1 Patent Pools and the Structure of Innovation

In many important industries, prominently so in electronics, computer software, telecommusurplus. The analysis was further refined in a general model by Lerner and Tirole (2004), who also conclude that the more complementary the patents in the pool are, the greater

Should this be the case, patent holders prefer to remain independent, despite the otherwise recognized advantages of pool-formation. Indeed, it is even possible that overall welfare is reduced due to pooling, calling into question the unqualified policy recommendations made concerning pool formation of complementary patents.

The importance of the innovation structure on product development and downstream competition has been studied elsewhere in the literature, notably so in the context of research joint ventures (RJVs). Since the seminal papers by Katz (1986) and d'Aspremont and Jacquemin (1988) implications of spillovers in product development have been studied extensively.[9] However, the focus is generally on cooperation between rivals in the development process, frequently in order to internalize spillovers, avoid cost-duplications and generally coordinate development efforts. This is in contrast to the potential effect of patent pooling on development with spillovers. In particular, the decision to pool is made by IP holders, rather than the developing firms; and the existence of a pool does not induce any cooperation or coordination among the competing downstream developing firms.

An exception to the majority of the literature on coordination and spillovers in RJVs is the notion of research sharing joint ventures (RSJVs) in which firms agree to share the results our model of patent pooling and RSJVs is that the pooling decision does not lie in the hands of the firms that undertake the commercialization and then compete in the product market, but rather, it depends on the incentives and interests of the upstream patent holders.

Closely related to spillovers at the development stage, we further contend that patent pooling may affect the downstream product market competition. The more tightly aligned are the research paths that are pursued, the smaller is the degree of horizontal product differentiation that result from research efforts that are undertaken to develop and commercialize final products. Hence, pooling is likely to lead to less-differentiated products than when firms develop on a more independent basis, due to the congruence inherent in research trajectories that are closely interrelated.[11]

The effect of the degree of product differentiation on development efforts has also been examined elsewhere, with some models specifically examining endogenous product differentiation. A precursor to this literature is Choi (1993) who examines the private and social incentives of research collaboration in anticipation of its effect on product market profits. However, he considers generic profits, rather than derived profits in a closed form model. Similarly, Amir *et al.* (2003) also use generic profit functions and consider differences between cooperative and non-cooperative R&D. As for the interplay of effort and spillovers in development, Molto *et al.* (2005) have a closed-form model with a result that is similar to one of ours (albeit in a very different set-up) in that the social planner may wish to limit the extent of spillovers in development, as these lead to under-performance due to free-riding. Bourreau and Dogan (2010) allow for cost sharing in development and study how increased collaboration in development leads to diminished product differentiation. However, effort is not part of the development process. Ghosh and Morita (2008) also study possible trade-offs concerning development collaboration and product differentiation, using a circular city model with a focus on how insiders differ from outsiders.[12]

The remainder of the paper is structured as follows. In Section 2 the model is presented

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[11] Indeed, the compatibility of product lines across firms is precisely the main rationale for standard-setting patent pools in computing and electronics.

[12]

and the continuation equilibrium for product development and competition is derived. Section 3 gives a benchmark in which it is assumed that the pooling decision has no direct bearing on the development process or the subsequent product market competition, and it is shown that the conventional wisdom regarding the effect of pooling of perfectly complementary patents holds in more general settings. In Section 4 we lay the groundwork to extend this by considering the impact of pooling in an extended model. Specifically, we examine the impact of marginal changes in spillovers in development and marginal changes in the degree of product differentiation on the payoffs of market participants; *viz.*, patent holders, downstream firms, and consumers. On the basis of this, the welfare implications of patent pools are more fully evaluated in Section 5, where we distinguish between royalty contracts

2.1 The Basic Framework

Stage I | Pool Formation Stage I begins after foundation research has already been completed and two patents have been awarded to two distinct patent holders, *k* and *l*. The two patents are both deemed essential in the further development and commercialization of a final product. That is, the patents constitute perfectly complementary inputs. Patent holders can either license their patents independently to downstream developing/retailing firms, or they can form a pool and license both patents jointly.

There are two possible types of licensing contracts between patent holders and the developing/retailing firms that we consider. Following Shapiro (2001) and Lerner and Tirole (2004), the first are per-unit-of-output royalty rates, denoted by R. This is the standard contractual structure that underlies the Cournot-Shapiro double-marginalization result, and is also the prevalent type of contract found in pools (Serafino, 2007; Gilbert, 2010). Absent a pool, each patent holder independently (non-cooperatively) sets a royalty rate for each of the developing/retailing firms, whereas a uniform royalty rate for the downstream firms is agreed upon between the patent holders when they have formed a pool.

