Exclusive Contracts, Innovation, and Welfare

by

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Abstract

We analyze the impact of exclusive contracts on industry research and development (R&D) and total surplus (welfare). An exclusive contract between an incumbent supplier and a buyer often reduces the R&D of potential entrants, and can reduce the incumbent supplier's R&D as well. Exclusive contracts often reduce welfare when the R&D ability of potential entrants is pronounced, but can increase welfare when the incumbent's R&D ability is pronounced and strong patent protection for innovation prevails. Contracts that fully exclude rivals can increase welfare while contracts that only partially exclude rivals can reduce welfare.

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1 Introduction.

An exclusive contract between a buyer and a supplier arises when the buyer agrees to deliver a specified damage payment to the supplier if the buyer ultimately purchases the product in question from a different supplier. Recent research has shed considerable light on the competitive effects and welfare implications of exclusive contracts in settings where industry cost structures and product quality are exogenous.[1] In practice, though, exclusive contracts arise in vibrant, dynamic industries such as computer hardware and software industries where production costs and product quality are highly sensitive to the research and development (R&D) efforts of existing and potential industry suppliers. To illustrate, Intel allegedly provides its customers with pronounced financial incentives to buy most or all of their microprocessor chips from Intel.[2] Intel's competitors claim that such arrangements amount to exclusive contracts, and that these contracts inhibit industry innovation and harm consumers.[3]

The purpose of this research is to analyze the impact of exclusive contracts on industry R&D and welfare in a setting where industry competition is fueled by the R&D activities of existing and potential suppliers. In order to focus on the special considerations introduced by the potential for industry innovation, we adapt the classic model of Aghion and Bolton (1987) to analyze a setting in which exclusive contracts would not affect welfare if innovation were not feasible. In our basic model, an incumbent supplier (S1) initially sells a product of value v_l to a single buyer (B). B purchases at most one unit of the (indivisible) product. S1 and a potential industry entrant (S2) can both undertake R&D to (stochastically) develop a superior product of value $v_h > v_l$.[4] Before S1 and S2 undertake R&D, S1 and B can sign an exclusive contract. The exclusive contract specifies

[1] Whinston (2006) and Abbott and Wright (2009) provide useful reviews of both the relevant economic literature and recent legal decisions with regard to exclusive contracts.

[2] In a complaint filed against Intel, its competitor, Advanced Micro Devices (AMD) alleges that "... the Intel arsenal includes direct payments in return for exclusivity and near-exclusivity; discriminatory rebates, discounts and subsidies conditioned on customer "loyalty" that have the practical and intended effect of creating exclusive or near-exclusive dealing arrangements ... [and] threats of economic retaliation against those who give, or even contemplate giving, too much of their business to AMD" (AMD Civil Action, 2005, ¶ 35).

[3] AMD suggests, for example, that "Were it not for Intel's acts, AMD and others would be able to compete for microprocessor business on competitive merit, ... bringing customers and end-product consumers lower prices, enhanced innovation, and greater freedom of choice." Furthermore, "Intel's conduct has caused and will continue to cause injury to the relevant market in the form of higher prices and reduced competition, innovation and consumer choice" (AMD Civil Action, 2005, ¶¶ 127,139).

[4] Results analogous to those reported below would emerge if R&D served to reduce production costs rather than increase product quality.

a damage payment (D) that B must deliver to S1 if B ultimately buys the product from S2 rather than from S1.[5] The contract can be fully excluding in the sense that D is so high that S2 will not invest in R&D and will not enter the market. The contract can also be partially excluding in the sense that it will reduce, but not eliminate, S2's R&D and thereby impede, but not preclude, S2's entry.

B always buys the high-quality (v_h) product when it is available in the equilibrium of our model. Furthermore, S1 and S2 have the same production costs. Therefore, an exclusive contract does not affect total surplus (welfare) for any given set of product offerings by S1 and S2. However, an exclusive contract affects welfare through its impact on the suppliers' R&D investments.

S1 faces an important trade-off in determining the magnitude of the damage payment in the exclusive contract (and whether to implement an exclusive contract). A large damage payment ensures S1 a large share of the surplus that arises if S2 is the only firm to innovate successfully. However, a large damage payment may reduce S2's R&D, and thereby reduce the likelihood that S2 innovates successfully. The details of this trade-off vary with S1's own R&D activity which, like S2's R&D, depends upon the suppliers' relative R&D abilities and the strength of prevailing innovation protection (patent and trade secret protection).

S1 will choose not to implement an exclusive contract when its relative R&D ability is sufficiently limited and when the prevailing innovation protection is limited. In these cases, S1 is careful not to reduce the R&D activity of the particularly proficient innovator. Instead, S1 benefits from S2's R&D activity by imitating its successful innovation. In contrast, S1 often will implement an exclusive contract when the prevailing innovation protection is more pronounced. Unless its own relative R&D ability is particularly pronounced, S1 typically will set a modest damage payment to ensure that S2 continues to conduct R&D, and therefore innovates and operates in the industry with positive probability.

Just as it reduces S2's incentive to undertake R&D, an exclusive contract reduces S1's incentive to engage in R&D, *ceteris paribus*. This is the case because S1 receives D more often when it fails to innovate than when it innovates successfully. Because S1's R&D and S2's R&D are strategic substitutes, the equilibrium effects of an exclusive contract on the suppliers' R&D investments can

[5] The exclusive contract also specifies a lump-sum payment that S1 delivers to B when B signs the contract. The payment compensates B fully for the damage payment and the potentially higher equilibrium price that he faces under the exclusive contract.

be varied. An exclusive contract will always reduce the R&D investment of at least one industry supplier, and can reduce the equilibrium R&D of both suppliers.

The impact of exclusive contracts on welfare in our model varies with the prevailing innovation protection. If no patent protection is available but innovating firms can fully protect their innovations via trade secret, then S1 and S2 will undertake efficient levels of R&D in the absence of an exclusive contract. Consequently, an exclusive contract reduces welfare in this setting, even if it does not fully exclude S2 from the industry. In contrast, industry participants may undertake inefficiently large levels of R&D when substantial patent protection is available. Exclusive contracts can increase welfare in such settings by reducing R&D toward efficient levels, particularly when S1's R&D ability is relatively pronounced. Exclusive contracts can thereby increase welfare even if they fully exclude S2 from the industry. Thus, partially excluding contracts can reduce welfare while fully excluding contracts can increase welfare.

The impacts of environmental parameters (e.g., the degree of innovation protection or the relative R&D abilities of S1 and S2) on the R&D incentives of individual suppliers are straightforward to assess in our model. However, the corresponding impacts on equilibrium R&D and welfare are more difficult to analyze, in part because the terms of the equilibrium exclusive contract change as environmental parameters change. To illustrate, an increase in patent protection increases S2's incentive to conduct R&D, *ceteris paribus*. However, the increased patent protection can induce S1 to increase the damage payment in the exclusive contract that it implements. The more pronounced damage payment can induce S2 to reduce its equilibrium R&D investment as industry patent protection increases.

We develop these findings and others as follows. Section 2 describes the key elements of our model. Section 3 presents and explains our main findings. Section 4 provides additional characterization of equilibrium outcomes in selected settings of interest. Section 5 considers extensions of our model, and suggests directions for further research. The proofs of all formal conclusions appear in the Appendix.

Before proceeding, we briefly emphasize our contribution to the literature.[6] As noted, we extend Aghion and Bolton (1987)'s analysis to allow for industry R&D and innovation. This extension is important because exclusive contracts arise in settings where R&D and innovation are instrumental

[6] The concluding section provides additional discussion of the relationship between our work and its predecessors.

determinants of industry performance. Our consideration of partially excluding contracts allows us to demonstrate that an exclusive contract can either reduce innovation selectively (i.e., for just one supplier) or systematically (i.e., for both suppliers).[7,8] Our consideration of varying degrees of innovation protection and different R&D abilities of actual and potential industry suppliers also allows us to determine how the impacts of exclusive contracts vary with the environment in which they are implemented. Our finding that exclusive contracts can either enhance or diminish welfare provides support for a "rule of reason" approach to assessing exclusive contracts.[9]

2 Elements of the Model.

There are three main actors in the model: an incumbent supplier (S1), a potential entrant (S2), and a buyer (B). B purchases at most one unit of the product that S1 and S2 supply.[10] Initially, S1 alone supplies a variant of this product that delivers value $v_l > 0$ to B. Both S1 and S2 can undertake research and development (R&D) to discover how to produce a new variant of the product that will deliver value v_h ($> v_l$) to B. S2 discovers how to produce this high-quality product with probability $\rho(k_2) \in [0, 1]$ when it undertakes R&D $k_2 \in [0, \overline{k}]$, where $\overline{k} \leq \infty$. $\rho(\cdot)$ is a strictly increasing, strictly concave function. S1's corresponding probability of discovering how to produce the high-quality product when it undertakes R&D $k_1 \in [0, \overline{k}]$ is $r\rho(k_1)$, where $r \geq 0$ is a parameter that reflects S1's R&D ability relative to S2's R&D ability. For simplicity, we normalize to zero the costs that S1 and S2 incur in producing the high-quality product after discovering how to produce it. S1 also can produce the low-quality product at no cost.

