vs. Commission*[3] and in *Bayer vs. Süllhöfer*[4] that an obligation on the licensee to not challenge the validity of the underlying patents restricts competition within the meaning of Article 101(1) TFEU.[5]

While sustaining wrongly-granted intellectual property rights is against the public interest, no-challenge clauses can also have positive welfare effects:

1. Litigation imposes substantial private and social costs (Farrell and Merges, 2004; Bessen and Meurer, 2012; Hall and Harhoff, 2012; Schankerman and Schuett, forthcoming). No-challenge clauses avoid later (legal) conflicts between the licensor and the licensee and thus potentially wasteful litigation costs.

[1] Historically, the situation in the US was different as even absent contractual provisions, it was not possible for a licensee to challenge the validity of a patent (*Kinsman vs. Parkhurst*, 59 U.S. 18 How. 289 (1855)).

[2] *Rates Tech. Inc. vs. Speakeasy, Inc.*, No. 11-4462 (2nd Cir. 2012).

[3] Case 193/83 *Windsurfing International Inc. vs. Commission,* paras 89-94.

[4] Case 65/86 *Bayer AG and Maschinenfabrik Hennecke GmbH vs. Heinz Süllhöfer,* paras 89-93.

[5] In Europe, no-challenge clauses are also regarded as excluded restrictions and, thus, are removed from the scope of the Technology Transfer Block Exemption Regulation (Commission Regulation (EC) No. 772/2004) and from the R&D Block Exemption Regulation (Commission Regulation (EC) No. 1217/2010).

2. No-challenge clauses can foster inventions and promote the public disclosure of those inventions (Goldstucker, 2008; Server and Singleton, 2011; Brenner, 2013).

3. The patent holder may offer reduced royalty rates as a compensation for the obligation to not challenge the validity of patents.[6]

Despite the long-standing legal debate about no-challenge clauses, there is surprisingly little economic analysis of their effects on the royalty rates or on efficiency and consumer surplus. We contribute by analyzing how no-challenge clauses affect the royalty rates and social welfare, as well as whether they reduce the equilibrium frequency of patent litigation.

We build on the seminal model of Farrell and Shapiro (2008) and extend this in various ways to allow for a comprehensive analysis of no-challenge clauses. The model incorporates probabilistic patents in the sense that a patented technology does not deserve patent protection with some probability and could be declared invalid if challenged in court (Lemley and Shapiro, 2005). This assumption is based on studies which estimate that large fractions of patents in the US and Germany would be found invalid if challenged in court.[7] For the main analysis, we consider that a patent holder licenses the patented technology to a number of downstream firms with non-discriminatory two-part tariffs, consisting of a fixed fee F and a running royalty r. A licensee learns about the patent's validity with some probability after contract acceptance and can decide to challenge its validity in court.

A main finding of our analysis is that a ban of no-challenge clauses does not necessarily increase the frequency that wrongly-granted patents are invalidated in equilibrium (first column in Table 1). In this case the main justification for banning no-challenge clauses (as expressed e.g., in *Lear vs. Adkins*) is not warranted and—as we show—a ban can even be detrimental for welfare. Absent a no-challenge clause, the patent holder may offer license terms that make it financially unattractive for licensees to challenge the underlying patent.

[6]The German patent law acknowledges that royalties for a compulsory license should reflect whether a licensee has the ability to challenge the licensed patent or not. See MSD vs. Shionogi (Federal Court of Justice, X ZB 2/17, No. 28).

[7]For the US, Miller (2013) estimates that 28 percent of all patents would be found invalid if subject to an innovation-based (i.e., anticipation or obviousness) decision. For Germany, and focusing on all potential invalidation reasons, Henkel and Zischka (2019) predict in a similar study the probability of a partial or full invalidation of a randomly drawn patent to be around 80 percent.

This can occur even if the licensee knows with certainty that a court would invalidate the patent in the event of a lawsuit.[8]

A contract offer that renders a patent challenge unprofitable is particularly beneficial for the patent holder in the case of *weak patents* (where the probability of the patent being valid is below a certain threshold). For such patents in particular, there is arguably a large public interest in successful invalidation as the patent holder is granted a quasi-monopoly although, with a high probability, a detailed assessment would reveal that the requirements for granting such market power are not fulfilled. A free-riding problem among the licensees, however, makes it profitable for the patent holder to offer license terms that discourage patent invalidation: if a patent is invalidated, all firms in an industry are free to use the technology without the obligation to pay royalties.[9] For weak patents, a ban of no-challenge clauses therefore does not increase the likelihood of licensees challenging invalid patents.

	Effects of a no-challenge clause	
	on frequency of successful patent challenges	on consumer surplus
for weak patents (invalid with high probability)	0	$\uparrow$ or 0
for strong patents (invalid with low probability)	$\downarrow$	$\downarrow$

Table 1: Equilibrium effects of a no-challenge clause relative to no such clause.

The overall effect of a no-challenge clause on consumer surplus and social welfare also depends on the patent strength (second column of Table 1). If a patent challenge is contractually feasible, holders of weak patents induce the licensees to not challenge the patent. In this case, we find that a no-challenge clause can increase both consumer and total surplus (or, at worst, leaves them unaffected). Absent a no-challenge clause, the

[8]Other market participants may not have an incentive to challenge a patent either. For instance, Choi (2005) shows that patent holders of substitute patents lack the incentives to invalidate patents through litigation. Kesan and Gallo (2006) and Schankerman and Schuett (forthcoming) analyze a competitor's incentives to challenge and—among other aspects—point out that the patent is not challenged if litigation costs are high.

[9]Farrell and Merges (2004) have pointed out this public-good problem. In the US, licensees may avoid further royalty payments, regardless of the provisions of their contract, once a third party proves that the patent is invalid. See Supreme Court decision *Blonder-Tongue Labs, Inc. vs. University of Illinois Foundation*, 402 US 313 (1971).

patent holder optimally avoids a challenge by offering a low fixed fee to the downstream firms. Importantly, this license contract involves a (weakly) higher running royalty rate (and therefore also consumer prices) than with a no-challenge clause. Hence, the patents will not be invalidated—neither with nor without a no-challenge clause—but the running royalties and consumer prices can be higher absent such a clause.

The situation is different for *strong patents* where the probability of success in a patent challenge is low. Holders of such patents accept a positive invalidation risk absent a no-challenge clause. Intuitively, they do not benefit from offering higher profits to the downstream firms just to prevent relatively rare cases of successful patent challenges. We show that the running royalties for a strong patent and the resulting consumer prices are lower absent a no-challenge clause. Unsurprisingly, this holds when the patent is challenged and invalidated as all downstream firms can then use the technology free of charge. Interestingly, the result also holds when the patent remains unchallenged and valid. Hence, for strong patents, consumer surplus is higher without a no-challenge clause. Social welfare can be either higher or lower, depending on the litigation costs.

In summary, the results of our analysis indicate that a no-challenge clause affects both the royalty rates as well as the frequency of patent challenges. Whereas banning a no-challenge clause may be an effective instrument to incentivize licensees to challenge the validity of strong patents, this may not hold for weak patents. We therefore find that these clauses can even have positive effects on consumer surplus and social welfare.

Closely related to our article is Miller and Gal (2015). They provide a detailed legal assessment of no-challenge clauses and an initial formal analysis of how such contract clauses affect social welfare. Miller and Gal (2015) argue that that no-challenge clauses affect social welfare only through the probability that an invalid patent will be successfully challenged. In a related article, Gal and Miller (2017) call for a prohibition of such contract clauses because they would harm competition without having pro-competitive effects. In line with Miller and Gal, Cheng (2015) emphasizes that no-challenge clauses tend to be harmful by increasing the exclusion period of weak patents. He calls for a rule-of-reason approach.

We complement the existing literature by emphasizing that a patent holder can avoid a patent challenge even absent a no-challenge clause. We find that banning no-challenge clauses can result in an increased running royalty and thereby higher consumer price without necessarily increasing the frequency of invalidation, in particular for weak patents. Based on our analysis, and given further efficiency justifications for such clauses described above, a general prohibition, as proposed in Gal and Miller (2017), may not be optimal.

The above results lead to the question as to whether licensees can be further incentivized to challenge the validity of patents. One approach is to remove the downsides for licensees of failed patent challenges by allowing licensees to challenge the licensed patents while keeping the license contract. A measure in this direction is to prohibit so-called 'termination-upon-challenge' clauses that allow the patent holder to cancel the license contract with a challenging licensee. Moreover, the US Supreme Court landmark case *MedImmune, Inc. vs. Genentech, Inc.* of 2007 reduced the legal requirements to bring a patent challenge to court.[10] Commentators have noted that this decision should make patent challenges substantially more attractive and thus more likely to occur (Dreyfuss and Pope, 2009). We study whether these measures increase patent challenges in equilibrium. Interestingly, despite the fact that the prospects of challenging a patent should be substantially better if a licensee can continue to rely on the initial license contract in case of an unsuccessful challenge, we obtain results similar to our benchmark model: the patent holder can nevertheless avoid a patent challenge with a license contract that provides for higher running royalties compared to a license contract with a no-challenge clause. Due to the increased risk of a patent challenge, the incentive to avoid such a challenge can be substantially larger than when licensees loose the license contract, leading to even fewer invalid patents that are successfully challenged in court.

Finally, we show that our main result is robust if we restrict the analysis to linear license tariffs. Similarly to the benchmark model with two-part tariffs, patent challenges occur in equilibrium only if the patent is sufficiently strong. In this case, the welfare effects of a no-challenge clause are ambiguous. On the downside, the invalidation of wrongly-granted patents is less frequent, whereas on the upside the royalty rates (and consumer prices) are lower and litigation costs are saved. For weak patents, we find that license contracts are such that downstream firms have no incentive to challenge the patent. In this case, a no-challenge clause (weakly) reduces welfare as the invalidation probability remains at

[10] *MedImmune, Inc. vs. Genentech, Inc.*, 549 US 118 (2007).

zero but royalty rates and consumer prices increase.

The remainder of the article is structured as follows: In Section 2 we introduce the model and describe the equilibrium payoffs for the different regimes. In Section 3 we analyze the benchmark model of two-part tariffs and derive our main results. In Section 4 we provide a detailed analysis of the effects on the license outcome of the prohibition termination clauses and the *MedImmune, Inc. vs. Genentech, Inc.* judgment. Moreover, we extend the analysis to linear license contracts and show that patent holders can prevent a patent invalidation by means of favorable license terms similar to the case of two-part tariffs. In Section 5 we conclude with a summary of our findings, discuss limitations of our analysis and discuss policy implications.

2 Model

We model the licensing of probabilistic patents in the shadow of litigation, building on and extending the model of Farrell and Shapiro (2008). The patent holder P offers non-discriminatory licenses with a (possibly negative) fixed fee F and a running royalty r to n symmetric downstream firms.[11][12] The patent holder does not compete with the downstream firms. The patented technology is available to society and allows production of final products at zero marginal production costs.[13] There also exists an alternative technology to produce final products with higher marginal costs equal to v. The parameter v is hence a measure of the patent size.

Ex-ante the patent is valid with publicly-known probability $\theta \in (0, 1)$ and invalid otherwise.[14] Valid means that the technology qualifies as a non-obvious and novel invention that deserves patent protection. Invalid means that the technology belongs in the public

[11]Empirical studies show that a majority of license contracts contain a combination of running royalties and fixed fees (Rostoker, 1983; Bousquet et al., 1998; Hegde, 2014).

[12]As discussed by Farrell and Shapiro (2008), the literature on multilateral vertical contracting has shown that the equilibrium outcome depends on the form of contracts allowed, on the downstream firms' information, and on their beliefs about what they cannot observe. Requiring non-discriminatory offers avoids obtaining extreme results. Moreover, non-discriminatory offers are used in practice and are typically required for the licensing of patents incorporated into industry standards.

[13]Equivalently, the technology makes each unit of the product worth an extra v to all customers. Encaoua and Lefouil (2009) also analyze seminal inventions that enable a firm to produce entirely new products.

[14]The assumption of a publicly-known patent strength abstracts from potentially conflicting assessments of the patent holder and the licensees about the patent strength. It has been used in related analyses (Farrell and Shapiro (2008); Encaoua and Lefouil (2009); Palikot and Pietola (2019)).

domain and should not be protected by a patent. A court challenge is necessary and sufficient to identify the patent as invalid, and in this case all market participants can use the technology for free. If the patent is invalid (with probability $1-\theta$), a randomly drawn licensee receives a conclusive invalidity signal with probability γ. Otherwise, no downstream firm receives an invalidity signal.[15]

We solve for a symmetric subgame-perfect Nash equilibrium as the contract offers are public and all actions common knowledge in later stages. We focus on the equilibrium in which all downstream firms accept the patent holder's non-discriminatory contract offer.[16] A downstream firm accepting a license with per-unit royalty r has marginal cost r. If the patent is invalidated, all licensees can use the patent free of charge and have zero marginal costs. For the analysis, it is sufficient to consider situations in which a downstream firm has marginal costs of a while all its competitors have marginal costs of b. Denote a firm's output by $x(a,b)$ and profits gross of fixed fees by $\pi(a,b)$.

We structure the description of the game along the licensees' decisions regarding (i) contract acceptance and (ii) challenge decision.

Contract Offer and Acceptance Decision. The patent holder offers a non-discriminatory license contract $\{F, r\}$ to the n symmetric downstream firms, either with or without a no-challenge clause. We follow Farrell and Shapiro (2008) in imposing $r \leq v$ and no restrictions on the fixed fee.[17] Moreover, we assume that the fixed fee F is payable after the potential challenge decision, which resembles the case of a long-term license contract and a licensee taking its challenge decision during the contract duration. We discuss this assumption in more detail at the end of this section.

Each downstream firm decides simultaneously and individually whether to accept the contract offer. Alternatively, a downstream firm can decide to (a) reject the contract offer

[15]The invalidity signal is independent of patent strength θ. Assuming that only one downstream firm potentially finds this evidence simplifies the model without significant loss of generality. Thereby, we abstract from the question of how licensees coordinate to challenge a patent in court and share the litigation costs in the case that several licensees receive an invalidity signal.

[16]See Encaoua and Lefouil (2009) for an analysis of asymmetric equilibria, in which only a subset of downstream firms accepts the contract offer and litigation cannot be excluded. We abstract from this issue as our main focus is to analyze whether a patent holder is able to fully prevent patent litigation by means of no-challenge clauses or appropriate royalty rates, and the effects of these provisions on the contracting outcome.

[17]Such a restriction may be imposed by competition law, as higher royalty levels are likely to be anticompetitive. See Farrell and Shapiro (2008), footnote 22. See Hegde (2014) for empirical evidence regarding license contracts from the biomedical industry.

and use the old technology, or to (b) use the new technology without license, and thereby infringe on the patent. As in Farrell and Shapiro (2008), patent infringement (Option (b)) is the relevant alternative to contract acceptance for the downstream firms:[18] it is not profitable for a downstream firm to use the old technology even if there is some probability that one of the remaining downstream firms will challenge and invalidate the patent.[19]

As in Farrell and Shapiro (2008), the patent holder sues any infringing downstream firm and a court publicly determines the validity of the patent. If it is held valid, the patent holder can again offer a contract to the infringing downstream firm. If the patent is invalid, all downstream firms can use it free of charge. For simplicity, we focus on the case of conclusive evidence in the sense that a court invalidates the patent with certainty in view of this evidence.[20] With a no-challenge clause, the description of the game is complete at this stage and payoffs realize. In Figure 1, we illustrate the game tree for this case.

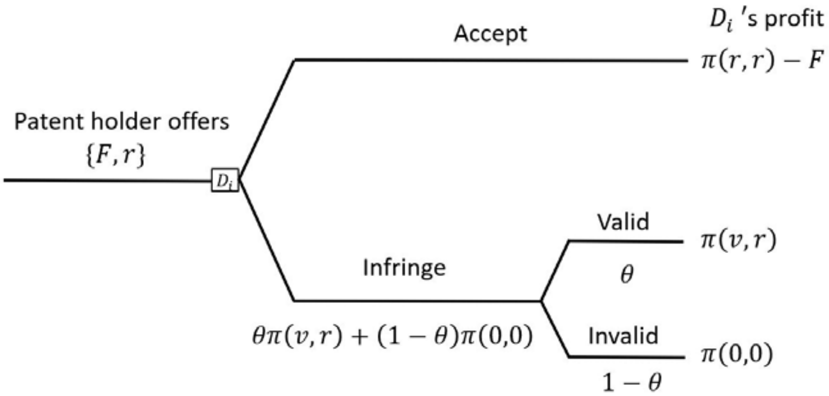


Figure 1: Contract acceptance decision (with no-challenge clause) from the perspective of one downstream firm (D_i) anticipating that all other downstream firms accept the contract.

[18]Even if a downstream firm expects another firm to challenge the patent post contract acceptance, patent infringement yields a higher profit than using the old technology (with the chance that another firm invalidates the patent) if $\theta\pi(v,r) + (1-\theta)\pi(0,0) > \frac{(1-\theta)(n-1)\gamma}{n}\pi(0,0) + \left(1 - \frac{(1-\theta)(n-1)\gamma}{n}\right)\pi(v,r)$. This inequality holds for all admissible royalty rates $r \in [0, v]$ as $(1-\theta)\left(1 - \frac{\gamma(n-1)}{n}\right)(\pi(0,0) - \pi(v,v)) > 0$.

[19]Our analysis is robust to allowing for positive litigation costs for infringing the patent. With positive costs for patent infringement, it is necessary to distinguish whether patent infringement or using the old technology is the relevant outside option to contract acceptance. For the sake of notational simplicity, we abstract from this form of litigation costs. The analysis for this case is available upon request.

[20]If the patent holder can avoid patent challenges if licensees are certain about the litigation process, it can certainly also do so in the presence of uncertainty. See Henkel and Zischka (2019) for an overview of the empirical evidence on validity decisions on litigated patents.