As the double marginalization caused by independently set royalty payments provides a central rationale for pool formation of perfectly complementary inputs, we also consider non-distortionary licensing arrangements for comparison purposes. Thus, the second form of contract is an upfront fixed fee F that firms pay to access the patent rights. Because the fee constitutes a fixed cost for the firms, it does not distort downstream actions. In particular, it does not affect the firms' marginal costs of production in Stage III and, because the firm is the residual claimant of all market profit, it also does not distort efforts applied in product development in Stage II.

Since our focus is on the welfare implications of pool formation in light of its effects on development and product market competition, we preclude the possibility of strategic foreclosure (*e.g.*, the deliberate creation of monopoly in the final-demand market by excluding all but one downstream firm from access to the patents). Indeed, foreclosure would be the subject of independent antitrust concerns, and in both European and U.S. jurisprudence patent pools are subject to non-discrimination rules.

Independent of the contract form that governs the IP transfer, the pooling decision has the potential to affect both subsequent stages. Thus, if there are knowledge-spillovers between the downstream firms in the development stage (Stage II), then the formation of a pool may increase these, as the pool may serve a conduit for knowledge transfer. As for Stage III, should a pool be formed, then the products that are sold in the final demand market may be more similar to one another, that is, the degree of horizontal product differentiation may become diminished and product homogeneity increases.

Stages II and III | Product Development and Commercialization Much of the effort only enters the firms' objective function.[13] In particular,

$$A_i = a + e_i + \beta e_j; \qquad i, j = 1, 2; \ i \neq j; \tag{2}$$

where $\beta \in \{\beta_p, \beta_n\}$, with $1 \geq \beta_p \geq \beta_n \geq 0$ denotes the degree of spillovers in development, measuring how much of firm j's effort is captured and appropriated by firm i in order to augment firm i's base demand.

Firms face a quadratic cost of effort in development and for simplicity we assume that the only production costs are associated with acquiring the requisite IP. Thus, the marginal cost is given by any royalty rates the firms pay, R, and any upfront license fees, F, constitute the firms' (sole) fixed costs.

The sequence of events characterizing the structure of innovation and competition is depicted in Figure 1.

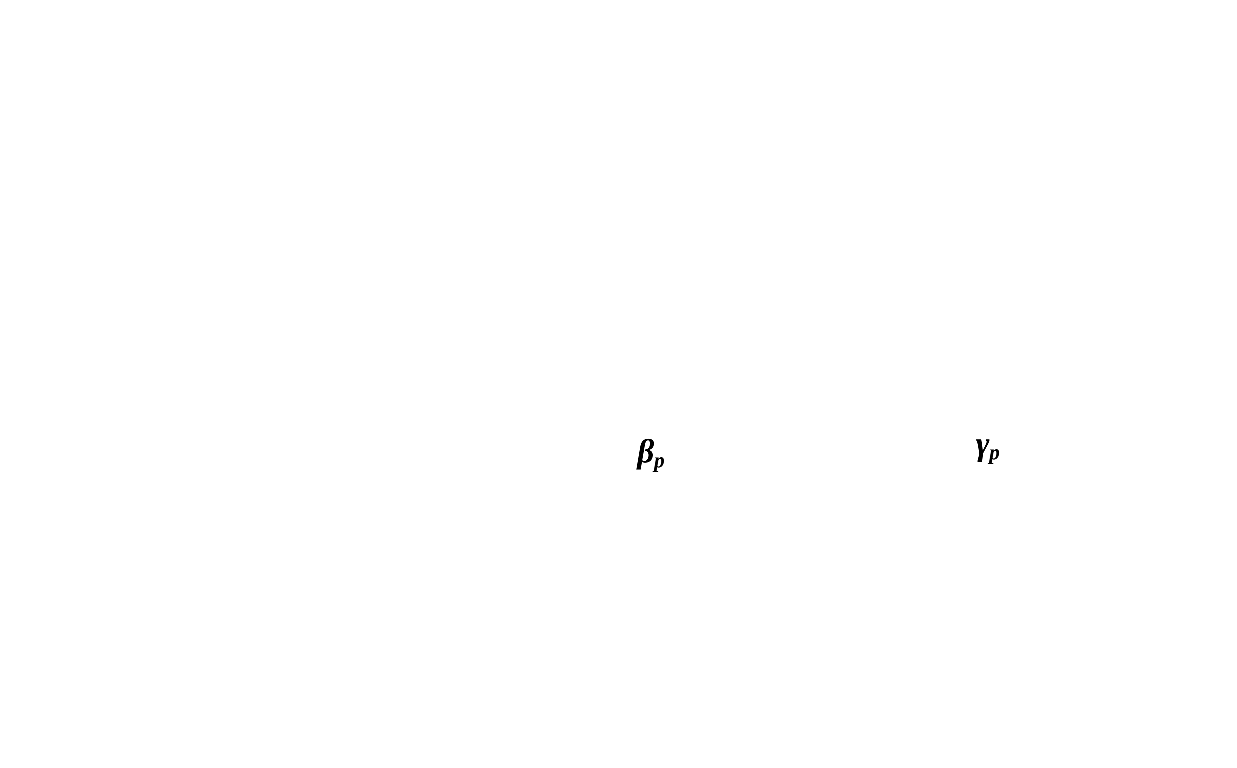

Figure 1: The Structure of Innovation and Competition

[13] See Zucker *et al*. (2001), esp. p. 167.