A supplier can learn how to produce the high-quality product either through successful inno-

[7] Stefanadis (1997) finds that fully excluding contracts reduce R&D in a setting where the R&D of upstream suppliers exhibits scale economies. An exclusive contract between an upstream supplier and a designated downstream buyer limits the potential sales of rival upstream suppliers, and thereby limits their expected return to R&D. Scale economies in R&D are not present in our model. Furthermore, in contrast to Stefanadis, we do not impose the assumption that exclusive contracts cannot be renegotiated. Therefore, Spier and Whinston's (1995) critique of analyses that impose this assumption does not apply to our model.

[8] Segal and Whinston (2000a,b) find that exclusive contracts do not affect a supplier's (R&D) investment in a setting where the supplier's investment does not affect value of the buyer's trade with other suppliers. The authors presume that all contracts can be renegotiated costlessly and that an agent's payoff from bargaining is a linear combination of his marginal contribution to each possible coalition of buyers and suppliers. De Meza and Selvaggi (2007) critique this bargaining structure. Milliou (2008) demonstrates that Segal and Whinston's "irrelevance result" can be overturned when a buyer's decision to make its production technology more compatible with one supplier necessarily renders the technology less compatible with another supplier.

[9] Greenlee et al. (2008) show that loyalty discounts, which can function much like exclusive contracts, can either increase or decrease welfare. The authors do not analyze the impact of loyalty discounts on industry R&D.

[10] The concluding section discusses the additional considerations that arise when B's demand is elastic (downward-sloping).

vation or through imitation of its rival's discovery. A supplier that innovates successfully can seek patent protection for its innovation in order to limit imitation by a rival. The innovator that files for a patent first secures the patent with probability $\phi \in [0,1]$, in which case the rival is prohibited from marketing the high-quality product. The innovation is judged to be non-patentable with probability $1-\phi$, in which case the rival can replicate the innovation after incurring any relevant imitation costs. If S1 and S2 both innovate successfully and both decide to seek patent protection for their innovation, each supplier is the first to file for a patent with probability $\frac{1}{2}$.

A supplier may attempt to protect its innovation as a trade secret rather than through a patent. A supplier that pursues innovation protection via trade secret is successful with probability $\phi_t \in [0,1]$, in which case the rival cannot imitate the innovation. Trade secret protection fails with probability $1-\phi_t$, in which case the rival can replicate the innovation after incurring any relevant imitation costs. In the ensuing discussion, we will refer to $\theta \equiv \max\{\phi, \phi_t\} > 0$ as the prevailing level of innovation protection.[11]

Due to its experience in the industry as the incumbent supplier, S1 can imitate its rival's innovation at lower cost than can S2. For simplicity, we normalize to zero S1's cost of imitating S2's innovation, absent successful patent or trade secret protection. Because S2 faces positive imitation costs and eventual Bertrand price competition if it competes against S1, S2 will not enter the industry unless it innovates successfully.[12]

To focus on settings in which S2 may impose meaningful competitive pressure on S1, we impose sufficient structure on the innovation probability $\rho(\cdot)$ to ensure that S2 will undertake a strictly positive (and finite) level of R&D if S1 undertakes no R&D. This structure is reflected in condition (iii) of Assumption 1.

Assumption 1. (i) $\rho'(k) > 0$ and $\rho''(k) < 0$ for all $k \in [0,\overline{k}]$; (ii) $\rho(0) = 0$; (iii) $\rho'(0) \in \left(\frac{1}{\theta[v_h - v_l]}, \infty\right)$ and $\rho'(\overline{k}) = 0$; and (iv) $v_h > \left[\frac{2}{2-\phi}\right] v_l$.

[11] For simplicity, we assume that a supplier has no recourse against imitation following an unsuccessful attempt either to patent an innovation or to protect the innovation via trade secret. In particular, trade secret protection is not viable after a patent application has been denied, perhaps because of the proprietary information that must be disclosed publicly in a patent application. Similarly, patent protection is not possible following the failure of trade secret protection, perhaps because the novelty of the innovation is questioned once it is known to be widely available in the industry.

[12] S2 will prefer not to incur the imitation costs regardless of how small these (strictly positive) costs might be.

Condition (i) of Assumption 1 reflects the positive but diminishing returns to R&D effort. Condition (ii) implies that some R&D is required for successful innovation. This assumption facilitates a focus on the effects of R&D rather than the effects of exogenous, stochastic forces. Condition (iv) simply requires the incremental value of successful innovation to be sufficiently pronounced. Assumption 1 is presumed to hold throughout the ensuing analysis.[13]

The product quality that B ultimately secures and the price that he pays for the product depend upon the R&D outcomes that arise and the terms of any contract that he has signed with S1 before S1 and S2 undertake R&D. The contract between B and S1 consists of two elements: (i) a damage payment, $D \geq 0$, that B must deliver to S1 if B ultimately buys the product from S2; and (ii) a lump-sum payment, $L \geq 0$, that S1 delivers to B when he signs the contract. This lump-sum payment compensates B fully for the damage payment and the potentially higher equilibrium price that he faces if he signs the contract. A contract in which D is strictly positive will be referred to as an *exclusive contract*. A *fully excluding* contract is an exclusive contract that induces S2 to refrain from R&D (so $k_2 = 0$ in equilibrium), and thereby ensures that S2 never enters the industry. A *partially excluding* contract is an exclusive contract that does not reduce S2's equilibrium R&D to zero, and so does not preclude S2's participation in the industry.[14]

The interactions among S1, S2, and B proceed in three successive stages. At the start of the first stage, S1 may propose an exclusive contract to B. B then either accepts or rejects the contract. The terms of the contract and B's acceptance decision are both observed publicly. In the second stage, S1 and S2 choose their R&D investments simultaneously and independently. The R&D outcomes (success or failure) are then observed publicly, as are the results of any ensuing patent applications or attempted trade secret protection. In the third stage, S2 either enters the market or declines to do so. If S2 enters, S1 and S2 engage in Bertrand price competition.[15] If S2 does not enter, S1 unilaterally sets the price at which it will sell its product to B.

The profits that S1 and S2 secure and the surplus that B ultimately receives depend upon the outcomes of the R&D process. If neither firm innovates successfully, then S1 will be the monopoly supplier of the low-quality product. S1 will charge B the maximum amount (v_l) that he is willing

[13] We also assume that $\rho(\cdot)$ is sufficiently concave. See inequality (5) below.

[14] We will say that S1 declines to implement an exclusive contract when S1's preferred damage payment is 0.

[15] The concluding section discusses the changes that arise if the high-quality products that S1 and S2 offer are horizontally differentiated, and so the two suppliers engage in less intense price competition.

to pay for the product. Therefore, S1's variable profit (i.e., its profit before accounting for R&D costs) will be v_l. S2's variable profit will be 0, and B will secure no surplus in this case.

If S1 is the only firm to innovate successfully, it will charge B the monopoly price v_h for the high-quality product. S1's variable profit will be v_h, S2's variable profit will be 0, and B will secure no surplus in this case.

If S2 is the only firm to innovate successfully, it is able to protect its innovation with probability θ. In this event, S2 will sell the high-quality product to B at price $v_h - v_l - D$. This price reflects the incremental value that B derives from buying the high-quality product from S2 (and therefore paying D to S1) rather than buying the low-quality product from S1.[16] To simplify the exposition, we assume that $D \leq v_h - v_l$ throughout the ensuing analysis.[17] S2's variable profit when it is the sole innovator and it successfully protects its innovation will be $v_h - v_l - D$. S1's variable profit will be D (the payment it receives from B). B's surplus will be v_l, which is the difference between the value of the product (v_h) he purchases and the sum of the price he pays to S2 ($v_h - v_l - D$) and the damage payment (D) he delivers to S1.