Challenge Decision. Absent a no-challenge clause and after contract acceptance, the licensees can decide to challenge the licensed patent in court. This decision can be contingent on having received an invalidity signal. We assume that the license contract is terminated if a licensee challenges the patent. This is in line with so-called termination-upon-challenge clauses and the actual controversy requirement, which is a common legal prerequisite for a patent challenge. In Section 4.1, we relax this assumption, such that a licensee keeps the initial license contract when challenging the patent. A licensee incurs costs of $L^{\mathcal{C}}$ when going to court.

We focus in our analysis on the economically interesting case that a licensee can have the economic incentive to challenge a patent's validity and that the inclusion of a no-challenge clause actually alters the license contract. This implies that a patent challenge cannot be prohibitively costly for the licensees. Otherwise a patent holder would not need to contractually avoid a patent challenge by imposing a no-challenge clause. In order to capture this logic, we assume that challenging the patent after receiving the invalidity signal yields a higher profit for a licensee than infringing the patent or using the old technology at the contract acceptance stage:

Assumption 1. $L^{\mathcal{C}} < \theta\left(\pi\left(0,0\right) - \pi\left(v,v\right)\right)$.[21]

This assumption ensures that if the patent holder offers the minimum profit level to ensure contract acceptance, a patent challenge can be economically reasonable for a licensee. If it is more expensive to challenge, a licensee will never decide to go to court after it has accepted the license contracts.

If the patent is challenged, a court publicly determines whether the patent is valid. This has the same consequences as in the case of patent infringement. The downstream firms simultaneously make their production decisions and payoffs realize (downstream revenues and all license payments).

We illustrate the possible events for a patent challenge in Figure 2 from the perspective of downstream firm D_i. Suppose that all n downstream firms have accepted the contract offer, and that downstream firm D_i obtains the invalidity signal (which occurs with

[21]A patent challenge yields a higher profit than patent infringement if $\pi\left(0,0\right) - L^{\mathcal{C}} \geq \theta\pi\left(v,r\right) + \left(1-\theta\right)\pi\left(0,0\right)$. This inequality holds for all $r \in [0,v]$ if $L^{\mathcal{C}} < \theta\left(\pi\left(0,0\right) - \pi\left(v,v\right)\right)$.

probability $(1-\theta)\frac{1}{n}\gamma$).[22]

- If D_i challenges the patent in court, it incurs litigation costs $L^{\mathcal{C}}$ and invalidates the patent with certainty. This yields a profit of $\pi(0,0) - L^{\mathcal{C}}$ for D_i and a profit of $\pi(0,0)$ for each of the other downstream firms as everyone can now use the patented technology free of charge.

- If D_i does not challenge the patent, it avoids the litigation costs $L^{\mathcal{C}}$ and the initial contract remains in place, yielding a profit of $\pi(r,r) - F$ for each downstream firm.

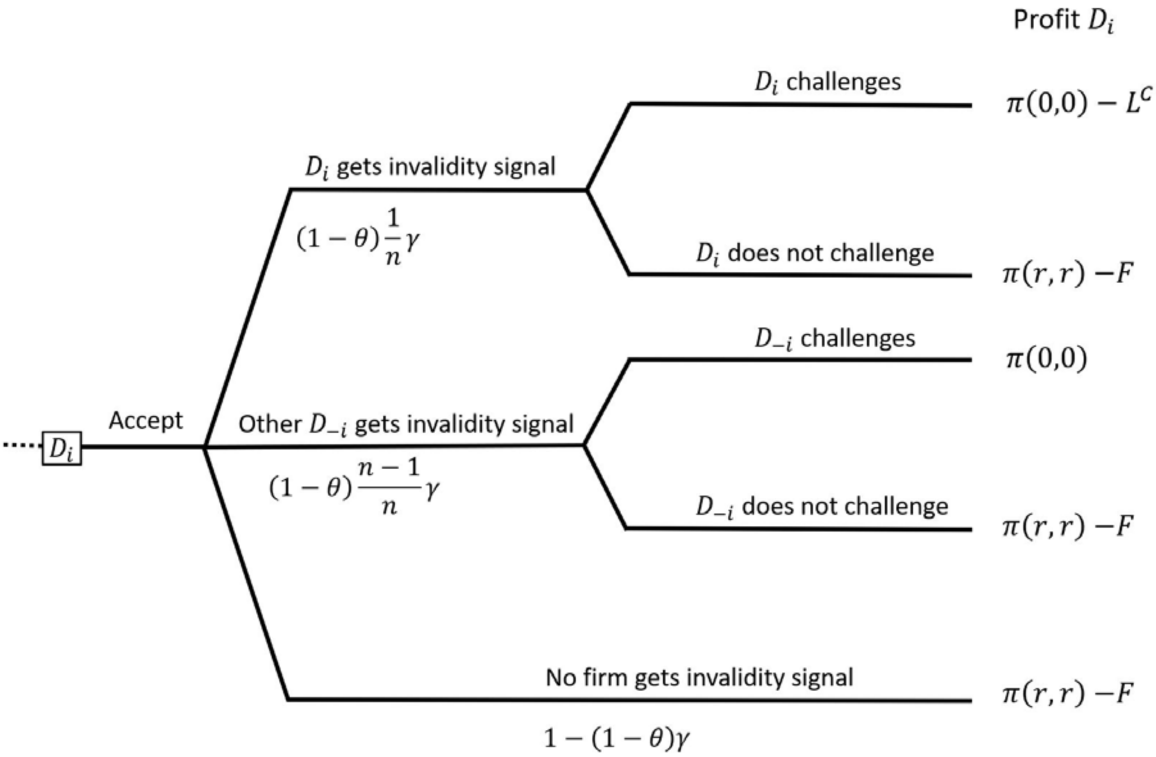


Figure 2: Challenge decision after contract acceptance from the perspective of one downstream firm (D_i).

With probability $(1-\theta)\frac{n-1}{n}\gamma$, another downstream firm (denoted D_{-i} in the figure) gets the invalidity signal and faces the same decision. With the remaining probability of $1-(1-\theta)\gamma$ no licensee obtains the invalidity signal and the initial contract remains in place.

Assumptions on profits and patent size. We follow Farrell and Shapiro (2008) in imposing standard assumptions on the reduced-form profits. These assumptions are satisfied, for instance, with demand that is linear in prices.

[22] We can focus on the challenge decision of a downstream firm with a signal as licensees without a signal do not benefit from a challenge. See Lemma A.1 in Appendix A.

Assumption 2. *The operational profit of a downstream firm $\pi(a,b)$ satisfies*

(i) $\pi_1(a,b) < 0$*: a firm's profits decrease in its own costs;*[23]

(ii) $\pi_2(a,b) \geq 0$*: a firm's profits weakly increases in the other firms' costs, with* $\pi_{22}(a,b)$ *not too negative;*[24]

(iii) $\pi_1(a,a) + \pi_2(a,a) < 0$ *: each firm's profits fall if all firms' costs increase from the same level.*

In order to illustrate some of our results, we provide parametric solutions based on the case of $n = 2$ downstream firms competing in prices and the linear demand system

$$x^i\left(p^i, p^{-i}\right) = \left(1/\left(1+\sigma\right)\right)\left(1 - \left(1/\left(1-\sigma\right)\right)p^i + \left(\sigma/\left(1-\sigma\right)\right)p^{-i}\right), \tag{1}$$

where $x^i\left(p^i, p^{-i}\right)$ is the demand that downstream firm i realizes if it charges a price of p^i while its competitor charges a price of p^{-i}.

If all downstream firms use the patented technology and pay royalties of r, the total (upstream and downstream) profits generated per downstream firm is

$$T(r) \equiv r \cdot x(r,r) + \pi(r,r). \tag{2}$$

On the total profit, we impose

Assumption 3. $T(r)$ *is strictly concave on the relevant range.*

Define the monopoly running royalty level $m = \arg\max_r T(r)$ that maximizes the industry profits. As in Farrell and Shapiro (2008), we assume that the patent size is (weakly) smaller than the monopoly running royalty, $v \leq m$. This corresponds to an incremental innovation for which the old technology still imposes a competitive constraint.

Welfare. Welfare is the sum of the industry profit and consumer surplus minus litigation costs. When all firms use the new technology as licensees, increasing the royalty r reduces

[23] We denote with g_j the partial derivative of $g(x_1, ..., x_N)$ with respect to its jth argument.

[24] The last part ensures that the patent holder's maximization problem has a unique maximum. See the related assumption in Farrell and Shapiro (2008) footnote 22.

output and lowers welfare (for $0 \leq r \leq v$) as the downstream price exceeds the social marginal costs at all positive running royalty levels.

Timing of license payments. We envision a long-term license contract (e.g., for 10 years) and a licensee learns about the patent's validity and decides to challenge the patent during the contract time (e.g., after 2 years). In order to capture this setting, we assume in our model that learning and challenge decision occur before production takes place. Consistent with the long-term nature of the license contract, we assume that the license payments are payable after the potential invalidation decision of the court. This means that the patent holder does not receive license payments if the patent is found to be invalid.

Settlements and Renegotiation. We assume that the patent holder reacts to a patent challenge by terminating the license contract with the challenging licensee. With this, we abstract from out-of-court settlements as a form of renegotiation between the patent holder and the challenging licensee. There are various reasons why court procedures may dominate settlements and why a patent holder has the commitment power not to renegotiate the contract. For example, a patent holder can have reputation concerns to discourage patent challenges by refusing to agree to patent settlements. Moreover, absent a no-challenge clause it might be difficult for a licensee to commit to not challenge the patent again after a settlement. Our focus is a patent holder's incentive and ability to avoid a public invalidation of the patented technology. We show that—even absent the possibility of private settlements—a patent holder can effectively prevent invalidation.

3 Equilibrium analysis

We highlight that a ban of a no-challenge clause does not necessarily improve the frequency with which invalid patents are challenged. The main mechanism for this result is that the patent holder can offer financial incentives that make it unprofitable for any licensee to challenge the patent even absent a no-challenge clause. This complements the analysis of Miller and Gal (2015) who do not relate the patent holder's offered royalty rate to the licensee's propensity to challenge the patent and thus draws different policy implications.

Moreover, we analyze the license terms in each scenario to derive the consequences on consumer surplus and social welfare, which depend on both the equilibrium challenge decisions and license terms.

3.1 Invalidation probability

With a no-challenge clause, the invalidation probability is zero. We now derive the equilibrium invalidation probability absent a no-challenge clause. Let us introduce the definition of two pricing regimes, which will turn out in the analysis absent no-challenge clauses, depending on the patent strengths.

Definition 1 (*Challenge-acceptance pricing*)**.** *The license terms are such that the licensees have incentives to challenge the patent upon receiving the invalidity signal.*

Definition 2 (*Challenge-avoidance pricing*)**.** *The license terms are such that the licensees have* ***no*** *incentive to challenge the patent upon receiving the invalidity signal.*

We highlight an important trade-off for the patent holder between the invalidation risk and the royalty payments from the license contract. The ex-ante probability that a licensee learns about the patent's invalidity after contract acceptance is $(1-\theta)\,\gamma/n$. In this event, it is not profitable to challenge the patent if invalidating the patent yields lower profits for the licensee than sticking to the initial contract:

$$\pi\,(0,0) - L^{\mathcal{C}} \quad \leq \quad \pi\,(r,r) - F. \tag{3}$$

The condition in Equation (3) pins down a minimum profit level that the patent holder has to grant to each licensee in order to financially incentivize them to not challenge the patent upon receiving the invalidity signal. Otherwise, a licensee that receives the invalidity signal challenges and thereby invalidates the patent. In this case the expected profit of a licensee at the stage of the contract acceptance is

$$(1-\theta)\,\gamma\left(\pi\,(0,0) - \frac{L^{\mathcal{C}}}{n}\right) + (1-(1-\theta)\,\gamma)\,(\pi\,(r,r) - F)\,. \tag{4}$$

With probability $(1-\theta)\,\gamma$, one of the downstream firms invalidates the patent and every downstream firm realizes a flow profit of $\pi\,(0,0)$. A downstream firm has to incur the litigation costs only in the event in which the firm itself receives the invalidity signal, which implies that its expected litigation costs are $L^{\mathcal{C}}/n$ at the contract acceptance stage. The outcome of no downstream firm receiving the invalidity signal arises either because the patent is valid or because no licensee learns about its invalidity. This outcome has a probability of $(1-(1-\theta)\gamma)$ and implies a profit of $\pi(r,r)-F$ from the license contract for each downstream firm.

If the patent holder does not incentivize downstream firms to refrain from patent challenges, as in Condition (3), it has to offer the downstream firms a license contract which yields at least an expected profit equal to their outside option when not accepting the license contract. The relevant outside option of a downstream firm expecting the remaining $n-1$ downstream firms to accept the contract $\{F,r\}$ is to infringe the patent, which yields a profit of

$$\theta \cdot \pi(v,r) + (1-\theta)\cdot \pi(0,0). \tag{5}$$

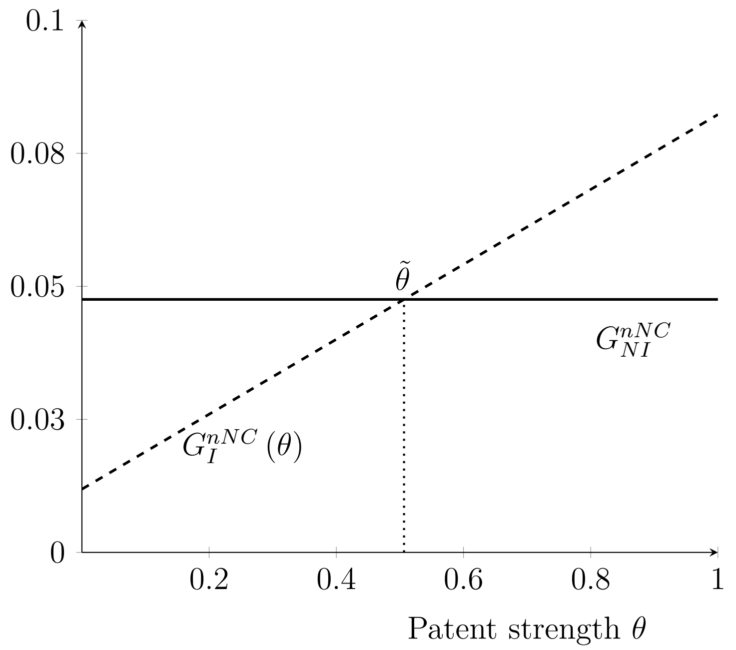
The patent holder sues the infringing downstream firm and the court invalidates the patent with probability $1-\theta$. This yields a profit of $\pi(0,0)$ as the competitors then also use the formerly patented technology free of charge. If the court validates the patent (with probability θ), the patent holder makes another take-it-or-leave-it offer to the infringing downstream firm. As the patent is valid with certainty in this case, the offer makes the downstream firm indifferent to its reservation payoff, which is equal to $\pi(v,r)$.

According to Assumption 1, the minimum profit level that prevents a challenge (Equation (3)) is larger than the minimum profit level that ensures contract acceptance (Equation (5)). The patent holder therefore faces a trade-off between invalidation risk and royalty payments when deciding on the contract offer: it can avoid the risk of patent invalidation (an event in which the patent holder realizes zero profit) but has to compensate the licensees by giving them a larger share of the profits. This trade-off is addressed in

Proposition 1. *Suppose there is no no-challenge clause. There exists a threshold value* $\tilde{\theta} \in (0,1)$ *defined in Equation* (46) *such that the patent holder offers a license contract that renders a patent challenge unprofitable for the licensees (even upon receiving the invalidity signal post contract acceptance) if* $\theta < \tilde{\theta}$. *If* $\theta \geq \tilde{\theta}$, *a licensee with the invalidity signal challenges and thereby invalidates the patent.*

Proof. See Appendix A. □

Under the conditions specified in Proposition 1, a patent holder offers favorable license fees that render a patent challenge unattractive for any licensee even if it receives the invalidity signal (challenge-avoidance pricing). Intuitively, this strategy is profitable for the patent holder if the patent is weak (i.e., small θ) and the probability that a licensee challenges the patent is large. If the risk of a patent invalidation is sufficiently small, the patent holder accepts a positive invalidation risk in order to extract a larger share of the total profits from the licensees.



The figure plots the patent holder's profit depending on patent strength θ absent a no-challenge clause with positive invalidation risk (I) and with no invalidation (NI) for the case of $n = 2$ licensees competing in prices. Marginal costs of old technology: $v = 1/10$; litigation costs are zero: $L^{\mathcal{C}} = 0$; signal probability: $\gamma = 3/4$. Demand is defined in Equation (1), with $\sigma = 3/4$.

Figure 3: Patent holder's profit in invalidation (I) and no-invalidation (NI) case.

Figure 3 illustrates the result of Proposition 1. Denote with G_{NI}^{nNC} the patent holder's profit absent a no-challenge clause (nNC) if it offers financial incentives to not invalidate (NI) the patent.[25] This profit level is independent of the patent strength θ. In contrast, G_{I}^{nNC} denotes the patent holder's profit for the case in which a patent challenge is profitable for a licensee upon receiving the invalidity signal (I). The dashed line in

[25]The examples and figures in this part are based on the assumption $L^{\mathcal{C}} = 0$ in order to represent the results for the whole support of patent strengths $\theta \in (0, 1)$. For $L^{\mathcal{C}} > 0$ the results are comparable but require case distinctions as Assumption 1 can be violated for some patent strengths.

Figure 3 illustrates that this profit increases in the patent strength. A stronger patent reduces the probability of patent invalidation, which is an event in which the patent holder realizes zero profits. At $\tilde{\theta}$, as described in Proposition 1, the patent holder is indifferent between challenge-avoidance pricing and challenge-acceptance pricing, that is, G_{NI}^{nNC} and G_{I}^{nNC} intersect. For patents stronger than $\tilde{\theta}$, the risk of patent invalidation under challenge-acceptance pricing is sufficiently small, so that the patent holder accepts a positive invalidation risk. For weaker patents, in contrast, it offers a license contract that induces the licensees to not challenge the patent even if they hold conclusive evidence about the invalidity of the patent. In this example, the patent holder prevents a patent challenge for patent strengths $\theta \lesssim 50\%$, which is well above the average patent strength of around 20%, as reported in Henkel and Zischka (2019) for the German patent system.