2.2 The Continuation Equilibrium

We seek the subgame perfect Nash equilibrium and solve the model through backward induction. We first consider the product market competition for a generic degree of product homogeneity $\gamma \in \{\gamma_n; \gamma_p\}$, arbitrary demand intercepts, A_i and A_j, and arbitrary licensing (royalty/fee) structures. Thereafter we analyze the optimal development efforts for generic spillovers $\beta \in \{\beta_n; \beta_p\}$. The analysis is conducted from firm i's point of view, which is without loss of generality as firms are symmetric.

The firms' inverse demand functions, given in (1), are solved for the firms' demands as functions of the strategic variables, namely the prices P_i and P_j:

$$Q_i = \frac{(A_i - P_i) - \gamma(A_j - P_j)}{1-\gamma^2}. \tag{3}$$

While all production costs apart from licensing expenses are normalized to zero, firms may face (per unit) royalty rates R. Moreover, for the case of fixed fees, firms make an upfront payment to patent holders of F. Letting $I \in \{0; 1\}$ be an indicator denoting the type of the licensing arrangement, with 1 designating the case of royalties and 0 the case of fixed fees, firm i's objective is to choose a price to maximize

$$\pi_i = (P_i - IR)Q_i - (1-I)F = (P_i - IR)\frac{(A_i - P_i) - \gamma(A_j - P_j)}{1-\gamma^2} - (1-I)F. \tag{4}$$

Detailed derivations of the model are found in Appendix A, where it is shown that the Bertrand-Nash equilibrium of this game yields,

$$Q_i = \frac{(A_i - P_i) - \gamma(A_j - P_j)}{(1-\gamma)(1+\gamma)} = \frac{\frac{(2-\gamma^2)A_i - \gamma A_j}{2-\gamma-\gamma^2} - IR}{(2-\gamma)(1+\gamma)}. \tag{5}$$

with

$$\pi_i(A_i; A_j) = \frac{(1-\gamma)\left[\frac{(2-\gamma^2)A_i - \gamma A_j}{2-\gamma-\gamma^2} - IR\right]^2}{(2-\gamma)^2(1+\gamma)} - (1-I)F. \tag{6}$$

Consider now the equilibrium effort exerted in the development stage. Equation (6) gives equilibrium market profits as a function of the demand intercepts A_i and A_j. In accordance with (2), these depend on the firms' effort levels, *viz.* $A_i = a + e_i + \beta e_j$. Thus, given quadratic effort costs of e_i^2, the firm's objective is given by

$$\max_{\{e_i\}} \pi_i(e_i; e_j) = \frac{(1-\gamma)\left[a - IR + \frac{(2-\gamma^2-\gamma\beta)e_i + (2\beta-\gamma-\beta\gamma^2)e_j}{2-\gamma-\gamma^2}\right]^2}{(2-\gamma)^2(1+\gamma)} - (1-I)F - e_i^2; \tag{7}$$

with first-order condition[14]

$$e_i = \frac{a \quad lR + \frac{(2 \quad ^2 \quad)e_i + (2 \quad ^2 \quad)e_j}{2 \quad ^2}}{(2 \quad)^2(1 + \quad)} \frac{2 \quad ^2}{2 + }: \tag{8}$$

This yields a best response function of

$$e_i(e_j) = \quad a \quad lR + \frac{(2 \quad ^2 \quad)e_j}{2 \quad ^2} \quad \frac{(2 \quad ^2 \quad)(2 \quad ^2 \quad)}{(2 \quad)^2(1 \quad ^2)(2 + \quad)^2 \quad (2 \quad ^2 \quad)^2}: \tag{9}$$

Given symmetry, the equilibrium effort choices are

$$e = (a \quad lR)\frac{2 \quad ^2}{(2 \quad)^2(1 + \quad)(2 + \quad) \quad (1 + \quad)(2 \quad ^2 \quad)}: \tag{10}$$

Thus far the firms' equilibrium behaviors for the general set-up of the development process and the downstream market competition. We now consider the implications of patent pooling for this general setting, proceeding first with the conventional analysis that abstracts from any possible effects that pooling may have on the subsequent development and commercialization. This is followed by a discussion of the impact of marginal changes in spillovers or product differentiation on welfare independent of the pooling structure. On the basis of this we then examine the welfare implication and potential pitfalls of patent pooling in Section 5, where we differentiate between license fees and royalties.