When S2 is the only successful innovator, it is unable to protect its innovation from imitation with probability $1 - \theta$. In this event, Bertrand competition between the two suppliers of the high-quality product will result in S1 selling the product to B at price D. B will not purchase the product from S2 at any positive price when he can purchase the product from S1 at price D. This is the case because B must pay D to S1 if he buys the product from S2. Thus, when S2 is the only successful innovator but fails to protect its innovation, S2's variable profit will be 0, while S1's variable profit will be D. B's surplus will be $v_h - D$.

When S1 and S2 both innovate successfully, trade secret protection is irrelevant since both suppliers have learned how to produce the high-quality product. If S1 files for a patent before S2 does (which occurs with probability $\frac{1}{2}$), then S1 receives the patent with probability ϕ. In this event, S1 charges the monopoly price v_h for the product, and thereby secures variable profit v_h.

[16] S2 can secure B's patronage by reducing its price for the high-quality product to (or just below) $v_h - v_l - D$ when S1 charges a price of 0. These two prices constitute the Nash equilibrium in the subgame that provides the highest joint profit to S1 and B. Furthermore, these are the only prices consistent with the subgame perfect equilibrium of the entire game that we specify below.

[17] This assumption is without loss of generality because S2's equilibrium R&D and industry outcomes are the same when $D > v_h - v_l$ as when $D = v_h - v_l$. In both cases, S2 will not undertake any R&D and will not operate in the industry because it recognizes that it can never profitably serve B, even when it is the sole innovator and when it successfully protects its innovation.

S1's variable profit and B's surplus are both 0 in this case. If the innovation is deemed to be non-patentable (which happens with probability $1-\phi$), then the ensuing Bertrand competition culminates in S1 selling the high-quality product to B at price D. S1's variable profit is D, S2's variable profit is 0, and B's surplus is $v_h - D$ in this case.

If S2 files for the patent first (which happens with probability $\frac{1}{2}$) and then is awarded a patent (which happens with probability ϕ), S2 sells the high-quality product to B at price $v_h - v_l - D$.[18] S2's variable profit is D, and B's surplus is v_l ($= v_h - [v_h - v_l - D] - D$) in this case. If, after filing first for a patent, S2's patent application is denied, the ensuing Bertrand competition results in B buying the high-quality product from S1 at price D. S1's variable profit in this case is D, S2's variable profit is 0, and B's surplus is $v_h - D$.

These considerations imply that when S1 undertakes R&D k_1 and S2 undertakes R&D k_2, S1's expected profit is:

$$\begin{aligned} \pi_1(k_1,k_2) &= [1-r\rho(k_1)][1-\rho(k_2)]\,v_l + r\rho(k_1)[1-\rho(k_2)]\,v_h + [1-r\rho(k_1)]\,\rho(k_2)\,D \\ &\quad + r\rho(k_1)\,\rho(k_2)\left\{\frac{1}{2}D + \frac{1}{2}[\phi v_h + (1-\phi)D]\right\} - L - k_1. \end{aligned} \tag{1}$$

S2's corresponding expected profit is:

$$\pi_2(k_1,k_2) = \rho(k_2)[v_h - v_l - D]\left\{\theta[1-r\rho(k_1)] + \frac{1}{2}\phi\, r\rho(k_1)\right\} - k_2. \tag{2}$$

B's expected surplus if he accepts the (D,L) contract is:[19]

$$\begin{aligned} S(D,L) &= r\rho(k_1(D))\,\rho(k_2(D))\left\{\frac{1}{2}\phi v_l + [1-\phi][v_h - D]\right\} \\ &\quad + [1-r\rho(k_1(D))]\,\rho(k_2(D))\,\{\theta v_l + [1-\theta][v_h - D]\} + L. \end{aligned} \tag{3}$$

At a (subgame perfect) equilibrium in this setting, Si chooses k_i to maximize $\pi_i(\cdot)$, taking k_j and the prevailing (D,L) contract as given, for $j \neq i,\ i,j \in \{1,2\}$. Furthermore, S1 implements the contract that maximizes its expected profit (anticipating the ensuing R&D choices), while ensuring that the contract delivers to B at least the expected surplus he secures in the absence of a contract with S1.[20]

[18] Again, this price reflects the incremental value that B derives from buying the high-quality product from S2 rather than the low-quality product from S1.

[19] The notation $k_i(D)$ in equation (3) reflects the dependence of equilibrium R&D on the specified damage payment, D.

[20] B's expected surplus in the absence of a contract with S1 is as specified in equation (3), with $D = L = 0$.

Before proceeding to characterize the equilibrium in this setting, we briefly consider the efficient outcome. The efficient outcome consists of the R&D investments by S1 and S2 (denoted k_1 and k_2, respectively) that maximize total expected surplus, or "welfare":

$$W(k_1, k_2) \; = \; v_l + [v_h - v_l] \{ r\rho(k_1) + \rho(k_2) [1 - r\rho(k_1)] \} - k_1 - k_2. \tag{4}$$

The expression in equation (4) reflects the fact that the probability that incremental value $v_h - v_l$ is realized is the sum of the probability that S1 innovates successfully ($r\rho(k_1)$) and the probability that S2 innovates successfully when S1 does not innovate successfully ($\rho(k_2)[1 - r\rho(k_1)]$).

We assume that:

$$\rho''(k_1)\rho''(k_2)[1 - \rho(k_2)][1 - r\rho(k_1)] \; > \; r[\rho'(k_1)\rho'(k_2)]^2 \tag{5}$$

for all relevant k_1, k_2. Inequality (5) ensures that $W(k_1, k_2)$ is concave for all relevant k_1 and k_2. Inequality (5) will hold if $\rho(\cdot)$ is sufficiently concave.

Differentiating equation (4) reveals that the efficient k_1 and k_2, denoted k_1^* and k_2^*, satisfy:

$$r\rho'(k_1^*)[1 - \rho(k_2^*)][v_h - v_l] \; \leq \; 1, \text{ with equality if } k_1^* > 0; \tag{6}$$

$$\rho'(k_2^*)[1 - r\rho(k_1^*)][v_h - v_l] \; \leq \; 1, \text{ with equality if } k_2^* > 0. \tag{7}$$

For future reference, denote by r_1^* the largest value of r such that welfare is maximized when S1 undertakes no R&D (so $k_1^* = 0$). Also, denote by r_2^* the smallest value of r such that welfare is maximized when S2 undertakes no R&D (so $k_2^* = 0$).[21]

3 Findings.

We now present our main findings. Lemmas 1 – 3 provide some preliminary observations about how changes in the environment in which S1 and S2 operate affect their unilateral incentives to undertake R&D. Propositions 1 – 5 then present the key equilibrium predictions of the model. To simplify the statement of Lemmas 1 – 3, the lemmas restrict attention to settings in which both firms undertake a strictly positive level of R&D in equilibrium.[22]

Lemma 1 characterizes the reaction functions of S1 and S2 in these settings. A supplier's reaction function specifies its profit-maximizing level of R&D for any given level of R&D undertaken by the

[21] Equations (6) and (7) and Assumption 1 imply that $0 < r_1^* < r_2^*$.

[22] Such interior solutions typically will arise, for example, when r is neither too close to 0 nor too large, and when ϕ and/or ϕ_t are sufficiently close to 1. Necessary conditions for an interior solution are $r > 0$ and $\theta > 0$. When a firm's equilibrium level of R&D is 0, the firm's R&D may not change as relevant parameter values change.

rival. Differentiating equation (1) with respect to k_1 reveals that S1's reaction function, $R_1(k_2)$, in the region where S1's equilibrium R&D (k_1^e) is strictly positive is given by the value of k_1 that solves:

$$r\rho'(k_1)\left\{[1-\rho(k_2)][v_h - v_l] + \rho(k_2)\frac{\phi}{2}[v_h - D]\right\} \;=\; 1. \tag{8}$$

Similarly, differentiating equation (2) with respect to k_2 reveals that S2's reaction function, $R_2(k_1)$, in the region where S2's equilibrium R&D (k_2^e) is strictly positive is given by the value of k_2 that solves:

$$\rho'(k_2)\left[\theta - r\rho(k_1)\left(\theta - \frac{\phi}{2}\right)\right][v_h - v_l - D] \;=\; 1. \tag{9}$$

Lemma 1. *The reaction functions of S1 and S2 are both downward sloping (i.e., $R_1'(k_2) < 0$ and $R_2'(k_1) < 0$). Furthermore, an interior (k_1, k_2) equilibrium is unique and stable.*

Lemma 1 indicates that a supplier's expected return from R&D increases as its rival's R&D declines – that is, k_1 and k_2 are strategic substitutes. Reduced R&D by a rival increases the likelihood that a supplier will be the only firm to innovate successfully, which is when a supplier's expected profit is greatest under Bertrand competition.