This result has important implications for the expectation expressed in *Lear, Inc. vs. Adkins, Inc.* that the licensees could be *"the only individuals with enough economic incentive to challenge the patentability of an inventor's discovery."* The analysis highlights that

(i) a licensee who challenges an invalid patent exerts a positive externality on consumers and on other licensees, who can then also use the technology without royalty payments; and

(ii) whether the licensee has enough incentive to challenge a patent crucially depends on the design of the license fees.

It is therefore possible that the main justification for a ban of no-challenge clauses is not warranted, as wrongly-granted patents are not necessarily challenged and invalidated in equilibrium. Proposition 1 shows that this mechanism occurs for weak patents where the public interest in invalidation is arguably particularly high.

3.2 License terms

License terms with no-challenge clause. Next, we compare the license terms with a no-challenge clause with the ones absent a no-challenge clause. To this end, we characterize the license terms both with and without a no-challenge clause. Suppose that the patent holder's contract contains a no-challenge clause. All market participants know that the licensed patent will not be challenged, and possibly discovered invalidity information will remain unused. The patent holder maximizes its profit per downstream firm

$$G^{NC} \quad = \quad r \cdot x\left(r, r\right) + F, \tag{6}$$

subject to the constraint that the licensees prefer the contract offer over their outside option. That is, the patent holder sets the fixed fee such that downstream firms are indifferent to their second-best alternative of infringing the patent:

$$\theta\pi\left(v, r\right) + \left(1 - \theta\right)\pi\left(0, 0\right) = \pi\left(r, r\right) - F.$$

The superscript NC indicates that the license contract contains a no-challenge clause. Solving for the fixed fee and inserting it in Equation (6) yields the reduced maximization problem

$$\max_{r} \; G^{NC}\left(r, \theta\right) = \max_{r} \left[\underbrace{T\left(r\right)}_{\text{total profit per-firm}} - \underbrace{\left(\theta\pi\left(v, r\right) + \left(1 - \theta\right)\pi\left(0, 0\right)\right)}_{\text{downstream outside option profit}} \right]. \tag{7}$$

The patent holder obtains the total profit per-downstream firm minus the downstream firms' outside option of infringing the patent. Importantly, the value of the licensees' outside option depends positively on the running royalty r: if a downstream firm has marginal costs of v and the remaining $n - 1$ licensees face a running royalty of r, the downstream firm's profit $\pi\left(v, r\right)$ increases in r (Assumption 2). Hence, the patent holder can strategically reduce the running royalty in order to decrease the value of the outside option for the downstream firm. Moreover, the first-order condition to the maximization problem in (7) reveals that this strategic effect increases in the patent strength θ:

$$G_1^{NC}\left(r, \theta\right) = T_1\left(r\right) - \theta\pi_2\left(v, r\right) = 0. \tag{8}$$

Let $r^{NC}\left(\theta\right)$ denote the optimal running royalty. Implicit differentiation of Equation (8) yields $\partial r^{NC}(\theta)/\partial\theta < 0$ for

$$\theta > \theta_V^{NC} \quad \equiv \quad T_1(v)/\pi_2(v,v). \tag{9}$$

For $\theta \leq \theta_V^{NC}$, the optimal running royalty equals $r^{NC}(\theta) = v$ because the running royalty implied by Equation (8) exceeds v. Recall that running royalties above v are ruled out by assumption. The following lemma summarizes the equilibrium outcome for the case with a no-challenge clause.

Lemma 1. *Suppose the patent holder includes a no-challenge clause in the license contract. The running royalty $r^{NC}(\theta)$ equals v if $\theta \leq \theta_V^{NC}$. Otherwise, $r^{NC}(\theta)$ is implicitly defined by the first-order condition in Equation* (8)*. For $\theta > \theta_V^{NC}$, the running royalty $r^{NC}(\theta)$ (weakly) decreases in θ. The fixed fee is $F^{NC} = \pi\left(r^{NC}(\theta), r^{NC}(\theta)\right) - \left(\theta\pi\left(v, r^{NC}(\theta)\right) + (1-\theta)\pi(0,0)\right)$.*

Proof. See Appendix A. ☐

The result of Lemma 1 replicates the result of Farrell and Shapiro (2008). The running royalty $r^{NC}(\theta)$ weakly decreases in θ and is characterized by the optimality condition in Equation (8).

License terms absent a no-challenge clause. We first compare the license contract with a no-challenge $\left\{F^{NC}, r^{NC}\right\}$ characterized in Lemma 1 to the license contract $\left\{F_{NI}^{nNC}, r_{NI}^{nNC}\right\}$ that, absent a no-challenge clause, induces the licensees financially to not challenge the patent (challenge-avoidance pricing). Recall that the risk of patent invalidation is zero in both cases, which implies that only differences in the royalty rates affect the consumer surplus. Absent a no-challenge clause, the relevant outside option is $\pi(0,0) - L^{\mathcal{C}} \leq \pi(r,r) - F$ (Equation (3)). As derived in the proof of Lemma A.2 in Appendix A, the patent holder chooses the running royalty in order to

$$\max_r \; G_{NI}^{nNC} \quad = \max_r \quad \left[T(r) - \pi(0,0) + L^{\mathcal{C}}\right]. \tag{10}$$

In contrast to the case with a no-challenge clause, the downstream firm's outside option in this case is independent of the running royalty because in the event of a successful challenge no downstream firm has to pay royalty rates. Consequently, the patent holder sets $r_{NI}^{nNC} = v$ in order to maximize the total profit $T(r)$ per downstream firm.

Comparing the license rates of the two contracts yields that a ban of a no-challenge clause (weakly) increases the running royalty to the level of the cost savings v under challenge-avoidance pricing. In particular, in the interval $\theta \in \left(\theta_V^{NC}, \tilde{\theta}\right)$ the patent holder charges strictly higher running royalties absent a no-challenge clause than with a no-challenge clause.[26] Consumer prices are therefore also strictly higher without a no-challenge clause. Below θ_V^{NC}, consumer surplus is unaffected by a ban of a no-challenge clause but it shifts profits from the patent holder to the licensees as they are financially incentivized to not challenge the patent absent a no-challenge clause (see Lemma 1). We summarize in

Proposition 2. *A ban of a no-challenge clause leads to (weakly) higher running royalties at the level of v and consumer prices if the patent holder practices challenge-avoidance pricing absent a clause.*

Proof. Direct implication of the license terms in Lemmas 1 and A.2. □

Proposition 2 highlights that a no-challenge clause can affect consumer surplus not only via its effect on the invalidation frequency but also through its effects on the license terms and prices, which complements the analysis of Miller and Gal (2015). In particular, a ban of a no-challenge clause can lead to lower consumer surplus even if the invalidation frequency remains unaffected.

Second, we compare the license contract with a no-challenge clause $\left\{F^{NC}, r^{NC}\right\}$ to the license contract that allows for a positive invalidation frequency $\left\{F_I^{nNC}, r_I^{nNC}\right\}$ (challenge-acceptance pricing). We characterize the latter license contract in Lemma A.3 in Appendix A. The derivation is qualitatively the same as in the case with a no-challenge clause (Lemma 1). The patent holder offers license rates that make the downstream firms indifferent between contract acceptance and patent infringement. The main difference is that the downstream firms have an expected profit from the contract acceptance of

$$(1-\theta)\gamma\left(\pi(0,0) - \frac{L^{\mathcal{C}}}{n}\right) + (1-(1-\theta)\gamma)(\pi(r,r) - F), \tag{11}$$

[26] For instance, for $v = 1/4$, $\gamma = 1/2$, linear demand defined in Equation (1), with $\sigma = 1/2$, and zero litigation costs $L^{\mathcal{C}} = 0$, we have $\theta_V^{NC} = 0$ and $\tilde{\theta} \approx 0.12$.

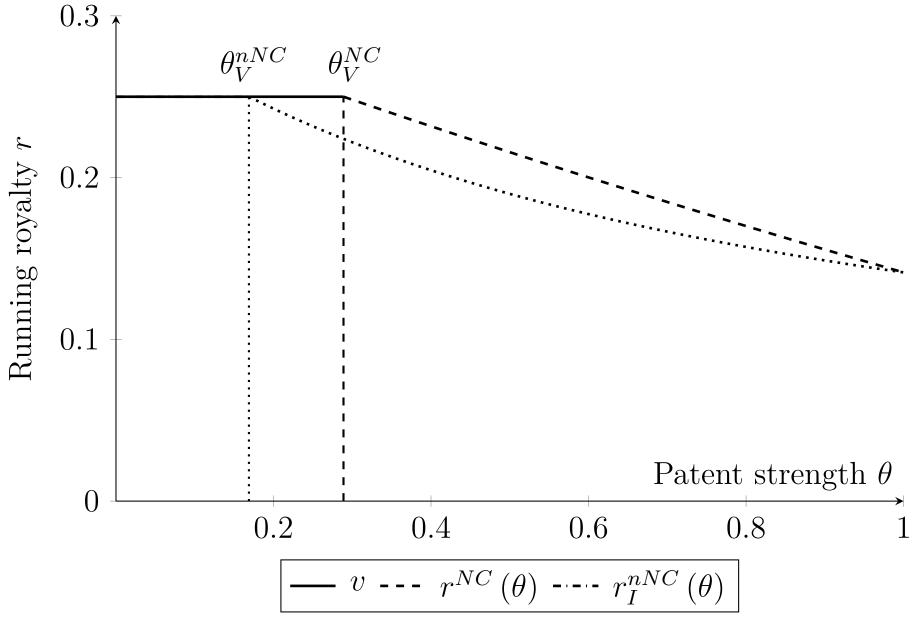
instead of the certain profit of $\pi(r,r) - F$ with a no-challenge clause (Equation (4)). We find that this difference leads to weakly lower running royalties in equilibrium absent a no-challenge clause. The patent holder's incentive to reduce the value of the downstream firms' outside options by means of low running royalties is stronger in the case of challenge-acceptance pricing than in the case with a no-challenge clause because high running royalties increase the patent holder's payoff only if the validity of the patent is not challenged. This yields

Proposition 3. *A ban of a no-challenge clause leads to (weakly) lower running royalties and consumer prices if the patent holder practices challenge-acceptance pricing absent a clause.*

Proof. See Appendix A. □

The result of Proposition 3 shows that a ban of no-challenge clauses increases consumer surplus if the patent is sufficiently strong. The probability that a wrongly-granted patent is challenged and invalidated in court increases from zero to $(1-\theta)\gamma$. In this case licensees therefore fulfill the important public role of *permitting full and free competition of ideas which are in reality a part of the public domain (Lear vs. Adkins).* A no-challenge clause effectively ensures that licensees do not challenge the validity of patents even if they would have had an incentive to challenge the patent absent this clause. Even if the patent goes unchallenged, the running royalties and consumer prices are lower than with a no-challenge clause, reducing deadweight loss. If the litigation costs L^C for challenging the patent are not too high then also social welfare also increases.

Figure 4 illustrates Proposition 3.



Equilibrium running royalties $r^{NC}(\theta)$ and $r_I^{nNC}(\theta)$ depending on θ for $n = 2$ licensees competing in prices. Marginal costs of the old technology: $v = 1/4$; signal probability: $\gamma = 6/10$; litigation costs: $L^{\mathcal{C}} = 0$. Demand is defined in Equation (1), with $\sigma = 1/2$.

Figure 4: Comparison of running royalties $r^{NC}(\theta)$ and $r_I^{nNC}(\theta)$ (Proposition 3).

3.3 Profitability of a no-challenge clause

Patent holder. Next, we establish that a patent holder always benefits from the inclusion of a no-challenge clause in the license contract, both for patents where otherwise challenge-acceptance pricing or challenge-avoidance pricing is optimal.

Proposition 4. *Implementing a no-challenge clause is strictly profitable for the patent holder for any patent strength $\theta \in (0, 1)$.*

Proof. See Appendix A. □

The proof establishes that it is more profitable for the patent holder to avoid patent invalidation by means of a no-challenge clause than by means of sufficiently favorable license fees. The reason for this result is that preventing patent challenges through challenge-avoidance pricing is costly for the patent holder. By implementing a no-challenge clause the patent holder can reduce the downstream profits from the level $\pi(0, 0) - L^{\mathcal{C}}$, which is required to avoid invalidation challenges absent a no-challenge clause (see Equation (3)), to the expected profit of infringing the patent in Equation (5).

For strong patents where—absent a no-challenge clause—the patent holder practices challenge-acceptance pricing, the logic of the proof is as follows: The patent holder's profit is higher with no challenge clause as (i) the invalidation frequency drops to zero and (ii) the running royalty is (weakly) higher than without a no-challenge clause, which increases the total profit per downstream firm $T(r)$. Both aspects increase the industry profit and ultimately result in higher profit for the patent holder.

Licensees. Gal and Miller (2017) argue that licensees would have a strong incentive to agree to no-challenge clauses, as the patent holder and licensee can benefit from externalizing the monopolistic harm onto consumers. This is true in our model for the case in which the patent gets challenged upon receiving the invalidity signal, which happens only for strong patents. Recall that the running royalty $r^{NC}(\theta)$ is weakly larger than $r_I^{nNC}(\theta)$ (Proposition 3). A downstream firm's expected profit from infringing the patent (see Equation (5)), which is the equilibrium profit in this scenario, is therefore smaller absent a no-challenge clause, because its outside option to infringe the patent is worse at smaller running royalties.

If the patent holder, however, engages in challenge-avoidance pricing absent a no-challenge clause, the downstream firms realize lower profits from the introduction of such a clause. In the absence of a no-challenge clause downstream firms obtain relatively attractive licensing terms to prevent them from challenging the patent's validity even after receiving the invalidity signal. This changes if the patent holder can insist on the inclusion of a no-challenge clause, in which case the licensees obtain a smaller share of the total profit because of a weaker outside option. The downstream firms, therefore, do not benefit from the inclusion of a no-challenge clause. This may explain the frequent disagreement between patent holders and licensees about the inclusion of no-challenge clauses in a license contract.[27] If it was in their mutual interest to include no-challenge clauses—as stipulated in Gal and Miller (2017)—we would expect such clauses to be silently included in the contracts and would accordingly expect less legal debate about their legitimacy between patent holders and licensees. We summarize this in

Corollary 1. *The downstream firms' expected profit from accepting the license contract*

[27]See, for instance, Harris (2015) documenting that Qualcomm Inc. conditioned the supply of baseband chips on a licensee's acceptance of no-challenge clauses.

is larger with a no-challenge clause if the patent holder practices challenge-acceptance pricing absent a no-challenge clause. Otherwise, the profit decreases with a no-challenge clause.

Proof. Omitted. □

3.4 Consumer surplus and welfare

The effect of a no-challenge clause on consumer surplus also depends on the patent strength. More specifically, consumers benefit from no a challenge-clause when the downstream firms suffer – and vice versa. First, consider the case of strong patents in which a licensee challenges the patent upon receiving the invalidity signal, such that there is a positive probability of patent invalidation in equilibrium. A no-challenge clause thus decreases the chance of the successful invalidation of an invalid patent and increases the running royalties. In turn, consumer prices are higher with no-challenge clauses. In this situation, consumer surplus is thus higher absent a no-challenge clause.

In stark contrast to this finding, with challenge-avoidance pricing, a ban of no-challenge clauses leaves the probability of patent invalidation at zero. Even worse, a ban of a no-challenge clause additionally changes the outside option for the downstream firms and thereby (weakly) increases the running royalty. A ban thus can increase the consumer prices, such that consumers are worse off. We summarize in

Corollary 2. *Consumer surplus is (weakly) lower with a no-challenge clause if the patent holder practices challenge-acceptance pricing absent a no-challenge clause. Otherwise, a no-challenge clause increases consumer surplus.*

Proof. Omitted. □

This finding on consumer surplus is in contrast to Miller and Gal (2015) who argue that the difference in welfare effects between contracts with and without a no-challenge boils down to the probability of a challenge. In fact, we find that a ban of a no-challenge clause can adversely affect consumer surplus and social welfare, especially if the probability of a challenge remains constant.

4 Extensions

In this section, we study how the license negotiations change if the patent holder cannot terminate the contract after a patent challenge and relate the analysis to the Supreme Court judgment in *Medimmune vs. Genentech*. Moreover, we analyze the case in which the patent holder is restricted from offering linear royalties (where $F = 0$).

4.1 Termination Clauses and MedImmune vs. Genentech

The results presented in Section 3 lead to the question as to whether one can further incentivize licensees to challenge the validity of patents. One approach that has been proposed in this direction is to remove the downsides of a patent challenge for a licensee. So far, we have assumed that the patent holder can (and optimally will) terminate the license contract of a licensee who challenges the patent. In this case, challenging a patent carries the risk of ending up with worse license terms than before the challenge if the court did not invalidate the patent.[28] This assumption is consistent with so-called termination-upon-challenge clauses that patent holder frequently include in the license contract (see Dreyfuss and Pope (2009) and Cheng (2015) for discussions of termination clauses).

In this extension, we therefore study the prohibition of termination clauses. We demonstrate, however, that this measure may not improve the invalidation frequency of wrongly-granted patents and can even lead to even less patent challenges than before. Despite the fact that the risk of challenging the patent is substantially lower absent termination clauses, the patent holder still has the incentive and the ability to avoid a patent challenge by means of favorable contract terms if the patent is weak. This challenge-avoidance pricing has the same detrimental effects on the invalidation frequency and consumer surplus as in the main analysis in Section 3. Our theory predicts that the range of patents where challenge-avoidance pricing occurs can increase as well because the judgment makes it more risky for a patent holder to engage in challenge-acceptance pricing.