3 Benchmark Analysis

Given the equilibrium effort and pricing decisions of the firms, we now consider the patent holders' incentives concerning the formation of a pool and analyze how welfare is affected by the pooling structure.

While we extend the existing literature on patent pooling by explicitly modeling the costly development of differentiated products in an imperfectly competitive market, in our benchmark analysis we remain in line with the received literature by initially supposing that the formation of a pool has no effect on the parameters governing the interaction between the downstream firms. That is, we assume that possible spillovers in the development process

[14] The first order conditions are sufficient and yield an interior solution (*i.e.*, positive equilibrium effort) provided that $\lesssim 0.9325$ | an assumption that we henceforth maintain.

by

$$R_n := r_k + r_l. \tag{13}$$

Using (56) once again yields

Q_i

3.2 Welfare

with differentiated products that first require further development. Indeed, for the case of royalties pool formation is strictly preferred over independent licensing. Furthermore, if transactions costs of contractual agreements between licensees and licensors are lower in the pool structure (an argument that is sometimes made, but goes beyond our stylized model), then pooling is also strictly preferred to a situation without a pool in the case of upfront fixed fees.

We now consider how marginal changes in spillovers and the degree of product differentiation impact the analysis.

4 Spillover- and Differentiation-Effects

To lay the groundwork for a discussion of how the interactions between pooling, development efforts, and product differentiation play out, this section deals with how marginal changes in spillovers and product differentiation affect payoffs assuming a given pooling structure.

Where the academic literature on patent pools addresses efficiency, total welfare is generally used as the standard for assessing the best structure for licensing patents. In the benchmark case in Theorem 1 any further differentiation between welfare measures leads to the same insights as an exclusive focus on total welfare, so any separate evaluation of payoffs to producers or patent holders or consumers does not lead to any additional insight regarding the desirability of pooling. However, in the presence of spillover and differentiation effects this is no longer necessarily the case and it needs to be determined when disparate measures of welfare are in congruence and when they are in conflict when it comes to evaluating the formation of patent pools. Thus, in addition to deriving total welfare, we continue to include in our analysis other measures of welfare, as these may result in distinct evaluations and insights, given the specifics of spillover and differentiation effects across industries.

A direct consideration of patent holder payoffs indicates when the formation of pools might be initiated by patent holders. Industry profit is relevant in this context as this will indicate in which circumstances the industry would lobby for or against policies that facilitate the formation of pools. Consumer surplus is also pertinent for our analysis, since, in contrast with much academic literature, antitrust practice often views consumer welfare as the guiding criterion that is to be considered when evaluating a given policy.[15]

4.1 Spillover Effects

We first consider the impact of changes in the amount of spillovers in development. Specifically, assuming a given licensing contract (either royalties or fees), we determine the marginal payoff implications of changes in spillovers for arbitrary constellations of inherent spillovers and fixed levels of product differentiation.

Ceteris paribus, increasing the spillover effect increases welfare by generating a greater demand base A. Hence, all else equal, patent holders view increased spillovers favorably. However, *ceteris non paribus*: When considering the impact that spillovers in the development process have on optimal effort choices, the degree of product differentiation plays a critical role. Thus,

Lemma 1 *Equilibrium effort at the development stage is increasing in the amount of spillovers if products are strongly differentiated, but decreasing if products are similar. Specifically, there exists a function S_e such that*

$$\frac{de}{d} \; R \; 0 \qquad (\;) \qquad 0$$

The two critical thresholds for the degree of product di erentiation are depicted in Figure

one would expect, the e ect of changed spillovers on total welfare lies (necessarily) between those of rms and consumers, being closer to consumers in the case of royalties.

Proposition 3 *Unless products are close substitutes, the spillover e ect makes pooling more attractive from a total welfare perspective. That is, there exists functions S_{TW_1} and S_{TW_0} with $S_{V_1;CS} < S_{TW_1} < S_{TW_0} < S_{V_0;}$, such that*

$$\frac{dTW_l}{d} \text{ R } 0 \quad (\ ) \quad \text{Q } S_{TW_l}; \quad l \ 2 \ f0; 1g: \tag{28}$$

The overall conclusion from this discussion is that in isolation, that is, absent di eren- tiation e ects and for a given licensing contract, spillover e ects tend to be bene cial when products are su ciently di erentiated.

4.2 Di erentiation E ects

We now consider the impact of marginal decreases in product di erentiation for given li- censing contracts and given degrees of spillovers in development. Again, a critical feature in understanding distinct welfare e ects of changes in product di erentiation is to understand rms' incentives to provide e ort at the development stage.