Lemma 2 explains how reactions functions shift as exogenous parameters in the model change.

Lemma 2. *Holding all else constant, including the rival's R&D: (i) a supplier's R&D increases as patent protection increases or as its relative R&D ability increases (i.e., $\frac{dR_1(k_2)}{d\phi} > 0$, $\frac{dR_2(k_1)}{d\phi} > 0$, $\frac{dR_1(k_2)}{dr} > 0$, and $\frac{dR_2(k_1)}{dr} < 0$); (ii) S1's R&D does not change as the level of trade secret protection varies (i.e., $\frac{dR_1(k_2)}{d\phi_t} = 0$); and (iii) S2's R&D increases as trade secret protection increases if and only if trade secret protection is at least as strong as patent protection (i.e., $\frac{dR_2(k_1)}{d\phi_t} \geq 0$, with strict inequality if and only if $\phi_t \geq \phi$).*

Conclusion (i) in Lemma 2 reflects the fact that stronger patent protection increases the likelihood that a successful innovator will be the monopoly supplier of the high-quality product, and thereby increases each supplier's expected return from R&D, *ceteris paribus.* S1's expected return from R&D also increases when its relative R&D ability increases. Holding S1's R&D constant, the probability that S1 innovates successfully increases as r increases. The increased likelihood of successful innovation by S1 reduces S2's expected return from R&D, and thereby reduces S2's profit-maximizing level of R&D, *ceteris paribus.*

Conclusion (ii) in Lemma 2 reflects the fact that trade secret protection is only of potential value to S1 when S2 has not innovated successfully. In this case, though, S2's relatively high imitation costs ensure that it will choose not to operate in the industry even if trade secret protection does not preclude imitation. Therefore the level of trade secret protection does not affect S1's R&D incentives. Conclusion (iii) in Lemma 2 arises because when trade secret protection is at least as strong as patent protection, stronger trade secret protection increases the probability that S2 will be the only firm with the high-quality product when it innovates successfully. This increased probability increases S2's expected return to R&D. When patent protection is stronger than trade secret protection, though, S2 will rely upon the former to protect its innovation when it succeeds alone. Consequently, marginal increases in trade secret protection are of no value to S2 in this case.

Lemma 3 explains how the level of the damage payment in an exclusive contract affects R&D incentives.

Lemma 3. *Holding all else constant, including the rival's R&D, S1's R&D declines whenever some patent protection is present and S2's R&D always declines as the damage payment (D) in an exclusive contract increases (i.e., $\frac{dR_2(k_1)}{dD} < 0$ and $\frac{dR_1(k_2)}{dD} \leq 0$, with strict inequality if $\phi > 0$).*

As the damage payment (D) in an exclusive contract increases, S2 must reduce the price it charges for its product in order to secure B's patronage. Therefore, an increase in D reduces S2's expected return from innovation, and thereby reduces its R&D, *ceteris paribus.*

Lemma 3's conclusion that an increased damage payment also reduces S1's incentives for innovation whenever some patent protection is present may be more surprising. This conclusion reflects the following considerations. S1 receives profit D when S2 innovates successfully and: (i) S1 fails to innovate; (ii) S1 innovates and S2 is first to the patent office; or (iii) S1 innovates, is first to the patent office, but no patent is granted. Therefore, when S2 innovates successfully, a unit increase in the probability that S1 innovates successfully reduces the probability that S1's payoff will be D by $1 - \frac{1}{2} - \frac{1}{2}[1-\phi] = \frac{1}{2}\phi$. Consequently, successful innovation reduces the probability that S1 receives D (when $\phi > 0$), and so an increase in D reduces S1's incentive to innovate. If $\phi = 0$, so that no patent protection is available, S1's payoff is D whenever S2 innovates successfully (regardless of the outcome of S1's R&D). Therefore, for a given level of R&D by S2, changes in D do not affect S1's incentive for R&D when $\phi = 0$.

Lemmas 1 – 3 indicate how environmental factors influence the R&D incentives of individual suppliers in isolation. The equilibrium outcomes reported in Propositions 1 – 5 reflect the interactions among these individual effects. Proposition 1 refers to: (i) $r_2^n(\phi)$, which is the smallest value of r for which S2 will undertake no R&D in the absence of an exclusive contract;[23] and (ii) D^e, which is the damage payment in the equilibrium contract between S1 and B.

Proposition 1. *Suppose innovation protection is sufficiently pronounced (i.e., θ is sufficiently close to 1) and S2's R&D is strictly positive in the absence of an exclusive contract (so $r < r_2^n(\phi)$). Then S1 will implement a partially excluding contract when S1's relative R&D ability, r, is sufficiently limited. In contrast, S1 will implement a fully excluding contract when r is sufficiently pronounced (i.e., for each $\phi \in [0,1]$, there exists some $\widetilde{r}(\phi) \in [\frac{1}{\rho'(0)[v_h - v_l]}, \min\{r_2^*, r_2^n(\phi)\}]$ such that $D^e > 0$ and $k_2^e > 0$ when $r \leq \widetilde{r}(\phi)$, whereas $D^e > 0$ and $k_2^e = 0$ when $r \in (\widetilde{r}(\phi), r_2^n(\phi))$).*

Proposition 1 indicates that when patent protection and S1's relative R&D ability are pronounced, S1 will set D at or above the level required to fully exclude S2 from the industry.[24] In contrast, S1 will set a smaller D when its relative R&D ability is more limited. These conclusions reflect the key trade-off that S1 faces in setting D. As D increases, S1 captures more of the surplus that arises from S2's successful innovation. However, as Lemma 3 suggests, an increase in D can reduce the likelihood that S2 will innovate successfully by reducing S2's expected return from R&D. When S1's R&D ability is relatively pronounced, S1 will rely entirely on its own R&D to increase industry surplus. S1 will set D high enough to eliminate S2's incentive to undertake R&D and thereby ensure that all of the realized industry surplus will accrue to S1.[25] In contrast, when S1's relative R&D ability is limited, S1 is unlikely to innovate successfully. Consequently, S1 will rely on S2 to increase industry surplus, and so will be careful not to stifle S2's innovation unduly by setting D at too high a level.

Although S1 often will implement a partially excluding contract in order to usurp some of the surplus that S2 generates, S1 may sometimes prefer to capture this surplus by imitating S2's

[23] It is readily shown that $r_2^n(\phi) > r_2^*$ when $\phi > 0$ and θ is sufficiently close to 1.

[24] If r is sufficiently pronounced that S2 will refrain from R&D even in the absence of an exclusive contract (i.e., if $r \geq r_2^n(\phi)$), then S1 has no strict preference to implement an exclusive contract.

[25] S1 must compensate B for agreeing to a contract that effectively precludes industry competition. However, the expected loss in surplus from excluding S2 is small when S2's relative R&D ability is limited. Consequently, the lump-sum payment (L) that will induce B to sign a fully exclusive contract will be relatively small.

innovation when innovation protection is limited. When it is intent on imitation, S1 will not want to reduce the likelihood of S2's innovation by reducing S2's incentive to undertake R&D. Consequently, S1 will not implement an exclusive contract, as Proposition 2 reports.