Termination clauses do not affect the licensing game between the patent holder and licensees if the contract includes a no-challenge clause. Hence, we obtain the same equilibrium outcome as in Lemma 1. For the case of contracts without a no-challenge clause,

[28] This is the main reason why licensees without an invalidity signal have no incentive to challenge the patent in the main model. See Lemma A.1 in Appendix A.

we consider the following, slightly modified game:

1. The patent holder offers a non-discriminatory license contract $\{F, r\}$ to the n downstream firms.

2. Downstream firms decide whether to accept the offer.

3. Sunspot stage: a public random device selects one downstream firm with equal probability.

4. Signal stage: with probability $(1-\theta)\gamma$, a public random device selects one downstream firm that receives the invalidity signal. With probability $1-(1-\theta)\gamma$, no downstream firm receives the signal.

5. Each licensee decides whether to challenge the patent. If a challenge is not successful, the licensee continues to rely on the initial contract. If it is successful, all downstream firms can use the new technology free of charge.

6. Payoffs realize.

This variant of the game allows us to study the effects of prohibiting termination clauses in a simple environment. To facilitate equilibrium selection, we introduce the sunspot stage, which is independent of the fundamentals of the game. In this variant of the game, licensees do not lose the initial contract if they unsuccessfully challenge the patent. Note that the outcome is equivalent to that in Section 3 if a challenge is only feasible with contract termination.

To ensure that a patent challenge can be a relevant decision for the licensees after they have accepted the contract, we replace Assumption 1 with

Assumption 4. $L^{\mathcal{C}} < \frac{(1-\gamma)(1-\theta)\theta}{1-\gamma(1-\theta^2)}\left(\pi\left(0,0\right)-\pi\left(v,v\right)\right).$

For higher litigation costs, the patent holder's problem is essentially the same as in the main model because licensees without a signal do not challenge the patent: either the licensee with a signal challenges the patent or no licensee does so.

For the case that a licensee receives the invalidity signal, we focus on the subgame perfect equilibrium in which only this licensee challenges the patent if that is profitable. Absent the invalidity signal, we focus on the subgame perfect equilibrium in which only the licensee in the spotlight (Stage 3) challenges the patent if this is profitable.

There are three relevant cases to distinguish:

1. Complete challenge-avoidance pricing: the patent holder offers a contract such that no licensee has an incentive to challenge the patent.

2. Partial challenge-acceptance pricing: the patent holder offers a contract such that licensees without an invalidity signal have no incentive to challenge the patent, but a licensee with a signal challenges the patent.

3. Complete challenge-acceptance pricing: the patent holder offers a contract such that every licensee has an incentive to challenge the patent after contract acceptance.

Case 1: Complete challenge-avoidance pricing. In this case, it must be that no licensee in Stage 5 wants to challenge the patent even if one of them has received the invalidity signal. The patent holder has to offer a contract such that

$$\pi(r,r) - F \geq \pi(0,0) - L^{\mathcal{C}}, \tag{12}$$

in order to completely avoid a patent challenge. This is the same constraint as in Lemma A.2 and therefore also gives rise to the same contract offer.

Case 2: Partial challenge-acceptance pricing. This is the case in which only an informed licensee with the invalidity signal has an incentive to challenge the patent. There are two conditions to construct this equilibrium.

First, if there is no invalidity signal, the selected licensee in the sunspot stage 3 must not have an incentive to challenge the patent even though no other licensee challenges the patent:

$$\begin{aligned}
\pi(r,r) - F &\geq \frac{\theta}{\theta + (1-\theta)(1-\gamma)}(\pi(r,r) - F) + \left(1 - \frac{\theta}{\theta + (1-\theta)(1-\gamma)}\right)\pi(0,0) - L^{\mathcal{C}} \\
\Rightarrow F &\leq \pi(r,r) - \pi(0,0) + \frac{(1-\gamma(1-\theta))}{(1-\theta)(1-\gamma)}L^{\mathcal{C}}.
\end{aligned} \tag{13}$$

Note that it is public knowledge whether a licensee has received the invalidity signal. This implies that the licensees can update their beliefs about the patent's validity to $\theta / \left(\theta + (1-\theta)(1-\gamma)\right)$.

Second, a licensee with invalidity signal must have an incentive to challenge, provided that all uniformed licensees do not challenge the patent:

$$\pi(r,r) - F < \pi(0,0) - L^{\mathcal{C}}. \tag{14}$$

This implies that the patent holder achieves partial-challenge acceptance if it makes an uniformed licensee indifferent to challenging the patent in the event that no invalidity signal occurs. Assumption 4 on the litigation costs $L^{\mathcal{C}}$ ensures that downstream firms are willing to accept the contract (instead of rejecting and infringing the patent) if they receive this profit level.

The patent holder sets the fixed fee such that the condition in Equation (13) holds with equality. Note that if (13) holds with equality, the condition in (14) also holds. In this case an uniformed licensee has no incentive to challenge that patent, but in case one licensee receives the invalidity signal the patent will be challenged. Inserting the fixed fee in the patent holder's profit function yields

$$G_{PCAc}^{nNC}(r,\theta) = \left(\theta + (1-\theta)(1-\gamma)\right)\left(T(r) - \pi(0,0) + \frac{\left(1-\gamma(1-\theta)\right)L^{\mathcal{C}}}{(1-\theta)(1-\gamma)}\right), \tag{15}$$

where $PCAc$ stands for partial-challenge acceptance. The patent holder receives a positive profit only if no licensee receives the invalidity signal, which occurs with probability $\left(\theta + (1-\theta)(1-\gamma)\right)$. By the same arguments as in Section 3.2, the patent holder sets the resulting running royalty r in order to maximize the total profit per downstream firm $T(r)$ as the remaining part of the objective function does not depend on r. This implies $r_{PCAc}^{nNC} = v$ and thereby that the same running royalty and consumer prices emerge as in Lemma A.2 if the patent remains unchallenged.

Case 3: Complete challenge-acceptance pricing. Next, suppose that the patent holder offers a contract that does not fulfill the condition in (13). The best alternative to contract acceptance is either to use the old technology and anticipate that a licensee will challenge the patent (see Section 2) or to infringe the patent. Both alternatives yield an expected profit of $\theta\pi(v,r)+(1-\theta)\pi(0,0)$. Each downstream firm has the same chance to end up as the licensee that challenges the patent hence each downstream firm has expected litigation costs of $L^{\mathcal{C}}/n$ at the stage of contract acceptance. A downstream firm therefore accepts the license contract if

$$\begin{aligned} \theta\left(\pi\left(r,r\right)-F\right)+\left(1-\theta\right)\pi\left(0,0\right)-\frac{L^{\mathcal{C}}}{n} &\geq \theta\pi\left(v,r\right)+\left(1-\theta\right)\pi\left(0,0\right) \\ \Rightarrow \pi\left(r,r\right)-F-\frac{L^{\mathcal{C}}}{\theta n} &\geq \pi\left(v,r\right) \\ \Rightarrow F &\leq \pi\left(r,r\right)-\pi\left(v,r\right)-\frac{L^{\mathcal{C}}}{\theta n}. \end{aligned} \tag{16}$$

Again, the patent holder makes the downstream firms indifferent to their outside option by setting the fixed fee such that the condition in Equation (16) holds with equality. Note that all downstream firms accept the offer in equilibrium, anticipating that the patent will be challenged after contract acceptance. The resulting expected profit of the patent holder is

$$\begin{aligned} G^{nNC}_{CCAc}\left(r\right) &= \theta\cdot\left(r\cdot x\left(r,r\right)+F\right) \\ &= \theta\cdot\left(T\left(r\right)-\pi\left(v,r\right)\right)-\frac{L^{\mathcal{C}}}{n}, \end{aligned} \tag{17}$$

where $CCAc$ stands for complete challenge-acceptance pricing. The corresponding first-order condition is $T_1(r)-\pi_2(v,r)=0$. Denote the corresponding running royalty r^{nNC}_{CCAc} which is the same as with no-challenge clauses reported in Lemma A.3 if the patent strength converges to $\theta\to 1$.

We summarize the results on the contracts absent a no-challenge clause in

Proposition 5. *Suppose that a licensee can continue to rely on the initial contract if a patent challenge is unsuccessful (MedImmune).*

- *If the patent holder wants to completely avoid a challenge, it optimally offers the licensees a contract with* $r^{nNC}_{NI}=v$ *and* $F^{nNC}_{NI}=\pi(v,v)-\pi(0,0)+L^{\mathcal{C}}$.
- *In the case of partial challenge-acceptance pricing, the patent holder sets* $r^{nNC}_{PCAc}=v$ *and* $F^{nNC}_{PCAc}=\pi(v,v)-\pi(0,0)+\frac{(1-(1-\theta)\gamma)L^{\mathcal{C}}}{(1-\gamma)(1-\theta)}$.

- *In the case of full challenge-acceptance pricing, it optimally offers a contract with* $r^{nNC}_{CCAc}(1)$ *and* $F^{nNC}_{CCAc} = \pi\left(r^{nNC}_{CCAc}(1), r^{nNC}_{CCAc}(1)\right) - \pi\left(v, r^{nNC}_{CCAc}(1)\right) - \frac{L^{\mathcal{C}}}{\theta n}$.

Proof. See the derivations above. □

In the cases of both challenge-avoidance pricing and partial challenge-acceptance pricing, we obtain that the patent holder sets the running royalty as high as possible, that is at v, the cost savings of the new technology. The only difference between the contracts is that the patent holder charges a different fixed fee.[29] If the patent holder decides on either of these pricing strategies we therefore obtain the same result, that running royalties and consumer prices are higher than with a no-challenge clause given that the patent is not invalidated.

Based on the parametric example of Figure 3, we find that the patent holder prefers to engage in challenge-avoidance pricing if the patent strength is $\theta < 0.57$.[30] Recall that the threshold value for the model analyzed in Section 3 (see Figure 3) is around $\tilde{\theta} \approx 0.5$, which means that prohibiting termination clauses leads to higher incentives for a patent holder to avoid a challenge in this case. The reason is that the patent holder knows with certainty that the patent will be challenged under complete challenge-acceptance pricing, which is the patent holder's second best alternative for small litigation costs $L^{\mathcal{C}}$. As long as this is the case, the range in which the patent holder completely avoids a patent challenge even further increases up to $\theta \approx 0.63$. The reason for this increase in the threshold value is that the patent holder's profit increases in L^C with complete challenge-avoidance pricing whereas the profit decreases in L^C in the case of complete challenge-acceptance pricing (see F^{nNC}_{CCAc} in Proposition 5).[31] We summarize these findings of the parametric example in

Summary. The prohibition of termination clauses can increase the range in which the patent holder strategically avoids a patent challenge because the risk of patent invalidation makes this strategy more profitable.

[29]Inspecting yields that F^{nNC}_{PCAc} and F^{nNC}_{NI} only differ in how they are affected by the litigation costs $L^{\mathcal{C}}$, and for $L^{\mathcal{C}} = 0$ these two cases are equivalent.

[30]The specification involves $v = 1/10$, $\sigma = 3/4$, and $L^{\mathcal{C}} = 0$.

[31]For higher litigation costs, the relevant comparison is between complete challenge-avoidance and partial challenge-acceptance pricing. In this range, the threshold value decreases in $L^{\mathcal{C}}$ up to the point that the constraint on the litigation costs in Assumption 4 holds with equality. In the current specification the threshold value at the highest admissible litigation costs $L^{\mathcal{C}}$ is $\theta \approx 0.58$, which is approximately the same threshold value as in the main model at this amount of litigation costs.

We conclude that even if commentators argue that removing the downsides of a patent challenge can be beneficial, the patent holder can avoid a patent challenge in the same fashion as if the licensee loses its contract upon challenging that patent. Moreover, this complete challenge-avoidance strategy has the same adverse effects on consumer prices as before (see Section 3). Contrary to the goals of this intervention, the patent holder might adopt this strategy for an even larger range of patent strengths, leading to the unintended result that prohibiting termination clauses may reduce the frequency of successful patent challenges.

Relation to the Medimmune vs. Genentech Judgment Moreover, until recently, the actual-controversy requirement in the US posed an additional legal hurdle on a licensee to challenge a patent. In particular, a licensee in good standing was usually barred from challenging a patent's validity. Instead, it was necessary for a licensee to create an *actual controversy* in the form of terminating the license contract or withholding the royalty payments before an challenge process was possible (see *Genprobe vs. Vysis*). Comparable to the use of termination clauses, this legal requirement leads to substantial risks for the case that a licensee unsuccessfully challenges the patent.

To improve the prospects of a patent challenge, the Supreme Court ruled in the landmark case *MedImmune vs. Genentech* that also a non-repudiating licensee is allowed to challenge a patent's validity. This decision is similar in spirit to the prohibition of termination clauses. By allowing also a non-repudiating licensee to challenge a patent's validity, the Supreme Court effectively removed this potential downside from challenging the patent. As with the prohibition of termination clauses, a licensee can continue to rely on the initial contract if the patent is held valid. In fact, Dreyfuss and Pope (2009) argue that termination clauses are an effective way to restore the pre-*Medimmune* situation. Although we formally model termination clauses and not a controversy requirement, the results analogously extend to that case, so that the insights of this sectionextend to the economic analysis of this judgment.

4.2 Linear license contracts

In this extension, we analyze the effects of no-challenge clauses when the license tariffs are restricted to being linear (this implies $F = 0$). As in Farrell and Shapiro (2008), a reason for linear tariffs can be that negative fixed fees are not feasible albeit they would be optimal. We call the running royalties "pure" in this case. The proofs as well as a parametric illustration based on the linear demand specification in Equation (1) are in Online Appendix B.

As in the main analysis (Section 3), a licensee has to terminate the license contract in order to challenge the patent. Similar to the case with two-part tariffs, we demonstrate that even if it is feasible to challenge the patent (i.e., absent a no-challenge clause), there may be no challenges of weak patents in equilibrium.

If all downstream firms use the patented technology and pay a running royalty s (but no fixed fee), the patent holder generates the following profit per downstream firm:

$$\begin{aligned} R(s) &= s \cdot x(s,s) \\ &= T(s) - \pi(s,s). \end{aligned} \tag{18}$$

Analog to Assumption 3, we impose

Assumption 5. $R(s)$ *is strictly concave on the relevant range.*

Define the pure running royalty that maximizes the patent holder's profit in Equation (18) as $s^* = \arg\max_s R(s)$. We establish first that the unconstrained royalty rate s^* cannot be part of an equilibrium.

Lemma 2. *With linear tariffs, the optimal unconstrained running royalty s^* is above the monopoly level: $s^* > m \geq v$.*[32] *.*

Proof. See Online Appendix B. □

Intuitively, if the patent holder only has the running royalty s available as an instrument to generate profits, it charges higher variable license terms than with two-part tariffs, leading to double-marginalization. The downstream firms do not accept pure running royalties

[32] Recall that $m = \arg\max_r T(r)$.

that exceed the cost savings of the new technology ($s > v$) as they would prefer to infringe the patent or to use the old technology. Together with Lemma 2, this implies that the patent holder cannot set the unconstrained pure running royalty s^* that maximizes the profit in Equation (18). The patent holder therefore optimally sets the highest feasible running royalty, which is at the level at which each downstream firm is indifferent to the outside option. As with two-part tariffs, this outside option is determined by the minimum profit level which either ensures contract acceptance alone or ensures contract acceptance and, in addition, avoids a patent challenge (see the derivation at the beginning of Section 3).

Risk of invalidation. As with two-part tariffs, absent a no-challenge clause the patent holder has to decide between either low license fees (challenge-avoidance pricing) or high license fees with the risk of a patent challenge (challenge-acceptance pricing). We characterize the equilibrium challenge decision depending on the patent strength θ in

Proposition 6. *Suppose the patent holder is restricted to a linear license tariff without a no-challenge clause. The equilibrium challenge decision post contract acceptance depends on the patent strength θ as follows:*

1. *For $\theta \in (0, \underline{\theta}]$ (with $\underline{\theta}$ defined in Lemma B.1), a licensee does not challenge the patent as this would yield a lower profit than the minimum profit level under the contract.*

2. *For $\theta \in \left(\underline{\theta}, \tilde{\theta}^s\right]$ (with $\tilde{\theta}^s < 1$ defined in Equation (78)), the patent holder engages in challenge-avoidance pricing. The interval $\left(\underline{\theta}, \tilde{\theta}^s\right]$ is nonempty if the litigation costs for a patent challenge are sufficiently high: $L^C > \underline{L}^C$ (with $\underline{L}^C$ defined in Equation (77)).*

3. *For $\theta > \max\left\{\underline{\theta}, \tilde{\theta}^s\right\}$, the patent holder engages in challenge-acceptance pricing.*

Proof. See Online Appendix B. □

Similar to the case of two-part tariffs, we find that a patent will only be challenged in equilibrium if it is sufficiently strong. If the patent is weak, the licensees may not challenge the patent for one of two reasons.

- First, in the interval $\theta \in (0, \underline{\theta}]$, the profit from a patent challenge is lower than the profit from contract acceptance.[33] The threshold value $\underline{\theta}$ is the level of the patent strength at which the expected profit from patent infringement equals the profit of a patent challenge upon receiving the invalidity signal. In this interval, a licensee does not find it profitable to challenge the patent after contract acceptance. Hence, there is no trade-off for the patent holder and the license outcome is as if the contract contains a no-challenge clause.

- Second, if the profit from a patent challenge upon receiving the invalidity signal exceeds the profit of contract acceptance (for patents with $\theta > \underline{\theta}$), there exists a range of patent strengths $\theta \in \left(\underline{\theta}, \tilde{\theta}^s\right]$ in which the patent holder engages in challenge-avoidance pricing, provided that the litigation costs $L^{\mathcal{C}}$ are sufficiently large. The patent holder is indifferent between avoiding a patent challenge (NI) and not avoiding it (I) at $\theta = \tilde{\theta}^s$ (defined in Equation (78)). Only if the patent is sufficiently strong $\left(\theta > \tilde{\theta}^s\right)$ will the patent holder accept a positive invalidation risk for the benefit of giving a smaller share of the total profits to the licensees.