In contrast to changes in spillovers, the e ect of marginal changes in the degree of product di erentiation on equilibrium development e ort is unambiguous, and therefore also results in an unambiguous e ect on the products' base market size re ected in A. In particular:

Lemma 3 *Equilibrium e ort, and hence equilibrium base market size, is decreasing in the degree of product homogeneity,* i.e.,

$$\frac{de}{d} < 0 \quad =) \quad \frac{dA}{d} < 0; \quad 8 \ ; \ : \tag{29}$$

The intuition is straightforward. As increases products become more similar and prod-

Proposition 4 *Increases in the degree of product homogeneity adversely a ect fee-charging patent-holders' and rms' interests. That is,*

$$\frac{dV_{l=0}}{d}; \frac{d}{d} \quad 0; \qquad 8 \; ; \; : \tag{30}$$

As discussed, Proposition 4 re ects that increases in translate into ercer product market competition. However, while rms and fee-charging patent holders eschew ercer competition, if this translates into increased output then per-unit royalty-charging patent holders may actually bene t from decreases in product di erentiation. Similarly, consumers also might bene t from increased competition. Indeed, this may, but need not be the case.

development process. Due to Lemma 3, if spillovers in the development process are large then the adverse effect of diminished effort results in a reduction in equilibrium output Q, which negatively impacts consumers' and patent holders' interests. Otherwise, if spillovers are sufficiently small (provided   is not too small), royalty-charging patent holders and consumers benefit from the differentiation effect.

This raises the question of what the overall welfare implications of the differentiation effect is, which, it turns out, is unambiguous for the case of fees, but depends on intrinsic differentiation not being too large and spillovers not being too small for the case of royalties.

Proposition 6 *A decrease in the degree of differentiation decreases total welfare unambiguously under fees and does so for royalties if spillovers are sufficiently small whenever goods are fairly homogenous to begin with. Thus, there exists $D_{TW_1} < D_{V_1}$ with*

$$\frac{dTW_l}{d} \begin{cases} < 0 & \forall \ ; \ l = 0; \\ \lesseqgtr 0 & \Leftrightarrow \ \lesseqgtr D_{TW_1}; \ l = 1. \end{cases} \tag{33}$$

Thus, despite the fact that consumers may benefit from the increased competition brought about by reduced differentiation, this is more than offset by reductions in profits. That is, once one accounts for the effort incentives in development, total welfare is unambiguously increasing in product differentiation for the case of fees and also so for the case of royalties provided intrinsic differentiation is not too large and spillovers not too small.

We now turn to how spillover and differentiation effects affect the incentives to form patent pools and determine what the implications of patent pooling is for welfare.

5 Welfare Effects of Patent Pools

Having studied the marginal impact of spillover and differentiation effects for a given contract structure, we are now in a position to evaluate the overall incentives to pool and derive the welfare implications of patent pooling. We first consider the case of upfront licensing fees, since for this case some insights can directly be gleaned from the analysis of the previous section. In contrast, when it comes to pool formation with (per-unit) royalties, the avoidance of double-marginalization and royalty-stacking adds another distinct element to consider when contemplating pools.

5.1 Fees

In the case of upfront fixed fees, the incentives implied by the spillover and differentiation effects carry over and can directly be applied to the analysis of pool formation. However, because spillover effects and differentiation effects do not paint a consistent picture across interests and generally depend on the magnitude of intrinsic spillovers and the inherent degree of product differentiation, there are few immediate and straightforward results. Nevertheless some patterns emerge and some noteworthy constellations exist, which we discuss in greater detail now.

Of the three market participants — patent holders, firms, and consumers — the direction of marginal welfare effects are most sensitive to intrinsic spillovers and inherent product differentiation when it comes to consumers and least so when it comes to firms, with patent holders being in between. That is, whether consumers benefit or suffer on the margin from either of the effects generally depends on the degree of spillovers and the degree of product differentiation, whereas for firms most constellations of parameters have the same implications concerning the marginal impact of the effects. In particular, firms and fee-charging patent holders largely benefit from increases in spillovers (*cf*. Prop. 1) and decreases in product homogeneity (Prop. 4).

However, while it may generally be easy to evaluate the marginal effects for firms and hence also for fee-charging patent holders, this does not mean that the incentive to form a pool is straightforward. Notice, thus, from Propositions 1 and 4 and the accompanying Figures 3 and 4 that from the fee-charging patent holders' perspective the two effects almost always operate in opposite directions so that any definitive evaluation of the desire to pool must account for the magnitude of the two effects. In general, whenever the differentiation effect increases, to keep the incentives for pooling the same, there must also be an increase in the spillover effects.