Proposition 2. *S1 will sometimes choose not to implement an exclusive contract (so $D^e = 0$) when innovation protection is sufficiently limited (i.e., when θ is sufficiently close to 0).*

Propositions 1 and 2 address the equilibrium incidence of exclusive contracts. Proposition 3 considers the impact of an exclusive contract on equilibrium R&D. The proposition refers to: (i) k_i^n, which is Si's equilibrium R&D in the absence of an exclusive contract; and (ii) $r_1^n(\phi)$, which is the largest realization of r for which $k_1^n = 0$, given ϕ. The proposition also refers to the following inequality, which will hold when $\rho(\cdot)$ is sufficiently concave:

$$-\rho''(k_1)\left[1 - r\rho(k_1)\right] \;\geq\; r\left[\rho'(k_1)\right]^2 \rho(k_2)\left[\frac{v_h - v_l}{v_h}\right] \quad \text{for all relevant } k_1, k_2. \tag{10}$$

Proposition 3. *(i) An equilibrium exclusive contract will always reduce the R&D of at least one supplier (so $k_1^e < k_1^n$ and/or $k_2^e < k_2^n$) and can reduce the R&D of both suppliers. (ii) The exclusive contract will reduce S2's R&D (so $k_2^e < k_2^n$) if ϕ is small or if inequality (10) holds. (iii) The exclusive contract will increase S1's R&D when its R&D ability is sufficiently pronounced, particularly when patent protection is limited (i.e., $k_1^e > k_1^n$ when $r \geq r_2^*$ or when $r > r_1^n(\phi)$ and ϕ is sufficiently small).*

Recall from Lemma 3 that an increase in the damage payment (D) in an exclusive contract reduces each supplier's incentive for R&D, *ceteris paribus*. An increase in the rival's R&D would further reduce the return that a firm anticipates from R&D. (Recall Lemma 1.) Consequently, an increase in D reduces the equilibrium R&D of at least one firm. Because the firms' R&D investments are strategic substitutes, the reduction in one firm's equilibrium R&D induced by an exclusive contract can increase the equilibrium R&D of the other firm.[26] As Proposition 3 reports, an exclusive contract will increase S1's equilibrium R&D when its relative R&D ability (r) is sufficiently pronounced. For example, when r is so high that S2's efficient level of R&D is 0, S1 will optimally set D at or above the level that induces S2 to refrain from R&D. By doing so and

[26] We conjecture that an exclusive contract will always reduce S2's equilibrium R&D when inequality (5) holds. We have been unable to identify a setting in which $k_2^e > k_2^n$ when inequality (5) holds.

by supplying the efficient level of R&D (k_1^*), S1 can maximize expected surplus and ensure that S2 receives none of the surplus.

An exclusive contract also will increase S1's equilibrium R&D when patent protection is limited. In this case, S1 is likely to receive D whenever S2 succeeds, regardless of whether S1 innovates successfully or fails to innovate. Consequently, an exclusive contract (i.e., an increase in D above 0) will have little impact on S1's R&D. However, an exclusive contract will reduce S2's R&D, as Lemma 3 suggests. The reduction in S2's R&D increases S1's expected return from R&D, and so S1's R&D increases.

Having explored some of the impacts of an exclusive contract on equilibrium R&D, we now consider the corresponding welfare implications. Proposition 4 identifies three settings in which an exclusive contract will reduce welfare.

Proposition 4. *The equilibrium exclusive contract will reduce welfare when: (i) there is perfect trade secret protection and no patent protection ($\phi_t = 1$ and $\phi = 0$); (ii) there is imperfect trade secret protection and sufficiently limited patent protection ($\phi_t < 1$ and ϕ is small); or (iii) S1's relative R&D ability is sufficiently limited ($r \leq r_1^n(\phi)$).*

Conclusion (i) in Proposition 4 reflects the following considerations. In the presence of perfect trade secret protection and no patent protection (and no exclusive contract), a firm receives the full incremental value of its innovation when and only when it innovates alone. In this case, the private incentives for innovation coincide with the social objectives (recall equation (4)), and so the firms undertake the efficient levels of R&D in the absence of an exclusive contract. An exclusive contract reduces welfare by distorting R&D away from its efficient levels.

Conclusion (ii) in Proposition 4 arises because S1 will undertake more and S2 will undertake less than the efficient level of R&D in the presence of imperfect trade secret protection and limited patent protection. To understand why this is the case, recall that S2 undertakes the efficient level of R&D when there is perfect trade secret protection and no patent protection. Starting from this point (or from a point of sufficiently limited patent protection), reduced trade secret protection reduces S2's R&D incentives without affecting S1's R&D incentives. (Recall Lemma 2.) The resulting decline in S2's R&D causes S1 to anticipate relatively pronounced private gains from R&D, and so S1 undertakes an inefficiently large level of R&D. An exclusive contract aggravates these investment distortions, thereby reducing welfare.

To understand conclusion (iii) in Proposition 4, note that if S1's relative R&D ability is sufficiently limited, S1 (efficiently) undertakes no R&D in the absence of an exclusive contract (so $k_1^* = 0$). In this case, S2 will undertake the efficient level of R&D (k_2^*) if innovation protection is complete and less than the efficient level of R&D if innovation protection is incomplete. In this setting, an exclusive contract reduces S2's R&D (further) below the efficient level and/or increases S1's R&D above the efficient level. Both investment distortions reduce welfare.

Proposition 5 points out that although an exclusive contract often will reduce welfare, it can also increase welfare. It will do so, for example, when S1's relative R&D ability is sufficiently pronounced that S2's efficient level of R&D is zero, but patent protection induces S2 to undertake R&D in the absence of an exclusive contract. In this setting, an exclusive contract will increase welfare by reducing S2's R&D to its efficient level.[27]

Proposition 5. *S1 will implement an exclusive contract that increases welfare when patent protection and S1's R&D ability are relatively pronounced. (Formally, when $\phi \to 1$, there exists some $\hat{r}_2 \leq r_2^* < r_2^n(\phi)$ such that $D^e > 0$ and $W(k_1^e, k_2^e) > W(k_1^n, k_2^n)$ if $r \in (\hat{r}_2, r_2^n(\phi))$).*

Propositions 4 and 5 provide the following conclusion.

Corollary 1. *A fully exclusive contract can increase welfare while a partially exclusive contract can reduce welfare in equilibrium.*

4 Settings with Additional Structure.

Additional conclusions about the incidence and effects of exclusive contracts can be drawn if sufficient structure is imposed to admit explicit solutions to equations (8) and (9). To this end, we suppose that $\rho(k) = \frac{1}{3}\left[1 - (1-k)^2\right]$ in this section, and examine how the incidence of exclusive contracts and their impacts on R&D and welfare vary as the key parameters in the model (ϕ, ϕ_t, and r) change.

First consider how equilibrium outcomes vary as the degree of patent protection (ϕ) changes. To do so, suppose S1 and S2 have the same R&D abilities ($r = 1$), trade secret protection is perfect

[27] The buyer (B) does not share in these welfare gains in our simple model where S1 is endowed with all of the bargaining power in its interaction with B. In settings where B's bargaining power is more pronounced, B will enjoy a portion of the welfare gains produced by an exclusive contract.

($\phi_t = 1$), $v_h = 3$, and $v_l = 1$. Table 1 reports how equilibrium R&D investments (k_i^n) and welfare (W^n) vary with ϕ in the absence of an exclusive contract in this setting. The table also reports how the corresponding equilibrium investments (k_i^e), welfare (W^e), and damage payment (D^e) vary with ϕ when exclusive contracts are not prohibited.

ϕ	k_1^n	k_2^n	W^n	D^e	k_1^e	k_2^e	W^e
0.00	0.1655	0.1655	1.0533	0.1485	0.2138	0.0717	1.0495
0.25	0.1808	0.1704	1.0531	0.1761	0.2206	0.0713	1.0495
0.50	0.1959	0.1773	1.0525	0.2061	0.2273	0.0702	1.0493
0.75	0.2112	0.1859	1.0513	0.2381	0.2337	0.0685	1.0491
1.00	0.2272	0.1960	1.0494	0.2717	0.2396	0.0665	1.0488

Table 1. Effects of Patent Protection ($r = 1$; $\phi_t = 1$; $v_h = 3$; $v_l = 1$)**.**

Recall that when trade secret protection is perfect, patent protection induces R&D above efficient levels in the absence of an exclusive contract. The resulting decline in welfare is reflected in the fourth column of Table 1. An exclusive contract reduces welfare even more (i.e., $W^e < W^n$) in the present setting by increasing S1's investment further above the efficient level.