Comparison of linear royalty rates. We compare the royalties in a contract with a no-challenge clause $\left(s^{NC}(\theta)\right)$ to the royalties absent a no-challenge clause, for the case both with positive $\left(s_I^{nNC}(\theta)\right)$ and with zero invalidation risk $\left(s_{NI}^{nNC}\right)$. The contracts for each case are characterized in the Lemmas B.2, B.3, and B.4 in Online Appendix B. The royalty rates $s_I^{nNC}(\theta)$ and s_{NI}^{nNC} are only defined for $\theta \geq \underline{\theta}$.

Proposition 7. *Suppose the patent holder is restricted to a linear license tariff. For weak enough patents ($\theta < \underline{\theta}$, see Lemma B.1), a no-challenge clause does not affect the license outcome. For stronger patents, the following holds: If absent a no-challenge clause*

- *challenge-acceptance pricing prevails, the equilibrium royalty is higher than with a no-challenge clause: $s_I^{nNC}(\theta) > s^{NC}(\theta)$.*

- *If challenge-avoidance pricing prevails, the equilibrium royalty is independent of θ and smaller than with a no-challenge clause: $s_{NI}^{nNC} < s^{NC}(\theta)$.*

[33] Note that we exclude this case in the main analysis in Section 3 by Assumption 1. We relax this assumption in this section because, in contrast to the case of two-part tariffs, the prevalence of challenge-avoidance pricing here depends more directly on the litigation costs for a patent challenge ($L^{\mathcal{C}}$).

Proof. See Online Appendix B. □

Compared to the contract with a no-challenge clause, the patent holder charges a lower royalty if it avoids a patent challenge (NI). In contrast, if it accepts a positive invalidation risk (I), it charges a higher royalty.

Effects on welfare. The results of Propositions 6 and 7 imply ambiguous welfare effects of a no-challenge clause in the case of linear license contracts. If, absent a no-challenge clause, a patent holder engages in patent-acceptance pricing, then such a clause clearly reduces the invalidation probability (bad for welfare, as an invalid patent remains unchallenged) but royalty rates and hence consumer prices are lower in the case where no invalidation occurs (good for welfare).

In contrast, under challenge-avoidance pricing by means of a low royalty rate, a no-challenge clause reduces welfare because it leads to a higher royalty rate and thus consumer prices while leaving the invalidation frequency unaffected (at zero).

Effects on profits. With linear license contracts, the patent holder always benefits from a no-challenge clause (as with two-part tariffs). The downstream firms do not benefit from the introduction of a no-challenge clause. This is in contrast to the case of two-part tariffs where downstream firms benefit from a no-challenge clause if the patent holder engages in challenge-acceptance pricing absent the clause. This result reinforces the conclusion that licensees do not prefer the inclusion of a no-challenge clause in many cases. Again, this contrasts Gal and Miller (2017) who argue that licensees have a strong incentive to accept such clauses (see the discussion of Corollary 1 in Section 3 for the case of two-part tariffs).

To illustrate these results, consider first the case of challenge-avoidance pricing absent a no-challenge clause. Without a no-challenge clause, the licensees receive a high profit that incentivizes them to not challenge the patent. A no-challenge clause allows the patent holder to offer a lower profit level to the downstream firms and keeps the frequency of patent challenges at zero. In this case, a no-challenge clause is therefore clearly beneficial for the patent holder to the detriment of the downstream firms.

Second, the same qualitative result holds when the patent holder accepts a positive invalidation risk in equilibrium. The licensees' profit decreases for two reasons. To see this, recall that their profit in this case is

$$(1-\theta)\,\gamma\left(\pi\,(0,0)-L^{\mathcal{C}}/n\right)+(1-(1-\theta)\,\gamma)\,(\theta\pi\,(v,s)+(1-\theta)\,\pi\,(0,0))\,.$$

First, a no-challenge clauses reduces the probability of a patent challenge from $((1-\theta)\,\gamma)$ to zero. The licensees' thus do not realize the expected profit of $\pi\,(0,0)-L^{\mathcal{C}}/n$ with certainty. Second, recall that the expected profit from patent infringement, $\theta\pi\,(v,s)+(1-\theta)\,\pi\,(0,0)$, increases in the royalty rate s. As $s_I^{nNC}\,(\theta)>s^{NC}$, the expected profit of patent infringement is lower with a no-challenge clause. The licensees' profit is therefore lower with a no-challenge clause. For the same reasons, the patent holder benefits from a no-challenge clause: the patent cannot be challenged and the downstream firms' outside option is worse than without a no-challenge clause.

5 Conclusion

A major pillar of the patent system is that it should only reward novel and non-obvious inventions with patent protection. There are, however, many patents for technologies that do not fulfill these requirements and thus are invalid. Against this backdrop, the patent system heavily relies on licensees of such technologies to identify and challenge invalid patents in courts. Following this logic, the use of no-challenge clauses in technology licensing agreements are treated with great scrutiny.

We demonstrate that banning no-challenge clauses may be a futile intervention to increase the invalidation of wrongly-granted patents. This is particularly the case for weak patents where there is a large public interest in successful invalidation. In our model, we find that if a patent is weak, the patent holder finds it profitable to avoid a challenge by means of favorable license terms. Consequently, licensees do not have the incentive to serve the public interest of challenging invalid patents. Patent challenges arise in equilibrium only if the patent is sufficiently strong. These results arise under different pricing schemes; in particular, we study both linear royalty rates as well as two-part tariffs.

A ban of no-challenge clauses can even deteriorate welfare in the case of two-part license contracts. In particular, if the patent holder avoids a patent challenge (i.e., if the patent is weak), the running royalties and, hence, consumer prices can be higher than in a contract with a no-challenge clause. A ban of no-challenge clauses for weak patents is therefore welfare-decreasing in our framework.

The situation is different for strong patents where the probability of success in a patent challenge is low. Holders of such patents accept a positive invalidation risk absent a no-challenge clause. Intuitively, they do not benefit from offering higher profits to the downstream firms just to prevent relatively rare cases of successful patent challenges. We demonstrate that the running royalties for a strong patent and the resulting consumer prices are lower absent a no-challenge clause. Hence, for strong patents, consumer surplus is higher without a no-challenge clause. Social welfare can be either higher or lower, depending on the litigation costs. The dependence of the result on the patent strength is similar to Farrell and Shapiro (2008) who find stronger detrimental price effects the weaker the patent. Similarly, Palikot and Pietola (2019) predict pay-for delay settlements for strong enough patents and litigation or licensing for weaker patents. Whether a particular patent is weak or strong according to the thresholds determined by our results requires an empirical assessment. Empirical research, such as Miller (2013); Henkel and Zischka (2019), suggests that the contracting parties as well as courts have the tools available for this assessment.

We also analyze measures that are meant to improve the prospects of challenging a patent. In particular, we consider the prohibition of termination clauses and the effects of the *MedImmune vs. Genentech* Supreme Court judgment that removed the actual controversy requirement to bring a patent challenge to court. Both measures remove a major potential downside of a patent challenge because a licensee can continue to rely on the initial contract if the patent challenge is not successful. Perhaps surprisingly, we find that the basic trade-off for the patent holder remains essentially the same. For weak patents, it is profitable to avoid a patent challenge by means of favorable contract terms for the licensees and, again, this has the same price effects of increasing running royalties and consumer prices compared to a contract with no-challenge clauses. Moreover, as these measures increase the risk of a patent challenge for the patent holder, the range of patent strengths in which challenge-avoidance pricing occurs can be even larger. By taking into account the patent holder's adjustments in its license terms, we therefore show that prohibiting termination clauses as well as the *MedImmune vs. Genentech* judgment may have the unintended effect of reducing the number of patent challenges.

In summary, our results unfortunately cast doubt on the repeatedly-expressed hope that licensees fill the important role of identifying and challenging wrongly-granted patents. Our theory therefore contributes to the discussion of whether a general prohibition of no-challenge clauses, as it is expressed in Gal and Miller (2017), is socially optimal. As our analysis reveals, the ban of a no-challenge clause can lead to lower consumer surplus and social welfare, indicating that this is not the case. Our research therefore supports a rule-of-reason approach for these clauses and suggests that the patent strength should play an important role in the assessment.

References

Bessen, James and Michael J. Meurer, "The Private Costs of Patent Litigation," *Journal of Law Economics & Policy*, 2012, *9*, 59.

Bousquet, Alain, Helmuth Cremer, Marc Ivaldi, and Michel Wolkowicz, "Risk sharing in licensing," *International Journal of Industrial Organization*, 1998, *16* (5), 535 – 554.

Brenner, Melissa, "Slowing the Rates of Innovation: How the Second Circuit's Ban on No-Challenge Clauses in Pre-Litigation Settlement Agreements Hinders Business Growth," *Boston College Law Revue*, 2013, *54*, 57.

Cheng, Thomas K., "Antitrust Treatment of the No Challenge Clause," *Journal of Intellectual Property & Entertainment Law*, 2015, *5*, 437.

Choi, Jay Pil, "Live and Let Live: A Tale of Weak Patents," *Journal of the European Economic Association*, 05 2005, *3* (2-3), 724–733.

Dreyfuss, Rochelle C. and Lawrence S. Pope, "Dethroning Lear-Incentives to Innovate after MedImmune," *Berkeley Technological Law Journal*, 2009, *24*, 971 – 1007.

Encaoua, David and Yassine Lefouil, "Licensing Weak Patents," *The Journal of Industrial Economics*, 2009, *57* (3), 492–525.

Farrell, Joseph and Carl Shapiro, "How Strong are Weak Patents?," *American Economic Review*, 2008, *98* (4), 1347–1369.

— **and Robert P. Merges**, "Incentives to challenge and defend patents: Why litigation won't reliably fix patent office errors and why administrative patent review might help," *Berkeley Technological Law Journal*, 2004, *19*, 943.

Gal, Michal S. and Alan D. Miller, "Patent Challenge Clauses: A New Antitrust Offense?," *Iowa Law Review*, 2017, *102*, 1477 – 1532.

Goldstucker, Richard W., "Stop the Bleeding: MedImmune Ends the Unjustified Erosion of Patent Holders' Rights in Patent Licensing Agreements," *Journal of Intellectual Property Law*, 2008, *16*, 137.

Hall, Bronwyn H. and Dietmar Harhoff, "Recent Research on the Economics of Patents," *Annual Review of Economics*, 2012, *4* (1), 541–565.

Harris, Stephen, "An overview of the NDRC decision in the qualcomm investigation," *Antitrust Chronicle*, 2015, *7.*

Hegde, Deepak, "Tacit Knowledge and the Structure of License Contracts: Evidence from the Biomedical Industry," *Journal of Economics & Management Strategy*, 2014, *23* (3), 568–600.

Henkel, Joachim and Hans Zischka, "How many patents are truly valid? Extent, causes, and remedies for latent patent invalidity," *European Journal of Law and Economics*, Oct 2019, *48* (2), 195–239.

Kesan, Jay P. and Andres A. Gallo, "Why Bad Patents Survive in the Market and How Should We Change-The Private and Social Costs of Patents," *Emory LJ*, 2006, *55*, 61.

Lemley, Mark A. and Carl Shapiro, "Probabilistic Patents," *Journal of Economic Perspectives*, June 2005, *19* (2), 75–98.

Miller, Alan D. and Michal S. Gal, "Licensee patent challenges," *Yale Journal on Regulation*, 2015, *32*, 121 – 160.

Miller, Shawn P., "Where's the Innovation: An Analysis of the Quantity and Qualities of Anticipated and Obvious Patents," *Virgina Journal of Law & Technology*, 2013, *18* (1).

Palikot, Emil and Matias Pietola, "Pay-for-delay with settlement externalities," *Working Paper*, 2019.

Rostoker, Michael D., "A survey of corporate licensing," *IDEA*, 1983, *24*, 59.

Schankerman, Mark and Florian Schuett, "Patent Screening, Innovation, and Welfare," *Review of Economic Studies*, forthcoming.

Server, Alfred C. and Peter Singleton, "Licensee Patent Validity Challenges Following MedImmune: Implications for Patent Licensing," *Hastings Science and Technology Law Journal*, 2011, *3*, 243–.

A Appendix: Proofs of Section 3

Derivation of the results of Proposition 1

In this section, we derive the result of Proposition 1 as follows:

1. We derive as an auxiliary result that only a licensee with an invalidity signal can have an incentive to challenge the patent (Lemma A.1).
2. We derive the patent holder's contract offers for the cases in which it
   (a) avoids a patent invalidation by means of financial incentives for the licensees (Lemma A.2);
   (b) accepts that a licensee challenges the patent upon receiving the invalidity signal (Lemma A.3).
3. We compare the profit for the patent holder under the two scenarios and derive that the former contract offer dominates the latter if the probability of the invalidity signal $(1-\theta)\,\gamma$ is large.

Lemma A.1 (Step 1). *Suppose all downstream firms accepted the license contract. A licensee with the invalidity signal can have an incentive to challenge the patent. Any licensee without the invalidity signal does not challenge the patent.*

Proof of Lemma A.1. We derive the result of Lemma A.1 in two steps. First, we analyze the incentives of a licensee with an invalidity signal and second the incentives of a licensee without a signal.

First, suppose licensee D_i has received the invalidity signal yielding conclusive evidence that the patent is invalid. Recall that a court will invalidate the patent with certainty in light of this evidence. Hence, the licensee D_i knows that a patent challenge yields the profit of $\pi\,(0,0) - L^{\mathcal{C}}$ as stated in Equation (3). Hence, for every contract offer $\{F, r\}$ yielding a lower profit for the licensee, the licensee will challenge and thereby invalidate the patent. For instance, if the patent holder offers license terms that make licensees indifferent between contract acceptance and patent infringement at the contract acceptance stage, a licensee will challenge the patent if it receives the invalidity signal. Recall from Equation (5) that the expected profit from infringing the patent is

$$\theta \cdot \pi(v, r) + (1-\theta) \cdot \pi(0,0). \tag{19}$$

Under Assumption 1, it holds that this expected profit is lower than the profit from challenging the patent with certainty about the patent invalidity in Equation (3).

Second, the case for a licensee without the invalidity signal is different. Recall that the contract offer has to grant a minimum expected profit (Equation (19)) in order to ensure contract acceptance. For a lower expected profit a licensee is not willing to accept the contract. If a licensee does not receive the invalidity signal, it rationally updates its belief about the patent strength and expects the patent to be valid with a probability larger than θ. According to Bayes rule, the conditional probability that the patent is valid if a downstream firm does not receive the invalidity signal is

$$\begin{aligned} P(\text{valid}|i \text{ receives no signal}) &= \frac{P(i \text{ receives no signal}|\text{valid}) \cdot P(\text{valid})}{P(i \text{ receives no signal})} \\ &= \frac{1 \cdot \theta}{1 \cdot \theta + (1-\theta)\gamma\frac{n-1}{n} + (1-\theta)(1-\gamma)} \\ &= \frac{\theta}{1-(1-\theta)\frac{1}{n}\gamma} > \theta. \end{aligned} \tag{20}$$

The denominator is smaller than one. Recall that a licensee has to terminate the license contract in order to challenge the patent. Hence, the expected profit of challenging the patent without an invalidity signal is

$$\frac{\theta}{1-(1-\theta)\frac{1}{n}\gamma} \cdot \pi(v, r) + \left(1 - \frac{\theta}{1-(1-\theta)\frac{1}{n}\gamma}\right) \cdot \pi(0,0) - L^{\mathcal{C}}. \tag{21}$$

As an uninformed licensee is less optimistic about the success of patent challenge, this yields a lower expected profit than the expected profit in Equation (19), which is the minimal profit level to ensure contract acceptance. Hence, whenever a licensee has accepted the contract offer but has not received the invalidity signal, it has no incentive to challenge the patent. This establishes the result. □

Lemma A.2 (Step 2 (a))**.** *Suppose there is no no-challenge clause. If challenge-avoidance* *pricing prevails, the patent holder optimally charges the running royalty* $r_{NI}^{nNC} = v$ *and the fixed fee* $F_{NI}^{nNC} = \pi(v,v) - \pi(0,0) + L^{\mathcal{C}}$ *for all* $\theta \in (0,1)$.