The only exception to the fee-charging patent holders' two incentives moving in opposite directions is the case characterized in Proposition 1. Indeed, since here the patent holders'

Example 1 *Let* $_n = 0{:}7$ *and* $_n = 0{:}2$*, that is, products are strongly di erentiated and there are strong spillovers in development. Now consider spillover and di erentiation e ects such that* $_p\ 2\ [0{:}7; 1]$ *and* $_p\ 2\ (0{:}2; 0{:}9]$*, then there exist functions* F_{CS} *and* $F_{V_0;}$ *, with* $F_{CS} > F_{V_0;}$ *, such that*

$$CS_p < CS_n; \quad 8\ _p;\ _p\ 3\ \ _n =\ _p > F_{CS}(\ _n =\ _p)\ ; \tag{35}$$

$$W_p < W_n; \quad 8\ _p;\ _p\ 3\ \ _n =\ _p > F_{V_0;}\ (\ _n =\ _p) \text{ and } W\ 2\ f V_0;\ \ g: \tag{36}$$

Figure 5: Pooling and Non-Pooling with Fees

Thus, Example 1 shows how pooling can be undesirable, even for initially very di erentiated goods, provided that spillover e ects are small (*i.e.*, $_n =\ _p$ large) and di erentiation e ects are large (*i.e.*, $_n =\ _p$ small). In contrast, if di erentiation e ects are small, then all parties prefer the pooling outcome.

Moreover, as Figure 5 illustrates, as the di erentiation e ect becomes smaller (*i.e.*, $_n =\ _p$ increases) or the spillover e ect becomes larger (*i.e.*, $_n =\ _p$ decreases) it is rst consumers and only later the fee-charging patent holders who prefer the pooling structure. For this example, this implies two things. First, a su cient condition for pooling to be overall bene cial is that patent holders prefer to pool. And second, there are constellations for which consumers would prefer the pooling structure, while patent holders do not; and overall welfare would be higher without pooling. Indeed, F_{TW} in Figure 5 shows the threshold for which pooling becomes bene cial from a total welfare standpoint.

The tradeo s described in Example 1 and illustrated in Figure 5 are somewhat typical for large areas of the parameter space. In particular, it can be shown that the incentives to pool are much stronger for consumers than for patent holders in most cases. However, a

While there is an unambiguous finding for consumers, the picture is more nuanced for firms and, more importantly, in terms of the patent holders' interests as well. As was shown in the previous section, the differentiation effect makes pooling less attractive for firms (Proposition 4), and if spillovers are large then the spillover effect may also make pooling less profitable (Proposition 1). Analogous considerations exist for royalty-charging patent holders as well (see Propositions 5 and 2). Thus, it is typically the case that for either firms or patent holders to want to refrain from pooling, differentiation effects must be very strong. When this is the case, the aversion to pooling can then even be independent of spillover effects; as the following typical example illustrates.

Example 3 *Let* $_n = 0{:}5$ *and* $_n = 0{:}5$*, that is, products are moderately differentiated and theren* when the products are intrinsically highly di erentiated, but there are very strong di erentiation e ects that result in goods becoming close substitutes for one another, as is illustrated in the following example.

Example 4 *Let* $_n = 0{:}8$ *and* $_n = 0{:}1$*, that is, products are highly di erentiated and there are large spillovers in development. Now consider spillover and di erentiation e ects such that* $_p$ *2* $[0{:}8; 1]$ *and* $_p$ *2* $(0{:}1; 1]$*, then there exist* R_{TW}*, such that*

$$TW_p < TW_n; \quad 8 \ _p; \ _p \ 3 \ \ _n = _p < R_{TW}(\ _n = _p): \qquad (41)$$

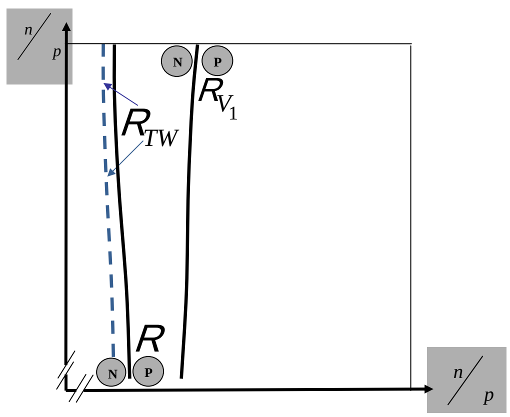

Figure 8: Reduction of Total Welfare due to Pooling with Royalties

The function R_{TW} from Example 4 is depicted as the blue dashed line in Figure 8. Note that the thresholdsNote

6 Conclusion

In the contemporary debate about overcoming the so-called `patent-thicket,' patent pooling is strongly advocated as a solution, provided that patents placed in the pool are complementary. We contend that this conventional wisdom — present in the academic literature, in policy circles, and antitrust practice — overlooks potential implications of pool formation for downstream product development and commercialization. In particular, largely missing from the debate on intellectual property rights reform is the impact of the transfer of embodied knowledge through either individual patents or the pooling of patents on the subsequent development and commercialization process.

We considered a model in which the pooling of perfectly complementary patents has three potential effects. First, it reduces distortions associated with the double-marginalization caused by royalty stacking. Second, because the pool may also serve as an information-sharing device in product development, the formation of a pool may increase spillovers in subsequent product development. And third, related to this, it may decrease the degree of product differentiation in the final product market.