S1 always implements a partially excluding contract in this setting in order to capture some of the surplus that arises from S2's innovation. The positive damage payment ($D^e > 0$) that S1 implements reduces both S2's R&D and welfare (i.e., $k_2^e < k_2^n$ and $W^e < W^n$).[28] Thus, the positive direct effect of increased patent protection on S2's R&D (recall Lemma 2) is outweighed by the reduction in S2's R&D induced by the higher damage payment that S1 implements as ϕ increases.[29]

Now consider how equilibrium outcomes vary as the prevailing trade secret protection varies. Table 2 explores this issue in a setting with imperfect patent protection ($\phi = 0.5$),[30] where S1 and S2 have identical R&D abilities ($r = 1$), and where $v_h = 6$ and $v_l = 1$.

[28] Although welfare always declines as patent protection (ϕ) increases in the setting of Table 1, welfare can increase as patent protection increases when trade secret protection is imperfect. It can be shown, for example, that welfare increases as ϕ increases from 0.75 to 1.0 when $\phi_t \leq 0.75$ in the setting where $r = 1$, $v_h = 3$, and $v_l = 1$.

[29] S1 implements a larger damage payment as ϕ increases in the setting of Table 1 in part because S1 becomes less concerned that a large damage payment will limit S2's R&D unduly when S2 enjoys pronounced patent protection.

[30] $\phi < 1$ admits a meaningful role for trade secret protection. When $\phi = 1$, S1 and S2 always seek patent protection following successful innovation, and so equilibrium outcomes are independent of ϕ_t.

ϕ_t	k_1^n	k_2^n	W^n	D^e	k_1^e	k_2^e	W^e
≤ 0.5	0.6600	0.2963	2.1110	0.0	0.6600	0.2963	2.1110
0.6	0.6476	0.3974	2.1663	0.5332	0.6545	0.3247	2.1290
0.7	0.6392	0.4733	2.1923	1.0893	0.6524	0.3249	2.1292
0.8	0.6331	0.5322	2.2034	1.5226	0.6508	0.3250	2.1294
0.9	0.6287	0.5794	2.2064	1.8696	0.6495	0.3251	2.1295
1.0	0.6254	0.6179	2.2050	2.1537	0.6485	0.3251	2.1296

Table 2. Effects of Trade Secret Protection ($r = 1$; $\phi = 0.5$; $v_h = 6$; $v_l = 1$).

Table 2 illustrates the conclusion drawn in Proposition 2. When innovation protection is limited ($\phi = 0.5$ and $\phi_t \leq 0.5$), S1 anticipates substantial benefit from imitating S2's innovation. Consequently, S1 does not wish to limit S2's R&D, and so does not implement an exclusive contract. As innovation protection increases, S1 becomes less likely to successfully imitate S2's innovation. Consequently, S1 focuses on capturing a portion of the surplus that arises from S2's innovation by implementing an exclusive contract. S1 increases the damage payment in the contract as ϕ_t increases, in part because S1 becomes less concerned with limiting S2's R&D unduly as the trade secret protection that S2 enjoys increases.[31]

The exclusive contract that S1 implements reduces welfare (i.e., $W^e < W^n$ when $D^e > 0$) in the setting of Table 2. The welfare reduction arises in part because the exclusive contract helps S1 to sustain an inefficiently high level of R&D.

Now consider how equilibrium outcomes vary as the relative R&D abilities of S1 and S2 change. Table 3 considers a setting where perfect trade secret protection prevails ($\phi_t = 1$), there is no patent protection ($\phi = 0$), $v_h = 3$, and $v_l = 1$. Recall that in the absence of exclusive contracts, equilibrium investment is efficient when $\phi = 0$ and $\phi_t = 1$.

[31] Recall from Lemma 2 that when $\phi_t \geq \phi$, S2's incentive for R&D increases as ϕ_t increases, *ceteris paribus*.

r	k_1^n	k_2^n	W^n	D^e	k_1^e	k_2^2	W^e
0.10	0.0	0.2500	1.0417	0.2763	0.0	0.1298	1.0320
0.50	0.0	0.2500	1.0417	0.2763	0.0	0.1298	1.0320
0.80	0.0	0.2500	1.0417	0.2763	0.0	0.1298	1.0320
1.00	0.1655	0.1655	1.0533	0.1485	0.2138	0.0717	1.0495
1.20	0.3703	0.0114	1.1125	0.0096	0.3730	0.0048	1.1125
1.50	0.5000	0.0	1.2500	0.0	0.5000	0.0	1.2500
2.00	0.6250	0.0	1.5208	0.0	0.6250	0.0	1.5208

Table 3. Effects of Relative R&D Abilities ($\phi = 0$; $\phi_t = 1$; $v_h = 3$; $v_l = 1$).

Welfare increases as r increases in the setting of Table 3 because S1's R&D ability increases and S2's R&D ability is unchanged as r increases.[32] Also, when S1's relative R&D ability is sufficiently limited (e.g., $r \leq 1.2$), S1 employs a partially excluding contract to capture some of the surplus generated by S2's R&D. The equilibrium exclusive contract reduces S2's R&D below its efficient level, and thereby reduces welfare. When S1's relative R&D ability is sufficiently pronounced (e.g., $r = 1.5$ or $r = 2.0$), S2 will refrain from R&D in the setting of Table 3 even in the absence of an exclusive contract, and so S1 does not gain by implementing an exclusive contract.

Table 4 illustrates that the effects of changes in r on equilibrium outcomes can vary as the level of prevailing patent protection (ϕ) changes. The table reveals that when patent protection is perfect ($\phi = 1$), the equilibrium exclusive contract reduces welfare when r is small ($r \leq 1$) and increases welfare when r is moderately large ($r = 1.2$ or $r = 1.5$). The welfare reduction for small r arises because the strictly positive damage payment that S1 implements in order to capture some of the surplus generated by S2's innovation reduces S2's R&D below its efficient level.[33] The increase in welfare when $r = 1.2$ or $r = 1.5$ arises because, in increasing S1's R&D and reducing S2's R&D, the exclusive contract moves R&D investments closer to their efficient levels.[34] S1 does not benefit

[32] The increase in welfare is strictly positive when S1's R&D ability is sufficiently pronounced that S1's equilibrium R&D is strictly positive.

[33] From Table 3, $k_2^* = k_2^n = 0.25$ when $r \leq 0.8$, whereas $k_2^* = 0.1655$ when $r = 1.0$.

[34] The socially excessive innovation protection that prevails in the setting of Table 4 induces S2 to undertake more than the efficient level of R&D in the absence of an exclusive contract. S1's corresponding best response is to undertake less than the efficient level of R&D. From Table 3, $k_1^* = k_1^n = 0.3703$ and $k_2^* = k_2^n = 0.0114$ when $r = 1.2$. When $r = 1.5$, $k_1^* = k_1^n = 0.5$ and $k_2^* = k_2^n = 0$. It can be shown that the equilibrium exclusive contract also increases welfare in the setting of Table 4 when the R&D abilities of S1 and S2 are more similar (e.g., $r = 1.05$).

from implementing an exclusive contract when r is sufficiently large (e.g., $r = 2$). In this case, S2's relative R&D ability is so limited that it chooses not to undertake any R&D even in the absence of an exclusive contract.

r	k_1^n	k_2^n	W^n	D^e	k_1^e	k_2^2	W^e
0.10	0.0	0.2500	1.0417	0.2763	0.0	0.1298	1.0320
0.50	0.0	0.2500	1.0417	0.2763	0.0	0.1298	1.0320
0.80	0.0277	0.2445	1.0389	0.2697	0.0388	0.1242	1.0298
1.00	0.2272	0.1960	1.0494	0.2717	0.2396	0.0665	1.0488
1.20	0.3603	0.1495	1.1037	0.2845	0.3744	0.0045	1.1125
1.50	0.4936	0.0787	1.2346	0.1539	0.5000	0.0	1.2500
2.00	0.6250	0.0	1.5208	0.0	0.6250	0.0	1.5208

Table 4. Effects of Relative R&D Abilities ($\phi = 1$; $\phi_t = 1$; $v_h = 3$; $v_l = 1$).