Proof of Lemma A.2. Let the superscript nNC indicate that the license contract does not contain a no-challenge clause and let the subscript NI indicate that licensees have financial incentives to not challenge and thereby invalidate the patent even upon receiving the invalidity signal. The patent holder maximizes its profit per downstream firm $G_{NI}^{nNC} = r \cdot x(r,r) + F$ under the constraints that all downstream firms accept the contract:

$$\pi(r,r) - F \geq \theta\pi(v,r) + (1-\theta)\pi(0,0), \tag{22}$$

and no licensee finds it profitable to challenge the patent even if it gets the invalidity signal:

$$\pi(r,r) - F \geq \pi(0,0) - L^{\mathcal{C}}. \tag{23}$$

By Assumption 1, Condition (23) implies Condition (22). This implies that the patent holder's problem is to

$$\begin{aligned} \max_{\{F,r\}} G_{NI}^{nNC} &= r \cdot x(r,r) + F \qquad (24)\\ s.t \qquad & \pi(r,r) - F \geq \pi(0,0) - L^{\mathcal{C}}. \end{aligned}$$

The latter constraint yields an optimal fixed fee of

$$F_{NI}^{nNC} = \pi(r,r) - \pi(0,0) + L^{\mathcal{C}}, \tag{25}$$

which makes each licensee indifferent between relying on the license contract and challenging the patent upon receiving the invalidity signal. Inserting the fixed fee from Equation (25) in Equation (24) yields the following reduced maximization problem for the patent holder:

$$\max_{r} G_{NI}^{nNC} = T(r) - \pi(0,0) + L^{\mathcal{C}}. \tag{26}$$

Under Assumption 3, G_{NI}^{nNC} is strictly concave in r. As in the above expression only $T(r)$ depends on the running royalty r , this implies that the patent holder sets the running royalty such that it attains the highest possible total profit per downstream firm. According to Assumption 3 and the restriction $r \leq v \leq m$, this implies that the ensuing running royalty is $r_{NI}^{nNC} = v$. Inserting $r_{NI}^{nNC} = v$ in Equation (25) yields $F_{NI}^{nNC} = \pi(v, v) - \pi(0, 0) + L^{\mathcal{C}}$. This establishes the result. □

Lemma A.3 (Step 2 (b))**.** *Suppose there is no no-challenge clause. If challenge-acceptance pricing prevails, a licensee that receives the invalidity signal challenges the patent. The patent holder optimally sets the running royalty*

$$r_I^{nNC}(\theta) = \begin{cases} v & \text{if } \theta < \theta_V^{nNC}, \\ \bar{r}_I^{nNC}(\theta) & \text{if } \theta \geq \theta_V^{nNC}, \end{cases} \tag{27}$$

where the royalty $\bar{r}_I^{nNC}(\theta)$ is implicitly defined by the first-order condition

$$T_1\left(\bar{r}_I^{nNC}(\theta)\right) - \frac{\theta \pi_2\left(v, \bar{r}_I^{nNC}(\theta)\right)}{1 - (1-\theta)\gamma} = 0, \tag{28}$$

and it decreases in $\theta \in \left(\theta_V^{nNC}, 1\right)$. The threshold value θ_V^{nNC} is defined in Equation (37)*. The fixed fee is*

$$\begin{aligned} F_I^{nNC} &= \pi\left(r_I^{nNC}(\theta), r_I^{nNC}(\theta)\right) \\ &\quad - \frac{\theta \pi\left(v, r_I^{nNC}(\theta)\right) + (1-\theta)(1-\gamma)\pi(0,0) + (1-\theta)\frac{\gamma}{n}L^{\mathcal{C}}}{1-(1-\theta)\gamma}. \end{aligned} \tag{29}$$

Proof of Lemma A.3. Together with Assumption 1, the lemma's requirement that the downstream firms are indifferent between contract acceptance and patent infringement implies that a licensee challenges (and thereby invalidates) the patent upon receiving the invalidity signal. Formally, this implies that the patent holder is only bound by the downstream firms' contract-acceptance constraints and Equation (22) holds with equality. Under the same reasoning as above, the condition in Equation (23) is therefore violated. We denote the equilibrium outcomes in this case with subscript I. The patent holder's problem is thus:

$$\max_{\{F,r\}} G_I^{nNC} = (1-(1-\theta)\gamma)(r\cdot x(r,r)+F) \tag{30}$$

$$\begin{aligned} s.t. \quad & \theta\pi(v,r)+(1-\theta)\pi(0,0) \\ = \; & \underbrace{(1-\theta)\gamma\left(\pi(0,0)-L^{\mathcal{C}}/n\right)}_{D_i \text{ exp. profit if patent challenged}} + \underbrace{(1-(1-\theta)\gamma)(\pi(r,r)-F)}_{D_i \text{ exp. profit if patent not challenged}}. \end{aligned} \tag{31}$$

If the patent remains valid, which occurs with probability $(1-(1-\theta)\gamma)$, the patent holder realizes a positive profit of $r\cdot x(r,r)+F$. With the complementary probability $(1-\theta)\gamma$, the patent is invalid, one licensee D_i receives the invalidity signal, and the patent is invalidated in court. In this event, the patent holder realizes a profit of zero. The right-hand side of Equation (31) contains a licensee's expected profit from accepting the contract. In equilibrium, a licensee is indifferent to its outside option of patent infringement (left-hand side of Equation 31).

Suppose a downstream firm expects the other $n-1$ downstream firms to accept the contract offer. The fixed fee that solves Condition (31) is

$$F_I^{nNC} = \pi(r,r) - \frac{\theta\pi(v,r)+(1-\theta)(1-\gamma)\pi(0,0)+(1-\theta)\frac{\gamma}{n}L^{\mathcal{C}}}{1-(1-\theta)\gamma}. \tag{32}$$

Inserting F_I^{nNC} in Equation (30) yields the patent holder's reduced problem to maximize $G_I^{nNC}(r,\theta)$ with respect to r, where

$$G_I^{nNC}(r,\theta) = (1-(1-\theta)\gamma)\left(T(r) - \frac{\theta\pi(v,r)+(1-\theta)(1-\gamma)\pi(0,0)+(1-\theta)\frac{\gamma}{n}L^{\mathcal{C}}}{1-(1-\theta)\gamma}\right). \tag{33}$$

Under Assumptions 2 and 3, $G_I^{NC}(r,\theta)$ is strictly concave in r. The first-order condition characterizes the running royalty $\bar{r}_I^{nNC}(\theta)$ that maximizes G_I^{nNC}:

$$G_{I,1}^{nNC}(r,\theta) = T_1\left(\bar{r}_I^{nNC}(\theta)\right) - \frac{\theta}{1-(1-\theta)\gamma}\pi_2\left(v,\bar{r}_I^{nNC}(\theta)\right) = 0, \tag{34}$$

which is the term reported in Equation (28) in the lemma.

Totally differentiating Equation (34) yields

$$\frac{d\bar{r}_I^{nNC}(\theta)}{d\theta} = \frac{(1-\gamma)\,\pi_2\left(v, \bar{r}_I^{nNC}(\theta)\right)}{\left(1-(1-\theta)\gamma\right)^2 G_{I,11}^{nNC}} \leq 0. \tag{35}$$

The change of $\bar{r}_I^{nNC}(\theta)$ with respect to θ is weakly negative as (i) $\pi_2(v,r) \geq 0$ under Assumption 2 (the inequality is strict if $\pi_2(v,r) > 0$), and (ii) the second-order derivative of the patent holder's profit with respect to the running royalty, $G_{I,11}^{nNC}(r,\theta)$, is negative at $\bar{r}_I^{nNC}(\theta)$ due to Assumptions 2 and 3.

For a small enough θ, it is possible that the running royalty $\bar{r}_I^{nNC}(\theta)$ implied by Equation 34 exceeds the cost savings from the new technology v. Due to the restriction that the running royalty cannot exceed v, there exists a threshold value on the patent strength below which the running royalty equals v, and above which it is determined by the first-order condition in Equation (34). The threshold value θ_V^{nNC} is thus defined by

$$T_1(v) - \frac{\theta_V^{nNC}\pi_2(v,v)}{1-(1-\theta_V^{nNC})\gamma} = 0. \tag{36}$$

Rearranging yields

$$\theta_V^{nNC} \equiv \frac{(1-\gamma)\,T_1(v)}{\pi_2(v,v)-\gamma T_1(v)}. \tag{37}$$

If the patent strength is below θ_V^{nNC}, the patent holder optimally charges a running royalty equal to the cost savings of the new technology (v). We therefore define the equilibrium running royalty as

$$r_I^{nNC}(\theta) = \begin{cases} v & \text{if } \theta < \theta_V^{nNC}, \\ \bar{r}_I^{nNC}(\theta) & \text{if } \theta \geq \theta_V^{nNC}. \end{cases} \tag{38}$$

Inserting the equilibrium running royalty from Equation (38) into Equation 32 yields the equilibrium fixed fee reported in the lemma. □

Proof of Proposition 1 (Step 3). Based on Lemma A.2 and Lemma A.3, we compare the profitability of both contract offers for the patent holder. If the patent holder avoids a patent challenge (subscript NI), it offers the contract $r_{NI}^{nNC} = v$ and $F_{NI}^{nNC} = \pi(v,v) -$

$\pi(0,0)+L^{\mathcal{C}}$ (Lemma A.2) and its (certain) profit is

$$\begin{aligned} G_{NI}^{nNC} &= vx(v,v)+\pi(v,v)-\pi(0,0)+L^{\mathcal{C}} \\ &= T(v)-\pi(0,0)+L^{\mathcal{C}}, \end{aligned} \tag{39}$$

which is independent of the patent strength θ and the signal probability γ. Moreover, it holds that this profit is strictly positive as

$$T(v)-\pi(0,0)+L^{\mathcal{C}} \;>\; T(0)-\pi(0,0)+L^{\mathcal{C}}=L^{\mathcal{C}}\geq 0, \tag{40}$$

where the first inequality follows from the fact that $T(r)$ increases in the interval $[0,v]$, and the equality follows from $T(0)=\pi(0,0)$ as there is no double marginalization at $r=0$.

The expected profit that the patent holder obtains if it does not disincentivize a patent challenge when a downstream firm learns about the invalidity (subscript I, see Equation (33) in Lemma A.3) is

$$\begin{aligned} & G_I^{nNC}\left(r_I^{nNC}(\theta),\theta\right) \\ =\;& (1-(1-\theta)\gamma)\,T\left(r_I^{nNC}(\theta)\right) \\ -\;& \left(\theta\pi\left(v,r_I^{nNC}(\theta)\right)+(1-\theta)(1-\gamma)\pi(0,0)+(1-\theta)\frac{\gamma}{n}L^{\mathcal{C}}\right). \end{aligned} \tag{41}$$

The equilibrium profit $G_I^{nNC}\left(r_I^{nNC}(\theta),\theta\right)$ in Equation (41) changes in θ according to

$$\underbrace{\frac{\partial G_I^{nNC}\left(r_I^{nNC}(\theta),\theta\right)}{\partial r_I^{nNC}(\theta)}\frac{\partial r^{nNC}(\theta)}{\partial\theta}}_{=0}+\frac{\partial G_I^{nNC}\left(r_I^{nNC}(\theta),\theta\right)}{\partial\theta}. \tag{42}$$

Note that the first term $\left(\partial G_I^{nNC}\left(r_I^{nNC}(\theta),\theta\right)/\partial r_I^{nNC}(\theta)\right)$ is equal to zero, whenever the equilibrium running royalty $r_I^{nNC}(\theta)$ is determined by the patent holder's first-order condition, as is the case for $\theta>\theta_V^{nNC}$. Moreover, the second term $\left(\partial r_I^{nNC}(\theta)/\partial\theta\right)$ is zero for $\theta\leq\theta_V^{nNC}$ as then the running royalty is invariant to θ and equal to v. Hence, the total change of G_I^{nNC} in θ is given by the partial derivative

$$\begin{aligned} & \frac{\partial G_I^{nNC}\left(r_I^{nNC}(\theta),\theta\right)}{\partial\theta} \\ = \quad & \gamma\left(T\left(r_I^{nNC}(\theta)\right)-\pi(0,0)\right)+\pi(0,0)-\pi\left(v,r_I^{nNC}(\theta)\right)+\frac{\gamma}{n}L^{\mathcal{C}}, \end{aligned} \tag{43}$$

which is larger than zero for all $\theta \in (0,1)$. To see this note that (i) $T\left(r_I^{nNC}(\theta)\right)-\pi(0,0) = T\left(r_I^{nNC}(\theta)\right)-T(0) > 0$, (ii) $\pi(0,0) > \pi\left(v, r_I^{nNC}(\theta)\right)$, and (iii) $L^{\mathcal{C}} \geq 0$. Hence, the patent holder's profit $G_I^{nNC}\left(r_I^{nNC}(\theta),\theta\right)$ increases in θ.

Toward establishing which contract offer is optimal for the patent holder, note from the above that:

- $G_I^{nNC}\left(r_I^{nNC}(\theta),\theta\right)$ increases monotonically in θ, and
- G_{NI}^{nNC} is constant in θ.

Given the monotonicity of $G_I^{nNC}\left(r_I^{nNC}(\theta),\theta\right)$, there is at most one intersection in the relevant range $\theta \in (0,1)$. We show that $G_I^{nNC}\left(r_I^{nNC}(\theta),\theta\right)$ and G_{NI}^{nNC} intersect once in $\theta \in (0,1)$. Call the intersection $\tilde{\theta}$. This implies that $G_I^{nNC}\left(r_I^{nNC}(\theta),\theta\right) < G_{NI}^{nNC}$ for $\theta < \tilde{\theta}$, and greater otherwise.

We first establish that it is profitable to avoid a patent challenge for weak patents ($G_{NI}^{nNC} > G_I^{nNC}$ for $\theta \to 0$). For $\theta \to 0$, Equation (41) becomes

$$G_I^{nNC}\left(r_I^{nNC}(0),0\right) = (1-\gamma)\left(T(v)-\pi(0,0)\right). \tag{44}$$

Recall that $r_I^{nNC}(0) = v$ and $L^{\mathcal{C}} = 0$ due to Assumption 1. At $\theta \to 0$, the condition $G_{NI}^{nNC} > G_I^{nNC}$ implies$\gamma > 0$. This result implies that for patents that are invalid almost surely, the patent holder strictly prefers to engages in challenge-avoidance pricing.

Next, we show that for $\theta \to 1$ it is never profitable for the patent holder to offer the contract G_{NI}^{nNC}. Equation (41) in this case becomes

$$G_I^{nNC}\left(r_I^{nNC}(1),1\right) = T\left(r_I^{nNC}(1)\right)-\pi\left(v,r_I^{nNC}(1)\right).$$

With $\theta \to 1$, the condition $G_I^{nNC} > G_{NI}^{nNC}$ holds if

$$T(v) - \pi(0,0) + L^{\mathcal{C}} < T\left(r_I^{nNC}(1)\right) - \pi\left(v, r_I^{nNC}(1)\right) \tag{45}$$
$$\Rightarrow \quad [T(v) - \pi(v,v)] + L^{\mathcal{C}} < \left[T\left(r_I^{nNC}(1)\right) - \pi\left(v, r_I^{nNC}(1)\right)\right] + [\pi(0,0) - \pi(v,v)],$$

where the second line follows from subtracting $\pi(v,v)$ on both sides of Equation (45). We compare the terms on both sides of the inequality and note that it holds for the following reasons:

- As $r_I^{nNC}(1) \in \arg\max_r\ T(r) - \pi(v,r)$ it holds that $T(v) - \pi(v,v) < T\left(r_I^{nNC}(1)\right) - \pi\left(v, r_I^{nNC}(1)\right)$ if $r_I^{nNC}(1) < v$. Note that the last inequality holds if $\pi_2(v,r) > 0$.
- By Assumption 1, the litigation costs $L^{\mathcal{C}}$ are smaller than $\pi(0,0) - \pi(v,v)$.

The left-hand side of the condition in Equation (45) is thus strictly smaller than the right-hand side. It follows that for $\theta \to 1$, $G_I^{nNC} > G_{NI}^{nNC}$.

We conclude that there exists a threshold value $\tilde{\theta} \in (0,1)$ such that the patent holder profitably avoids a patent challenge if $\theta < \tilde{\theta}$. The threshold value is defined by

$$G_I^{nNC}\left(r_I^{nNC}\left(\tilde{\theta}\right), \tilde{\theta}\right) = G_{NI}^{nNC}. \tag{46}$$

This establishes the result. □

Proof of Lemma 1

Proof. We prove that the running royalty $r^{NC}(\theta)$ weakly decreases in θ in the range $\theta > \theta_V^{NC}$, where the running royalty is defined by the first-order condition in Equation (8). The remaining results of the lemma are derived in the main text above the lemma.

Total differentiation of Equation (8) yields the comparative static

$$\frac{dr^{NC}(\theta)}{d\theta} = \pi_2\left(v, r^{NC}(\theta)\right) / G_{11}^{NC}\left(r^{NC}(\theta), \theta\right) \leq 0. \tag{47}$$

In the range $\theta > \theta_V^{NC}$, the change of $r^{NC}(\theta)$ with respect to θ is negative as (i) $\pi_2(v,r) \geq 0$ under Assumption 2, and (ii) the second-order derivative of the patent holder's profit with respect to the running royalty, $G_{11}^{NC}(r,\theta)$, is negative at $r^{NC}(\theta)$ due to Assumptions 2 and 3. This establishes the result. □

Proof of Proposition 3

Proof. We prove the result by separating the range of $\theta \in (0,1)$ in three intervals.

1. First, for a small $\theta \in \left(0, \theta_V^{nNC}\right]$, both running royalties, with and without a no-challenge clause, are equal to the cost savings of the new technology: $r_I^{nNC}(\theta) = r^{NC}(\theta) = v$.

2. Second, there exists an intermediate interval $\theta \in \left(\theta_V^{nNC}, \theta_V^{NC}\right]$ of patent strengths θ in which $r_I^{nNC}(\theta) < r^{NC}(\theta) = v$.

3. Third, for a large θ, both running royalties are strictly smaller than v, but it still holds that $r_I^{nNC}(\theta) < r^{NC}(\theta)$.

The **first step** is to show that $r_I^{nNC}(\theta) = r^{NC}(\theta) = v$ in the interval $\theta \in \left(0, \theta_V^{nNC}\right]$. The threshold value θ_V^{nNC} is defined in Equation (28) in Lemma A.3, and for $\theta < \theta_V^{nNC}$, it holds that $r_I^{nNC} = v$. We verify that $\theta_V^{nNC} < \theta_V^{NC}$ for $\gamma > 0$. This argument has three steps.

1. Note that θ_V^{NC} is constant in γ (Equation (9)).

2. We show that $\theta_V^{nNC} = \theta_V^{NC}$ at the endpoint of $\gamma = 0$.

3. We show that θ_V^{nNC} decreases monotonically in $\gamma \in (0,1)$.

From the first-order condition in Equation (28) in Lemma A.3, the threshold value θ_V^{nNC} is defined by

$$T_1(v) - \frac{\theta_V^{nNC}\pi_2(v,v)}{1-\left(1-\theta_V^{nNC}\right)\gamma} = 0. \tag{48}$$

Rearranging yields the expression

$$\theta_V^{nNC} = \frac{(1-\gamma)\,T_1(v)}{\pi_2(v,v) - \gamma T_1(v)}, \tag{49}$$

which is also reported in Equation (37).