The first point is generally viewed as the rationale for not only allowing, but actively encouraging patent pools to form for perfectly complementary patents; and the second aspect has also been cited as a strong reason to favor patent pools — in particular in biotechnology. However, we demonstrate that once the development incentives of the downstream firms are accounted for, patent pools — even for perfectly complementary patents — may, in fact, be welfare decreasing.

Nevertheless, there are also many constellations for which patent pools are beneficial. In particular, if consumer surplus is viewed as the relevant criterion for antitrust sanctioning of pools and royalties are paid on a per-unit-of-output basis, the pooling structure is always preferred to the non-pooling structure, regardless of the degree of spillovers and product differentiation and how pooling affects these.

However, when IP is licensed on an up-front fee basis, consumer surplus may be reduced under pooling. This happens, for instance, if products are relatively close substitutes and there are large spillovers in development, because free-riding in the development process lowers development efforts. In these cases firm profit and patent holders' revenues are also diminished under pooling, calling into question the unqualified advocacy for pooling — even when patents are perfectly complementary. Similarly, when using total welfare considerations, pooling is also detrimental when products are not close substitutes, but there are large differentiation effects, regardless of whether spillovers in development are affected by pooling.

A corollary of sorts to this observation has also emerged from our analysis. Thus, another encouraging finding is that, in many instances, a sufficient condition for total welfare to increase under pool formation is that patent holders prefer the pooling structure and therefore would seek it of their own volition. However, we have also been able to find important exceptions to this guide. Specifically, when products are close substitutes and spillovers are initially small, but become large due to pooling, then firms may benefit from reduced costs of effort at the development stage to the detriment of consumers.

In sum, we have found constellations in which even though industry desires to pool, consumer surplus (and even total welfare) is lower under a pool. Also, for the case of royalties, total welfare may decrease under pooling even without any spillover effects, provided that spillovers are already large, products are relatively close substitutes and there are differentiation effects from pooling. Finally, for the case of up-front fees, even minuscule spillover effects alone can decrease welfare when products are relatively similar and spillovers are large.

The model demonstrates that the welfare implications of pooling complementary patents is sensitive to industry specifics, and general policy recommendations based solely on the complementarity of patents ought to be avoided. Although the conventional wisdom may prevail in industries such as consumer electronics where spillovers and product differentiation are not affected by pooling; it may fail in industries such as biotech, where knowledge transfer

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Appendix A: Derivations

Market Pro t

The Bertrand-Nash equilibrium of this game yields:

$$P_i = \frac{\frac{(2 \quad ^2)A_i \quad A_j}{2+} + lR}{2}; \qquad i;j = 1;2;\ i \neq j: \tag{42}$$

Hence, since

$$A_i \quad P_i = \frac{\frac{2A_i \quad A_j}{2+} \quad lR}{2}; \tag{43}$$

substituting (43) into (3), one obtains

$$Q_i = \frac{(A_i \quad P_i) \quad (A_j \quad P_j)}{(1 \quad)(1+ \quad)} = \frac{\frac{(2 \quad ^2)A_i \quad A_j}{2 \quad ^2} \quad lR}{(2 \quad)(1+ \quad)}: \tag{44}$$

Note also that

$$P_i \quad lR = \frac{(1 \quad) \frac{(2 \quad ^2)A_i \quad A_j}{2 \quad ^2} \quad lR}{2} = 1 \quad ^2\ Q_i \ ; \tag{45}$$

So, from (44) and (45) one obtains pro t of

$$_i(A_i;A_j) = (P_i \quad lR)Q_i \quad (1 \quad l)F = (1 \quad ^2)(Q_i)^2 \quad (1 \quad l)F$$

$$= \frac{(1 \quad) \frac{(2 \quad ^2)A_i \quad A_j}{2 \quad ^2} \quad lR^{\ 2}}{(2 \quad)^2(1+ \quad)} \quad (1 \quad l)F; \tag{46}$$

which is (6).

E ort Equilibrium

Equation (7) has rst-order condition

$$e_i = \frac{(1 \quad) \ a \quad lR + \frac{(2 \quad ^2 \quad)e_i + (2 \quad ^2 \quad)e_j}{2 \quad ^2}}{(2 \quad)^2(1+ \quad)} \frac{2 \quad ^2}{2 \quad ^2}; \tag{47}$$

or

$$e_i = \frac{a \quad lR + \frac{(2 \quad ^2 \quad)e_i + (2 \quad ^2 \quad)e_j}{2 \quad ^2}}{(2 \quad)^2(1+ \quad)} \frac{2 \quad ^2}{2+}: \tag{48}$$