Table 4 reveals that the equilibrium damage payment (D^e) can vary non-monotonically with r. In the setting of Table 4, D^e increases as r increases from .8 to 1.0 to 1.2, while D^e decreases as r increases from 1.2 to 1.5. As r increases from .8 to 1.0 to 1.2, S1's increased R&D ability reduces its concern about diminishing S2's R&D, and so S1 increases the damage payment in the exclusive contract. As r increases from from 1.2 to 1.5, S1's large and increasing R&D ability reduces S2's R&D substantially. S1 reduces the damage payment in this case so as not to reduce S2's R&D unduly.[35]

Finally, Table 5 illustrates that the effects of changes in r on equilibrium outcomes can vary as the social value of innovation ($v_h - v_l$) changes. Table 5, like Table 4, considers a setting with perfect patent and trade secret protection. Table 5 presumes $v_h = 6$ and $v_l = 1$.

[35] Table 4 also reveals that welfare can decline as industry R&D ability increases (both with and without exclusive contracts). The welfare reduction arises because the increase in r stimulates additional R&D, which is already above efficient levels due to the prevailing excessive innovation protection.

r	k_1^n	k_2^n	W^n	D^e	k_1^e	k_2^e	W^e
0.10	0.0	0.7000	1.8167	2.4417	0.0	0.4137	1.6800
0.50	0.3180	0.6860	1.8101	2.4153	0.3062	0.3934	1.6950
0.80	0.5747	0.6632	2.0091	2.3981	0.5719	0.3530	1.9220
1.00	0.6603	0.6481	2.1956	2.3831	0.6604	0.3277	2.1304
1.20	0.7156	0.6937	2.3840	2.4044	0.7203	0.2915	2.3557
1.50	0.7746	0.6067	2.7319	2.4390	0.7807	0.2314	2.7251
2.00	0.8320	0.5563	3.3223	2.6031	0.8453	0.0724	3.4171

Table 5. Effects of Relative R&D Abilities ($\phi = 1$; $\phi_t = 1$; $v_h = 6$; $v_l = 1$).

When the social value of innovation is pronounced, S2 has considerable incentive to undertake R&D even in the presence of a relatively large damage payment (D). Consequently, S1 finds it optimal to implement an exclusive contract with a relatively large D. Recall from Lemma 3 that S1's incentive for R&D declines as D increases. Therefore, an exclusive contract can reduce S1's equilibrium R&D, as it does in the setting of Table 5 when $r = 0.5$ and $r = 0.8$. In this case, the exclusive contract reduces the R&D of both industry suppliers.

5 Extensions and Conclusions.

We have analyzed a simple variant of Aghion and Bolton's (1987) model in order to identify most clearly the primary effects of exclusive contracts on innovation and welfare. In our model, an exclusive contract reduces the R&D of at least one industry supplier, and can reduce the R&D of both suppliers, depending upon the environment in which the contract is implemented. The changes in R&D induced by exclusive contracts can either increase or decrease welfare, depending in part upon whether R&D is above or below efficient levels in the absence of an exclusive contract.

The key considerations and trade-offs that arise in our basic model persist in alternative settings. Consider, for instance, a setting that parallels the model developed above except that the high-quality products of S1 and S2 are horizontally differentiated.[36] The product differentiation reduces

[36] The particular form of horizontal differentiation that we have analyzed includes the following features. B's valuation of S1's high-quality product is $v_h - tx$ while his valuation of S2's high-quality product is $v_h - t[1 - x]$, where $t \geq 0$ is a measure of product differentiation. S1 and S2 both view x as a random variable with a uniform distribution on $[0, 1]$ at the time they choose their R&D investments. The suppliers learn the realization of x before they set their prices.

the intensity of price competition and thereby increases the profits the suppliers secure when they both market the high-quality product. Consequently, product differentiation increases the suppliers' expected return from R&D, *ceteris paribus.* The resulting increase in R&D that typically arises in equilibrium can increase (reduce) welfare when R&D is otherwise below (above) efficient levels. In turn, the welfare effects of exclusive contracts in this setting vary according to whether R&D is above or below efficient levels in the absence of an exclusive contract, much as in the setting analyzed above.

Elastic (downward-sloping) demand can also increase S2's incentive for R&D. When the buyer purchases additional units of the product as its price declines, S2 can secure positive profit even when both suppliers market the high-quality product. In this case, S1 will not sell to B at a price that generates a profit below D. This may allow S2 to secure B's patronage with a positive (and thus profitable) price, under which B's surplus from purchasing from S1 is the same as the surplus from purchasing from S2 and paying D to S1. The positive profit that S2 secures when both firms market the high-quality product increases S2's incentive for R&D, which can either increase or reduce welfare, depending upon whether S2's equilibrium R&D is above or below the efficient level.

Elastic demand complicates an analysis of the welfare effects of exclusive contracts in part because the damage payment in an exclusive contract typically will affect equilibrium prices in a nonlinear fashion (due to the nonlinearity of the consumer surplus function). Furthermore, deadweight loss arises when prices diverge from marginal cost. Despite these complications, unequivocal welfare conclusions can be drawn in settings of interest. For example, consider a setting that parallels the setting analyzed above except that B will demand $Q(p, v)$ units of the product when its price is p and its quality is v, where $\frac{\partial Q(\cdot)}{\partial p} < 0$ and $Q(p, v_h) > Q(p, v_l)$ for all $p \in [0, \overline{p}]$, where $\overline{p} \in (0, \infty)$. Suppose that S1's relative R&D ability in this setting is sufficiently small that S1 will not undertake any R&D in the absence of an exclusive contract. It can be shown that S1's preferred contract in this setting is a partially excluding contract that specifies a damage payment in excess of the welfare-maximizing damage payment. Thus, just as in the model analyzed above, settings arise in which S1's desire to capture some of the surplus generated by S2's R&D leads it to diminish S2's R&D to an extent that reduces welfare. This is the case despite the fact that deadweight loss is reduced when an exclusive contract compels S2 to reduce its price toward marginal cost in order to secure the buyer's patronage.

The single buyer in our basic model was never harmed by the introduction of an exclusive contract. In contrast, some or all buyers may be harmed by exclusive contracts in the presence of multiple buyers, as Rasmusen et al. (1991) have demonstrated in a related model (that does not permit R&D by industry suppliers).[37] To see why, suppose the parameters of the model are such that S2 will not find it profitable to undertake R&D in the absence of an exclusive contract if S2 can sell to only one buyer. In this case, if all buyers but one sign an exclusive contract that specifies a prohibitively high damage payment (D), then S2 will not enter the market regardless of whether the remaining buyer signs the contract. Consequently, S1 does not need to design the contract to ensure that the remaining buyer prefers it to no exclusive contract. These considerations admit an equilibrium in which all buyers sign an exclusive contract that leaves them with less expected surplus than they would secure in the absence of an exclusive contract.

These extensions do not exhaust the set of useful extensions of our model. Alternative settings of interest include those with additional incumbent suppliers (as in Stefanadis (1997) and Milliou (2008), for example) and those in which buyers are producers rather than consumers (as in Fumagalli and Motta (2006), Simpson and Wickelgren (2007), and Abito and Wright (2008), for example). Continuous (rather than binary) R&D outcomes and differences in the abilities of individual suppliers to protect their innovations might also be analyzed. These extensions and others await future research.

[37] Also see Segal and Whinston (2000a).

Appendix

Proof of Lemma 1.

Differentiating (8) provides:

$$\frac{\partial^2 \pi_1(k_1,k_2)}{\partial k_1 \partial k_2} \;=\; -\,r\rho'(k_1)\,\rho'(k_2)\left[v_h - v_l - \frac{\phi}{2}(v_h - D)\right] \;<\; 0\,, \tag{A1}$$

where $v_h - v_l - \frac{\phi}{2}[v_h - D] \geq v_h - v_l - \frac{\phi}{2}v_h > 0$ from Assumption 1. Similarly, differentiating (9) provides:

$$\frac{\partial^2 \pi_2(k_1,k_2)}{\partial k_1 \partial k_2} \;=\; -\,r\rho'(k_2)\,\rho'(k_1)\,[v_h - v_l - D]\left[\theta - \frac{\phi}{2}\right] \;<\; 0. \tag{A2}$$

The inequality in (A2) holds because $\theta = \max\{\phi_t, \phi\} > 0$ and $\theta \geq \phi$. (A1) and (A2) imply that both $R_i(\cdot)$ functions are downward-sloping when $r > 0$ and $\theta > 0$.