Note that for $\gamma = 0$, the threshold value equals the one from the case with a no-challenge clause, that is, $\theta_V^{nNC} = \theta_V^{NC} = T_1(v)/\pi_2(v,v)$ (Equation (9)). The derivative of $\theta_V^{nNC}(\gamma)$ with respect to γ is

$$\begin{aligned}\frac{\partial \theta_V^{nNC}(\gamma)}{\partial \gamma} &= \frac{-T_1(v)(\pi_2(v,v) - \gamma T_1(v)) - (1-\gamma) T_1(v)(-T_1(v))}{(\pi_2(v,v) - \gamma T_1(v))^2} \\ &= \frac{T_1(v)(T_1(v) - \pi_2(v,v))}{(\pi_2(v,v) - \gamma T_1(v))^2} < 0.\end{aligned} \tag{50}$$

The derivative is negative because $T_1(v) < \pi_2(v,v)$, which follows from the first-order condition in Equation (34). The fact that the derivative is negative implies that $\theta_V^{nNC}(\gamma)$ decreases monotonically in γ.

The **second step** applies to the intermediate interval of $\theta \in \left(\theta_V^{nNC}, \theta_V^{NC}\right]$. In this interval, under the definition of θ_V^{NC} (Equation (9)) and θ_V^{nNC} (Equation (37)), the running royalty $r_I^{nNC}(\theta)$ is strictly below v and $r^{NC}(\theta)$ is equal to v. This implies that $r_I^{nNC}(\theta) < r^{NC}(\theta) = v$ for $\theta \in \left(\theta_V^{nNC}, \theta_V^{NC}\right]$.

The **last step** applies to the case of patents with strength $\theta \in \left(\theta_V^{NC}, 1\right)$. In this range, both running royalties $r_I^{nNC}(\theta)$ and $r^{NC}(\theta)$ are determined by the patent holder's respective first-order condition (Equations (8) and (28)):

$$T_1\left(r^{NC}(\theta)\right) - \theta \cdot \pi_2\left(v, r^{NC}(\theta)\right) = 0, \tag{51}$$

$$(1 - (1-\theta)\gamma) \cdot T_1\left(r_I^{nNC}(\theta)\right) - \theta \cdot \pi_2\left(v, r_I^{nNC}(\theta)\right) = 0. \tag{52}$$

Note that the first-order condition in Equation (52), evaluated at the running royalty r^{NC} that solves Equation (51), collapses to $-(1-\theta) \cdot \gamma \cdot T_1\left(r_I^{nNC}(\theta)\right) < 0$. Hence, the patent holder has an incentive to charge a lower running royalty than r^{NC} absent a no-challenge clause. Together with Assumption 2, which ensures a unique solution to the patent holder's maximization problem, we conclude that $r_I^{nNC}(\theta) < r^{NC}(\theta)$ in the interval $\theta \in \theta_V^{NC}(0,1)$. This establishes the result. $\square$

Proof of Proposition 4

Proof. We verify that it is always profitable for the patent holder to insert a no-challenge clause in the license contract if possible. To this end, we compare the patent holder's equilibrium contract for the cases with and without a no-challenge clause. For the interval $\theta \in \left(0, \theta^{nNC}\right]$, we have $r^{NC}(\theta) = r_I^{nNC}(\theta) = r_{NI}^{nNC}(\theta) = v$. The patent holder's profit without a no-challenge clause is

$$T(v) - \left(\pi(0,0) - L^{\mathcal{C}}\right), \tag{53}$$

if it prevents patent invalidation and

$$(1 - (1-\theta)\gamma) T(v) - (\theta\pi(v,v) + (1-\theta)\pi(0,0)), \tag{54}$$

if it does not. If the contract specifies a no-challenge clause, the patent holder's profit is

$$T(v) - (\theta\pi(v,v) + (1-\theta)\pi(0,0)). \tag{55}$$

The profit level in (55) is larger than the profit levels in Equations (53) and (54). First note that $\pi(0,0) - L^{\mathcal{C}} > \theta\pi(v,v) + (1-\theta)\pi(0,0)$ by Assumption 1 which implies that the profit in (55) is larger than the one in (53). Second, the only difference between the profit levels in Equations (54) and (55) is the invalidation probability $(1-\theta)\gamma$ and hence the patent holder realizes a higher profit in (55) than in (54).

Next, consider the interval $\theta \in \left(\theta^{nNC}, 1\right)$. Suppose first that it is profitable for the supplier to restrict invalidation of the patent absent a no-challenge clause. If the patent holder can implement a no-challenge clause, its profit is

$$T\left(r^{NC}(\theta)\right) - \left(\theta\pi\left(v, r^{NC}(\theta)\right) + (1-\theta)\pi(0,0)\right). \tag{56}$$

By revealed preferences, the patent holder prefers to charge a running royalty of $r^{NC} < v$ instead of v and its profit is thus larger than $T(v) - (\theta\pi(v,v) + (1-\theta)\pi(0,0))$. Moreover, the latter profit is larger than $T(v) - \left(\pi(0,0) - L^{\mathcal{C}}\right)$, which is the profit from preventing invalidation by means of licensing fees.

Second, suppose that it is not profitable for the supplier to restrict invalidation of the patent. Recall that in this interval $r_I^{nNC}(\theta) < r^{NC}(\theta) \leq v$. Then, the profit without a no-challenge clause is

$$\begin{aligned} & (1-(1-\theta)\gamma)\, T\left(r_I^{nNC}(\theta)\right) \\ - & \left(\theta\pi\left(v, r_I^{nNC}(\theta)\right) + (1-\theta)\,\pi(0,0) - (1-\theta)\,\gamma\left(\pi(0,0) - L^{\mathcal{C}}\right)\right). \end{aligned} \tag{57}$$

Note that a no-challenge clause corresponds to $\gamma = 0$ and that this changes the patent holder's profit to

$$T\left(r_I^{nNC}(\theta)\right) - \left(\theta\pi\left(v, r_I^{nNC}(\theta)\right) + (1-\theta)\,\pi(0,0)\right), \tag{58}$$

holding the running royalty fixed at $r^{nNC}(\theta)$. This change increases the profit by $(1-\theta)\,\gamma T\left(r_I^{nNC}(\theta)\right)$ and decreases the profit by $(1-\theta)\,\gamma\left(\pi(0,0) - L^{\mathcal{C}}\right)$. Due to the fact that

$$T\left(r_I^{nNC}(\theta)\right) > T(0) = 0 \cdot x(0,0) + \pi(0,0) \geq \pi(0,0) - L^{\mathcal{C}}, \tag{59}$$

it holds that the increase in profit outweighs the decrease. Moreover, by revealed preferences to charge a running royalty of r^{NC} instead of $r_I^{nNC}(\theta)$ and it thus holds that

$$\begin{aligned} & T\left(r^{NC}(\theta)\right) - \left(\theta\pi\left(v, r^{NC}(\theta)\right) + (1-\theta)\,\pi(0,0)\right) \\ \geq\ & T\left(r_I^{nNC}(\theta)\right) - \left(\theta\pi\left(v, r_I^{nNC}(\theta)\right) + (1-\theta)\,\pi(0,0)\right). \end{aligned} \tag{60}$$

Hence, we conclude that the patent holder prefers to insert a no-challenge clause in the license contract for any patent strength $\theta \in (0,1)$. This establishes the result. $\square$

B Online appendix: Linear license tariffs

Proof of Lemma 2

Proof. Recall that the patent holder's objective function is $R^{NC}(s) = s \cdot x(s,s) = T(s) - \pi(s,s)$. The pure running royalty that maximizes the unconstrained maximization problem of the patent holder solves the first-order condition

$$R_1^{NC}(s) = T_1(s) - (\pi_1(s,s) + \pi_2(s,s)) = 0. \tag{61}$$

Denote with s^* the optimal pure running royalty implicitly defined by Equation (61). Note that the first derivative of R^{NC}, evaluated at the monopoly running royalty m, is

$$R_1^{NC}(m) = -(\pi_1(m,m) + \pi_2(m,m)) > 0, \tag{62}$$

which is positive under the assumption that $\pi_1(a,a) + \pi_2(a,a) < 0$. Due to the fact that $R^{NC}(s)$ is single-peaked, this implies that $s^* > m$, which establishes the result. □

Proof of Proposition 6

We prove Proposition 6 in five steps. In the section with linear tariffs, it is necessary to allow for litigation costs for a patent challenge $L^{\mathcal{C}}$ that violate Assumption 1. The reason is that the prevalence of challenge-avoidance pricing depends more directly on the litigation costs for a patent challenge $L^{\mathcal{C}}$ than in the main model with two-part tariffs.

1. As a preliminary result, we first characterize the range of patent strengths θ for which the introduction of a no-challenge clause changes the license outcome. The range depends on $L^{\mathcal{C}}$.

2. We characterize the optimal contract offer for which licensees do not challenge the patent. This occurs either because litigation costs for a patent challenge $L^{\mathcal{C}}$ are prohibitively large or because the license contract includes a no-challenge clause.

The next steps focus on contracts without a no-challenge clause:

3. We characterize the contract for which a licensee that obtains the invalidity signal challenges the patent (challenge-avoidance pricing).

4. We characterize the contract that financially ensures that no licensee has the incentive to do so (challenge-acceptance pricing).

5. We compare the patent holder's profits with both challenge-avoidance and challenge-acceptance pricing to derive the threshold value on the patent strength above which the patent holder prefers to accept a positive invalidation risk.

Lemma B.1 (Step 1)**.** *If the patent strength θ satisfies*

$$\theta \quad > \quad \underline{\theta} = \frac{L^{\mathcal{C}}}{\pi\left(0,0\right) - \pi\left(v,s\right)}, \tag{63}$$

a patent challenge yields higher profit than the expected profit from patent infringement. For $\theta \leq \underline{\theta}$, licensees do not have an incentive to challenge the patent after contract acceptance and Assumption 1 is violated.

Proof of Lemma B.1. For given litigation costs $L^{\mathcal{C}}$, there can exist a range of patent strengths θ for which a patent challenge yields a lower profit than the minimum profit level that ensures contract acceptance. In particular, a patent challenge yields lower profit than patent infringement if

$$\pi\left(0,0\right) - L^{\mathcal{C}} \quad \leq \quad \theta\pi\left(v,s\right) + \left(1-\theta\right)\pi\left(0,0\right). \tag{64}$$

The condition holds for

$$\theta \leq \underline{\theta} = \frac{L^{\mathcal{C}}}{\pi\left(0,0\right) - \pi\left(v,s\right)}. \tag{65}$$

If $\underline{\theta} < 0$, a patent challenge yields higher profit than the (expected) profit from patent infringement for all $\theta \in (0,1)$. For $\underline{\theta} > 1$, the litigation costs for a patent challenge $L^{\mathcal{C}}$ are prohibitively high, such that patent infringement yields higher profit than a patent challenge independent of how strong the patent is. Assumption 1 is violated in the interval $\theta \in (0, \underline{\theta}]$. This establishes the result. □

Lemma B.2 (Step 2)**.** *Suppose the patent holder is restricted to a linear license tariff and includes a no-challenge clause (or the costs of a patent challenge $L^{\mathcal{C}}$ are prohibitively high). The optimal running royalty is $s^{NC}(\theta)$, which is implicitly defined in Equation* (66) *and increases in θ.*

Proof of Lemma B.2. Suppose that a patent challenge is not feasible or is prohibitively costly after contract acceptance. Denote by $s^{NC}(\theta)$ the pure running royalty that makes a downstream firm indifferent between contract acceptance and its outside option of patent infringement:

$$\pi\left(s^{NC}(\theta), s^{NC}(\theta)\right) = \theta\pi\left(v, s^{NC}(\theta)\right) + (1-\theta)\,\pi(0,0). \tag{66}$$

Implicit differentiation of Equation (66) yields

$$\frac{ds^{NC}(\theta)}{d\theta} = -\frac{\pi(0,0) - \pi\left(v, s^{NC}(\theta)\right)}{\pi_1\left(\bar{s}^{NC}(\theta), s^{NC}(\theta)\right) + \pi_2\left(s^{NC}(\theta), s^{NC}(\theta)\right) - \theta\pi_2\left(v, s^{NC}(\theta)\right)} > 0. \tag{67}$$

The denominator is negative due to the assumptions that $\pi_2(a,b) > 0$ and $\pi_1(a,a) + \pi_2(a,a) < 0$. The nominator is positive as $\pi(0,0) > \pi\left(v, s^{NC}(\theta)\right)$. Taken together, these observations imply that the running royalty $\bar{s}^{NC}(\theta)$ increases in θ if it is implicitly defined by (66). This establishes the result. □

Lemma B.3 (Step 3)**.** *Suppose the patent holder is restricted to a linear license tariff absent a no-challenge clause. If challenge-acceptance pricing prevails, the optimal running royalty is $s_I^{nNC}(\theta)$, which is implicitly defined in Equation* (69) *and increases in θ.*

Proof of Lemma B.3. We focus on $\theta > \underline{\theta}$ (threshold defined in Lemma B.1), such that a patent challenge can alter the license outcome. If a licensee challenges the patent upon receiving the invalidity signal, the patent holder obtains the expected profit

$$\begin{aligned} R_I(s) &= (1-(1-\theta)\gamma)\, s \cdot x(s,s) \qquad (68)\\ &= (1-(1-\theta)\gamma)\,(T(s) - \pi(s,s)), \end{aligned}$$

where I stands for the case absent a no-challenge clause in which a licensee challenges and invalidates the patent upon receiving the invalidity signal. Due to the fact that the only difference to the objective function $R(s)$ in Equation (18) is the pre-multiplied term $(1-(1-\theta)\gamma)$, we conclude that also R_I is single-peaked in s and the unconstrained solution to the patent holder's maximization problem exceeds the monopoly running royalty, as derived in Lemma 2.

Denote the running royalty $s_I^{nNC}(\theta)$ that makes the downstream firms indifferent to patent infringement

$$\begin{aligned} & (1-(1-\theta)\gamma)\,\pi\left(s_I^{nNC}(\theta), s_I^{nNC}(\theta)\right)+(1-\theta)\gamma\left(\pi(0,0)-\frac{L^{\mathcal{C}}}{n}\right) \\ = \; & \theta\pi\left(v, s_I^{nNC}(\theta)\right)+(1-\theta)\,\pi(0,0), \end{aligned} \tag{69}$$

where the first line is the expected profit of contract acceptance and second line the outside option of patent infringement. Recall that a licensee has an incentive to challenge the patent if it receives the invalidity signal in this case as $\theta > \underline{\theta}$.

We show that the running royalty $s_I^{nNC}(\theta)$ implied by Equation (69) increases monotonically in θ. Note that this royalty decreases in $L^{\mathcal{C}}$ because it reduces the expected profit from contract acceptance. Moreover, implicit differentiation of Equation (69) yields

$$\begin{aligned} & \frac{ds_I^{nNC}(\theta)}{d\theta} = \\ - & \frac{\gamma\pi\left(s_I^{nNC}(\theta), s_I^{nNC}(\theta)\right)+(1-\gamma)\,\pi(0,0)-\pi\left(v, s_I^{nNC}(\theta)\right)+\frac{\gamma}{n}L^{\mathcal{C}}}{(1-(1-\theta)\gamma)\left(\pi_1\left(s_I^{nNC}(\theta), s_I^{nNC}(\theta)\right)+\pi_2\left(s_I^{nNC}(\theta), s_I^{nNC}(\theta)\right)\right)-\theta\pi_2\left(v, s_I^{nNC}(\theta)\right)} > 0. \end{aligned} \tag{70}$$

The denominator is negative due to the assumption that $\pi_2(a,b) > 0$ and $\pi_1(a,a) + \pi_2(a,a) < 0$. The nominator is positive as the convex combination of $\pi\left(s_I^{nNC}(\theta), s_I^{nNC}(\theta)\right)$ and $\pi(0,0)$ is larger than $\pi\left(v, s^{NC}(\theta)\right)$ for all $\gamma \in (0,1)$, and the litigation costs $L^{\mathcal{C}}$ are also (weakly) positive. This implies that the pure running royalty $s_I^{nNC}(\theta)$ increases in θ. This establishes the result. □

Lemma B.4 (Step 4). *Suppose the patent holder is restricted to a linear license tariff absent a no-challenge clause. If challenge-avoidance pricing prevails and if $\theta > \underline{\theta}$ (defined in Lemma B.1), the running royalty s_{NI}^{nNC} solves Equation* (71) *with equality, is independent of θ, and increases in $L^{\mathcal{C}}$.*

Proof. As derived in Lemma B.1, only for $\theta > \underline{\theta}$ a patent challenge can alter the license outcome. A downstream firm, which has obtained the invalidity signal, decides to not challenge the patent if

$$\pi(0,0) - L^{\mathcal{C}} \leq \pi(s,s). \tag{71}$$

The optimal running royalty s_{NI}^{nNC} solves (71) with equality and is independent of the patent strength θ. If licensees do not incur litigation costs when challenging the patent $\left(L^{\mathcal{C}} = 0\right)$, the patent holder is not able to enforce running royalties above zero. As $\pi(s,s)$ decreases in s, the equilibrium running royalty s_{NI}^{nNC} increases in $L^{\mathcal{C}}$. This establishes the result. □

Proof of Proposition 6 (Step 5). We characterize a licensee's challenge decision for the three intervals of θ defined in the proposition in turn.

First interval: For $\theta < \underline{\theta}$ (defined in Lemma B.1), the patent holder optimally behaves as if the license contract contains a no-challenge clause, charges $s = s^{NC}$ as characterized in Lemma B.2, and realizes a profit of

$$R^{NC}\left(s^{NC}(\theta)\right) = s^{NC} \cdot x\left(s^{NC}(\theta), s^{NC}(\theta)\right). \tag{72}$$

For $\theta \geq \underline{\theta}$, a patent challenge yields higher profits than the expected profit from contract acceptance. If $\underline{\theta} < 1$, the patent holder has to decide whether to avoid a patent challenge or not. We show that two cases can arise in this interval:

- Case 1: Challenge-avoidance pricing never occurs.
- Case 2: Challenge avoidance pricing occurs in an intermediate interval of patent strengths and for stronger patents the patent holder engages in challenge-acceptance pricing.