This yields a best response function of

$$e_i(2 \quad)^2(1+ \quad)(2+ \quad) = \quad a \quad IR + \frac{(2 \quad ^2 \quad)e_i + (2 \quad ^2 \quad)e_j}{2 \quad ^2} \quad (2 \quad ^2 \quad); \tag{49}$$

or

$$e_i \frac{(2 \quad)^2(1 \quad ^2)(2+ \quad)^2 \quad (2 \quad ^2 \quad)^2}{2 \quad ^2} = \quad a \quad IR + \frac{(2 \quad ^2 \quad)e_j}{2 \quad ^2} \quad (2 \quad ^2 \quad); \tag{50}$$

or

$$e_i(e_j) = \quad a \quad IR + \frac{(2 \quad ^2 \quad)e_j}{2 \quad ^2} \quad \frac{(2 \quad ^2 \quad)(2 \quad ^2 \quad)}{(2 \quad)^2(1 \quad ^2)(2+ \quad)^2 \quad (2 \quad ^2 \quad)^2}: \tag{51}$$

Equilibrium Consumer and Producer Surplus

Substituting the equilibrium e ort level (10) into the rm's payo (7) yields

$$_i = (a \quad IR)^2 \quad (2 \quad)^2(1 \quad ^{2+} \quad)^2 \quad (2 \quad ^2 \quad)^2$$

$$)^2(1+)(2+ \quad) \quad) \quad (2^2$$

Appendix B: Proofs

Proofs that are straightforward, or are implied by the discussion in the main text have been omitted.

Proof of Lemma 1 Equilibrium e ort is given by (10). After taking the derivative, dropping the denominator and consolidating it follows that $\frac{de}{d}$ carries the same sign as

$$(2 \quad)^2(1 + \quad)(2 + \quad) + (2 \quad {}^2 \quad)^2$$

Proof of Proposition 2 Taking the derivatives of (21) and (20) with respect to when I = 1 reveals that the sign is determined by the sign of (2 ^{2}) (1) , hence $S_{V_1;CS} = S_A$.

Proof of Lemma 3 Equilibrium e ort is given by (10). After taking the derivative, dropping the denominator and consolidating it follows that $\frac{de}{d}$ carries the same sign as

$$(2 \quad) \ 2 \ 2 \qquad ^2 + 3 \ ^3 + 2 \ ^4 + \quad 4 + 2 \ + 4 \ ^2 + 3 \ ^3 \ : \tag{63}$$

Both factors are obviously positive so that the negative of their product is negative; which is also su cient to prove the second statement.

Proof of Proposition 4 As remarked in the proof to Proposition 1, $\frac{dV_{I=0}}{d}$ carries the same sign as $\frac{d}{d}$. Applying the quotient rule in taking the derivative of (19) with respect to , it follows after some simpli cation that $\frac{d}{d}$ carries the same sign as

$$2(\quad 2)^2(1 + \ ) \quad 6 + 4 \ + \ ^2 \quad 5 \ ^2 \quad ^3 + \ ^4 \qquad 2 \qquad ^2$$
$$12 + 10 \ ^3 + 2 \ ^4 \quad 3 \ ^5 \quad ^6 + \quad (\quad 2)(1 + \ )^2 + \ ^2 \ 4 + 2 \ + 3 \ ^2 + 2 \ ^3 \tag{64}$$

Of the three factors it is straightforward to show that the rst is negative and the third is positive. The middle factor is shown to be positive in the proof to Proposition 1, from which it follows that $\frac{d}{d} < 0$.

Proof of Proposition 5 We undertake the same steps as in the proof to Proposition 2, but now take derivatives with respect to . From this it follows that $\frac{dV_{I=1}}{d}$

Of the three factors it is straightforward to show that the rst is negative and in the proof to Proposition 1 it is shown that the second is positive. Setting the third factor equal to zero and solving for yields

$$D_{CS} = \frac{(2 \quad)\sqrt{(384 + 964\,(\;\; + \;\; ^{2}) + 669 \;\; ^{3} + 454 \;\; ^{4} + 205 \;\; ^{5} + 36 \;\; ^{6})}}{2\,(8 + 4 \;\; + 2 \;\; ^{2} + 3 \;\; ^{3})} + (2 + \;\;)^{2}(4 \qquad ^{2}). \tag{68}$$

Proof of Theorem 2 It can be shown that $S_{V_0;} \;\; > D_{CS}$, whereupon the assertion follows immediately as a corollary to Propositions 1, 2, 4 and 5.

Proof of Theorem 4 Upon setting $_p = 0{:}85$ and $_p = 1$ Mathematica's FindInstance[$fCS_p < CS_n; 0 < \;\; _n < 0{:}85; 0 < \;\; _n < 1g; f \;\; _n; \;\; _n g$], shows that no such instance exists on the given domain. Since consumer surplus is concave, it then follows that the theorem holds for the entire domain.

Proof of Proposition 3:

carries the same sign as

= M

Set M = 0,

Where

If

carries the same sign as

= N

Set N = 0,

Proof of Proposition 6:

It carries the same sign as

Because , , e can conc!u"e that

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