First, we characterize the case in which challenge-avoidance pricing never occurs. The patent holder's profit in the case of challenge avoidance is

$$R_{NI}^{nNC}\left(s_{NI}^{nNC}\right) = s_{NI}^{nNC} \cdot x\left(s_{NI}^{nNC}, s_{NI}^{nNC}\right), \tag{73}$$

which is independent of the patent strength θ. Moreover, the patent holder's profit from challenge-acceptance pricing

$$R_I^{nNC}\left(s_I^{nNC}(\theta);\theta\right)=(1-(1-\theta)\gamma)\,s_I^{nNC}(\theta)\cdot x\left(s_I^{nNC},s_I^{nNC}\right), \tag{74}$$

which (weakly) increases in θ. This profit changes in θ according to

$$\frac{R_I^{nNC}\left(s_I^{nNC}(\theta);\theta\right)}{\partial\theta}=\gamma R^{NC}\left(s_I^{nNC}(\theta)\right)+(1-(1-\theta)\gamma)\frac{\partial R^{NC}\left(s_I^{nNC}(\theta)\right)}{\partial s_I^{nNC}}\frac{\partial s_I^{nNC}(\theta)}{\partial\theta}\geq 0. \tag{75}$$

The derivative in Equation (75) is positive due to the fact that $\partial s_I^{nNC}(\theta)/\partial\theta\geq 0$ (derived in Lemma B.3) and $\partial R^{NC}\left(s_I^{nNC}(\theta)\right)/\partial s_I^{nNC}>0$ (Lemma 2 together with the assumption that $s\cdot x(s,s)$ is single-peaked on the relevant range). This implies that if challenge-acceptance pricing is more profitable than challenge-avoidance pricing for at $\theta=\underline{\theta}$, it also holds for the entire range of θ that the patent holder does not engage in patent-avoidance pricing.

Formally, challenge-avoidance pricing does not occur if

$$\begin{aligned} R_{NI}^{nNC}\left(s_{NI}^{nNC}\right) &= s_{NI}^{nNC}\cdot x\left(s_{NI}^{nNC},s_{NI}^{nNC}\right) & (76)\\ &< (1-(1-\underline{\theta})\gamma)\left(s_I^{nNC}(\underline{\theta})\cdot x\left(s_I^{nNC}(\underline{\theta}),s_I^{nNC}(\underline{\theta})\right)\right)=R_I^{nNC}\left(s_I^{nNC}(\underline{\theta})\right). \end{aligned}$$

If this condition does not hold, there exists a range of patent strengths $\theta>\underline{\theta}$ such that the patent holder engages in challenge-avoidance pricing.

The case distinction depends on the litigation costs for a patent challenge ($L^{\mathcal{C}}$). Recall from Lemma B.4 that s_{NI}^{nNC} increases in $L^{\mathcal{C}}$ as long at it is below v. In particular, Equation (71) shows that s_{NI}^{nNC} approaches v if $L^{\mathcal{C}}\to\pi(0,0)-\pi(v,v)$. Due to the fact that $s_I^{nNC}(\theta)$ can be at most equal to v (the cost savings of the new technology), we conclude that Condition (76) is violated for high litigation costs $L^{\mathcal{C}}$. If $s_I^{nNC}(\underline{\theta})\leq s_{NI}^{nNC}=v$, it holds that $R_{NI}^{nNC}\left(s_{NI}^{nNC}\right)>R_I^{nNC}\left(s_I^{nNC}(\underline{\theta})\right)$ due to the fact there is no invalidation risk in the challenge-avoidance case and a (weakly) higher royalty rate increases the patent holder's profit. By continuity in $L^{\mathcal{C}}$, the condition also holds for a range of litigation costs of a patent challenge below $\pi(0,0)-\pi(v,v)$. Denote by $\underline{\mathbf{L}}^{\mathcal{C}}$ the smallest element in the support of $L^{\mathcal{C}}$ that fulfills Condition (76) with equality. As s_{NI}^{nNC} increases in $L^{\mathcal{C}}$, provided that $L^{C} < \pi(0,0) - \pi(v,v)$, and $s_{I}^{nNC}(\theta)$ (weakly) decreases in $L^{\mathcal{C}}$ (see Lemma B.3), the threshold $\underline{\mathrm{L}}^{\mathcal{C}}$ is uniquely defined by

$$R_{NI}^{nNC}\left(s_{NI}^{nNC}\right) = R_{I}^{nNC}\left(s_{I}^{nNC}\left(\underline{\theta}\right)\right). \tag{77}$$

Hence, we can summarize: If the litigation costs for a patent challenge are sufficiently small $L^{\mathcal{C}} < \underline{\mathrm{L}}^{\mathcal{C}}$, the patent holder engages in challenge-acceptance pricing for all $\theta > \underline{\theta}$ (Case 1). If the litigation costs are larger, there exists a range of patent strengths above $\underline{\theta}$ in which the patent holder engages in challenge-avoidance pricing (Case 2).

Next, we characterize the interval of intermediate patent strengths in which the patent holder engages in challenge-avoidance pricing if $L^{\mathcal{C}} > \underline{\mathrm{L}}^{\mathcal{C}}$. Recall from above that the patent holder's profit without challenge, R_{NI}^{nNC}, is independent of the patent strength for $\theta \in (\underline{\theta}, 1)$, and the profit with challenge-acceptance pricing R_{I}^{nNC} increases in θ.

Hence, if $L^{\mathcal{C}} > \underline{\mathrm{L}}^{\mathcal{C}}$, there exists a threshold value $\tilde{\theta}^{s}$ such that the patent holder is indifferent between avoiding a patent challenge (NI) and accepting a positive invalidation risk (I) in particular, at $\theta = \tilde{\theta}^{s}$, it holds that

$$R_{I}^{nNC}\left(s_{I}^{nNC}\left(\tilde{\theta}^{s}\right); \tilde{\theta}^{s}\right) = R_{NI}^{nNC}\left(s_{NI}^{nNC}\right). \tag{78}$$

For stronger patents $\theta > \tilde{\theta}^{s}$, the patent holder prefers to engage in challenge-acceptance pricing.

Last, we show that $\tilde{\theta}^{s}$ lies in the relevant interval $(\underline{\theta}, 1)$. By conditioning $L^{\mathcal{C}} > \underline{\mathrm{L}}^{\mathcal{C}}$, it holds that $\tilde{\theta}^{s} > \underline{\theta}$. Furthermore, $\tilde{\theta}^{s}$ needs to be smaller than 1 as for $\theta \to 1$, $R_{NI}^{nNC}\left(s_{NI}^{nNC}\right) < R_{I}^{nNC}\left(s_{I}^{nNC}(1)\right)$. The reason why this inequality holds is that, in both cases, the invalidation risk is zero and $s_{I}^{nNC}(1) = v$ takes the highest admissible value. This establishes the result. □

Proof of Proposition 7

Proof. Suppose that $\theta > \underline{\theta}$, such that a patent challenge yields higher profit than patent infringement. First, we compare the license fees $s^{NC}(\theta)$ and $s_{I}^{nNC}(\theta)$ (see Lemmas B.2

and B.3) to show that $s^{NC}(\theta) < s_I^{nNC}(\theta)$.

Recall that both running royalties are derived from a condition which sets each downstream firm indifferent between contract acceptance and the outside option of patent infringement instead of using the old technology (see Lemma B.3). With a no-challenge clause, this implies

$$\theta\pi\left(v, s^{NC}(\theta)\right) + (1-\theta)\,\pi(0,0) \;=\; \pi\left(s^{NC}(\theta), s^{NC}(\theta)\right). \tag{79}$$

We show that, for the case a without no-challenge clause, the downstream firm's outside option is slack at the running royalty $s^{NC}(\theta)$. In this case, the expected profit from contract acceptance is

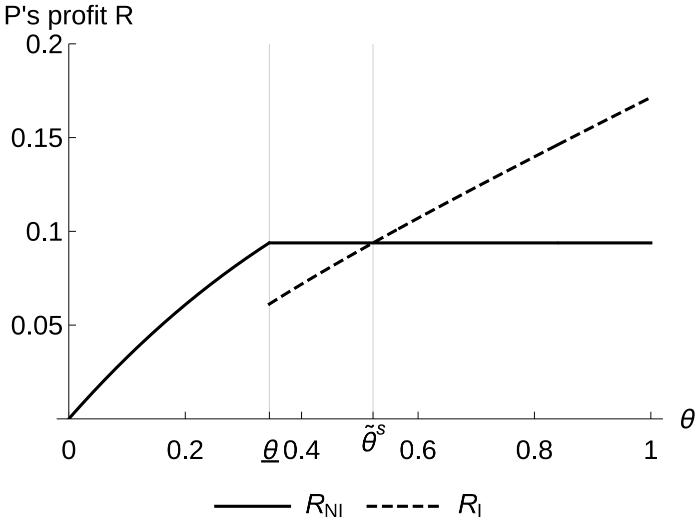
$$(1-(1-\theta)\gamma)\,\pi\left(s^{NC}(\theta), s^{NC}(\theta)\right) + (1-\theta)\gamma\left(\pi(0,0) - \frac{L^{\mathcal{C}}}{n}\right) \;>\; \pi\left(s^{NC}(\theta), s^{NC}(\theta)\right),$$

as the convex combination of $\pi\left(s^{NC}(\theta), s^{NC}(\theta)\right)$ and $\pi(0,0) - \frac{L^{\mathcal{C}}}{n}$ is larger than $\pi\left(s^{NC}(\theta), s^{NC}(\theta)\right)$ because $\pi(0,0) - \frac{L^{\mathcal{C}}}{n} > \theta\pi\left(v, s^{NC}(\theta)\right) + (1-\theta)\,\pi(0,0)$ for $\theta > \underline{\theta}$. The latter inequality holds because $\underline{\theta}$ is defined such that for $\theta > \underline{\theta}$ the profit of a patent challenge is larger than the expected profit of patent infringement. Hence, the patent holder charges a higher running royalty rate $s_I^{nNC}(\theta)$ if it accepts a positive invalidation risk compared to the royalty rate under a no-challenge clause, that is $s^{NC}(\theta)$. As the outside option of patent infringement increases in s, the downstream firms realize a higher expected profit absent a no-challenge clause.

Second, we compare the license contracts $s^{NC}(\theta)$ and s_{NI}^{nNC} (characterized in Lemmas B.2 and B.3). In both cases, the invalidation frequency is zero and the downstream firms realize with certainty $\pi\left(s^{NC}(\theta), s^{NC}(\theta)\right)$ and $\pi\left(s_{NI}^{nNC}, s_{NI}^{nNC}\right)$, respectively. The only difference is that, for $\theta > \underline{\theta}$, the downstream firms' outside option is larger absent a no-challenge clause. With linear license contracts, the only way to grant higher profits to the downstream firms is by reducing the royalty rate. Hence, we obtain $s^{NC}(\theta) < s_{NI}^{nNC}$. In this case, the downstream firms' profits are also larger absent a no-challenge clause. This establishes the result. $\square$

Parametric Example

Patent holder's profit. Figure 5 provides a parametric example of the results of Proposition 6 when the litigation costs for a patent challenge $L^{\mathcal{C}}$ exceed the threshold value $\underline{\mathrm{L}}^{\mathcal{C}}$. We compare the patent holder's profit when there is no invalidation in equilibrium (R_{NI}) with the expected profit that it receives when it accepts that a licensee challenges the patent upon receiving the invalidity signal (R_I).



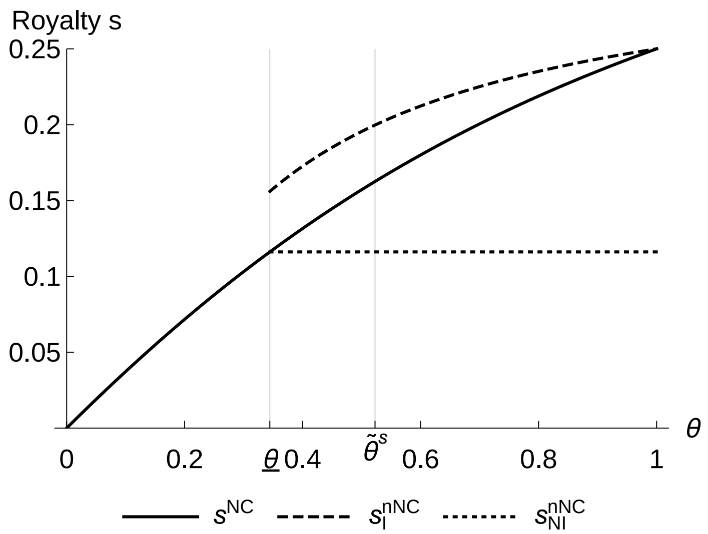
The figure shows the patent holder's (expected) profit depending on the patent strength θ and depending on whether the license contract is such that a licensee challenges the patent upon receiving the invalidity signal (R_I) or not (R_{NI}) for the case of $n = 2$ licensees competing in prices. Marginal cost of the old technology: $v = 1/4$, litigation costs: $L^{\mathcal{C}} = 2/100$; signal probability: $\gamma = 3/4$. The threshold $\underline{\theta}$ is defined in Lemma B.1 and $\tilde{\theta}^s$ is defined in Eq. (78). Demand is defined in Equation (1), with $\sigma = 3/4$.

Figure 5: Patent holder's profit with linear tariffs in invalidation (I) and no invalidation (NI) case.

For weak patents ($\theta \leq \underline{\theta}$), the patent holder does not face the risk of a patent challenge and its profit R_{NI} (solid line) increases in θ due to the fact that stronger patents reduce the downstream firms' outside option of infringing the patent which permits a higher running royalty. For stronger patents ($\theta > \underline{\theta}$), the patent holder can avoid a patent challenge only by giving a sufficiently high profit of $\pi(0,0) - L^{\mathcal{C}}$ to the licensees. Accordingly, in this range of θ, R_{NI} is constant. Alternatively, the patent holder can extract a larger share of total profits but thereby accepts a positive invalidation risk. The profit R_I (dashed line) is defined for $\theta \in (\underline{\theta}, 1)$ and increases in the patent strength θ. There exists a threshold $\tilde{\theta}^s$ at which the patent holder's profit with patent-acceptance pricing R_I surpasses the profit level R_{NI} of avoiding a challenge. For very strong patents ($\theta \to 1$), the risk of patent invalidation as well as the licensees' outside option are small whereas the profit level for the downstream firms to avoid a patent challenge $\pi(0,0) - L^{\mathcal{C}}$ remains at the same high level. As a result, the patent holder accepts a positive invalidation risk for strong patents $\theta > \tilde{\theta}^s$.

If the litigation costs for a patent challenge $L^{\mathcal{C}}$ are below the threshold value $\underline{L}^{\mathcal{C}}$, the intermediate interval $\theta \in \left(\underline{\theta}, \tilde{\theta}^s\right]$, in which the patent holder strategically avoids a patent challenge, is empty. For small values of $L^{\mathcal{C}}$, the royalty rate s_{NI}^{nNC} and the corresponding profit R_{NI} are small, such that this strategy is not profitable. In this case, a patent challenge is either not profitable for the licensees after contract acceptance ($\theta \leq \underline{\theta}$) or the patent holder accepts a patent challenge with positive probability in equilibrium ($\theta > \underline{\theta}$).

License terms. The next figure summarizes the result of Proposition 7 on the pure running royalties.[34] The solid line represents the pure royalty for the case with a no-challenge clause $s^{NC}(\theta)$ and is defined for all patent strengths $\theta \in (0,1)$. It increases in the patent strength because a stronger patent implies a worse outside option at the contract acceptance stage, which allows for higher royalty rates.



The figure shows three different running royalties as functions of the patent strength θ: s^{NC} for a license contract with no-challenge clause; s_I^{nNC} for a contract without clause and challenge acceptance pricing; s_{NI}^{nNC} for a contract without clause and challenge avoidance pricing. Setting: two licensees compete in prices; marginal cost of the old technology: $v = 1/4$; litigation costs: $L^{\mathcal{C}} = 2/100$; signal probability: $\gamma = 3/4$. The threshold $\underline{\theta}$ is defined in Lemma B.1 and $\tilde{\theta}^s$ is defined in Eq. (78). Demand is defined in Eq. (1), we set $\sigma = 3/4$.

Figure 6: Pure running royalties with and without a no-challenge clause.

[34]The figure is based on the same parametrization as in Figure 5.

Absent a no-challenge clause and for $\theta > \underline{\theta}$, the patent holder has to decide whether to accept a positive invalidation risk ($s_I^{nNC}(\theta)$, dashed line) or avoid a patent challenge by means of financial incentives for the licensees (s_{NI}^{nNC}, dotted line). The figure illustrates that the rate under challenge-avoidance pricing is independent of the patent strength and lower than the rate under a no-challenge clause. The reason is that, at the same invalidation risk θ, the patent holder has to give a higher share of the total profits to the licensees, which requires a lower royalty rate s.

In contrast, challenge-acceptance pricing yields a higher royalty rate than with a no-challenge clause although the licensees obtain the same expected profit level (equal to the profit from infringing the patent). Whereas licensees realize this profit with certainty in the case of a no-challenge clause, absent such a clause, they have the advantage that with some probability the patent will be invalidated. Hence, they are willing to accept a higher royalty for the event that the patent remains valid.

The vertical lines in the figure depict the same threshold values as introduced in Figure 5 and delineate the three intervals characterized in Proposition 6. Absent a no-challenge clause, the patent holder thus chooses the royalty rate as follows:

- for small patent strengths $\theta \leq \underline{\theta}$, the patent holder sets $s = s^{NC}(\theta)$,
- for intermediate patent strengths $\theta \in \left(\underline{\theta}, \tilde{\theta}^s\right]$, it charges $s = s_{NI}^{nNC}$, and
- for strong patents $\theta > \tilde{\theta}^s$, it increases the royalty to $s_I^{nNC}(\theta)$ and thereby accepts a positive invalidation risk.