Because both R_i functions are downward-sloping, a unique and stable equilibrium will exist if $R_1(\cdot)$ is more steeply sloped than $R_2(\cdot)$ in k_1-k_2 space. From (8), (9), (A1), and (A2), this will be the case if:

$$\left|\frac{\frac{\partial^2 \pi_1(\cdot)}{\partial k_1 \partial k_2}}{\frac{\partial^2 \pi_1(\cdot)}{\partial k_1^2}}\right|^{-1} \;>\; \left|\frac{\frac{\partial^2 \pi_2(\cdot)}{\partial k_2 \partial k_1}}{\frac{\partial^2 \pi_2(\cdot)}{\partial k_2^2}}\right|$$

$$\Leftrightarrow\quad \frac{r\rho''(k_1)\left\{[1-\rho(k_2)]\,[v_h - v_l] + \rho(k_2)\,\frac{\phi}{2}\,[v_h - D]\right\}}{\rho'(k_1)\,\rho'(k_2)\,[v_h - v_l - \frac{\phi}{2}(v_h - D)]} \;>\; \frac{r\rho'(k_2)\,\rho'(k_1)\left[\theta - \frac{\phi}{2}\right]}{\rho''(k_2)\left[\theta - r\rho(k_1)\left(\theta - \frac{\phi}{2}\right)\right]}$$

$$\Leftrightarrow\quad \rho''(k_1)\,\rho''(k_2)\left\{[1-\rho(k_2)]\,[v_h - v_l] + \rho(k_2)\,\frac{\phi}{2}\,[v_h - D]\right\}\left[\theta - r\rho(k_1)\left(\theta - \frac{\phi}{2}\right)\right]$$

$$>\; r\left[\rho'(k_1)\,\rho'(k_2)\right]^2\left[v_h - v_l - \frac{\phi}{2}\,[v_h - D]\right]\left[\theta - \frac{\phi}{2}\right]. \tag{A3}$$

The inequality in (A3) holds because:

$$\rho''(k_1)\,\rho''(k_2)\left\{[1-\rho(k_2)]\,[v_h - v_l] + \rho(k_2)\,\frac{\phi}{2}\,[v_h - D]\right\}\left[\theta - r\rho(k_1)\left(\theta - \frac{\phi}{2}\right)\right]$$

$$\geq\; \rho''(k_1)\,\rho''(k_2)\,[1-\rho(k_2)]\,[v_h - v_l]\,\theta\,[1 - r\rho(k_1)] \;>\; r\left[\rho'(k_1)\rho'(k_2)\right]^2[v_h - v_l]\,\theta \tag{A4}$$

$$\geq\; r\left[\rho'(k_1)\rho'(k_2)\right]^2\left[v_h - v_l - \frac{\phi}{2}\,(v_h - D)\right]\left[\theta - \frac{\phi}{2}\right]. \tag{A5}$$

The strict inequality in (A4) follows from (5). ■

Proofs of Lemmas 2 – 5.

Differentiating (8) implies that when $k_1 > 0$, $k_2 > 0$, and $v_h - v_l > D > 0$:

$$\frac{dR_1(k_2)}{dr} = -\frac{\frac{\partial^2 \pi_1}{\partial k_1 \partial r}}{\frac{\partial^2 \pi_1}{\partial k_1^2}} \stackrel{s}{=} \frac{\partial^2 \pi_1}{\partial k_1 \partial r} = \rho'(k_1)\left\{[1-\rho(k_2)][v_h - v_l] + \rho(k_2)\frac{\phi}{2}[v_h - D]\right\} > 0.$$

Similarly:

$$\frac{dR_1(k_2)}{d\phi} \stackrel{s}{=} \frac{\partial^2 \pi_1}{\partial k_1 \partial \phi} = r\rho'(k_1)\rho(k_2)\frac{1}{2}[v_h - D] > 0;$$

$$\frac{dR_1(k_2)}{d\phi_t} \stackrel{s}{=} \frac{\partial^2 \pi_1}{\partial k_1 \partial \phi_t} = 0; \quad \text{and}$$

$$\frac{dR_1(k_2)}{dD} \stackrel{s}{=} \frac{\partial^2 \pi_1}{\partial k_1 \partial D} = -r\rho'(k_1)\rho(k_2)\frac{\phi}{2} < 0. \tag{A6}$$

Differentiating (9) implies that when $k_1 > 0$, $k_2 > 0$, and $v_h - v_l > D > 0$:

$$\frac{dR_2(k_1)}{dr} = -\frac{\frac{\partial^2 \pi_2}{\partial k_2 \partial r}}{\frac{\partial^2 \pi_2}{\partial k_2^2}} \stackrel{s}{=} \frac{\partial^2 \pi_2}{\partial k_2 \partial r} = -\rho(k_1)\left[\theta - \frac{\phi}{2}\right]\rho'(k_2)[v_h - v_l - D] < 0.$$

Similarly:

$$\frac{dR_2(k_1)}{d\phi} \stackrel{s}{=} \frac{\partial^2 \pi_2}{\partial k_2 \partial \phi} = \rho'(k_2)\left[\frac{\partial \theta}{\partial \phi} - r\rho(k_1)\left(\frac{\partial \theta}{\partial \phi} - \frac{1}{2}\right)\right][v_h - v_l - D] > 0; \quad \text{and}$$

$$\frac{dR_2(k_1)}{d\phi_t} \stackrel{s}{=} \frac{\partial^2 \pi_2}{\partial k_2 \partial \phi_t} = \rho'(k_2)\frac{\partial \theta}{\partial \phi_t}[1 - r\rho(k_1)][v_h - v_l - D] \geq 0, \tag{A7}$$

where the inequality in (A7) holds strictly if and only if $\phi_t \geq \phi$. Also:

$$\frac{dR_2(k_1)}{dD} \stackrel{s}{=} \frac{\partial^2 \pi_2}{\partial k_2 \partial D} = -\rho'(k_2)\left[\theta - r\rho(k_1)\left(\theta - \frac{\phi}{2}\right)\right] < 0. \quad \blacksquare \tag{A8}$$

Proof of Proposition 1.

From (1) and (3), the joint surplus of S1 and B, given D, k_1, and k_2 is:

$$\begin{aligned} J(D) &= r\rho(k_1)[1-\rho(k_2)]v_h + [1 - r\rho(k_1)][1-\rho(k_2)]v_l \\ &+ r\rho(k_1)\rho(k_2)\left\{\frac{1}{2}D + \frac{1}{2}[\phi v_h + (1-\phi)D]\right\} + [1-r\rho(k_1)]\rho(k_2)D - k_1 \\ &+ r\rho(k_1)\rho(k_2)\left[\frac{1}{2}\phi v_l + [1-\phi](v_h - D)\right] + [1 - r\rho(k_1)]\rho(k_2)[\theta v_l + [1-\theta](v_h - D)] \\ &= v_l + r\rho(k_1(D))[v_h - v_l] - k_1(D) + \\ &\rho(k_2(D))\left\{[1 - r\rho(k_1(D))][\theta D + [1-\theta](v_h - v_l)] - r\rho(k_1(D))\frac{\phi}{2}[v_h - v_l - D]\right\}. \end{aligned} \tag{A9}$$

Differentiating (A9) provides:

$$
\begin{aligned}
J'(D) &= \left\{r\rho'(k_1(D))[v_h - v_l] - 1\right\} k_1'(D) \\
&+ \left\{-r\rho'(k_1(D))[\theta D + [1-\theta](v_h - v_l)] - r\rho'(k_1(D))\frac{\phi}{2}[v_h - v_l - D]\right\} k_1'(D)\rho(k_2(D)) \\
&+ \left[\theta - r\rho(k_1(D))\left(\theta - \frac{\phi}{2}\right)\right]\rho(k_2(D)) + \rho'(k_2(D))k_2'(D)\cdot \\
&\quad \left\{[1 - r\rho(k_1(D))][\theta D + [1-\theta](v_h - v_l)] - r\rho(k_1(D))\frac{\phi[v_h - v_l - D]}{2}\right\}.
\end{aligned} \tag{A10}
$$

If $r < r_1^n(\phi)$, then $k_1(0) = 0$ and $k_1'(D)|_{D=0} = 0$. Therefore, since $\rho(k_1(0)) = \rho(0) = 0$ by Assumption 1, (11) implies:

$$
J'(0) = \theta\rho(k_2(0)) + [1-\theta][v_h - v_l]\rho'(k_2(0))k_2'(0). \tag{A11}
$$

The expression in (A11) will be strictly positive when θ is sufficiently close to 1. Therefore, $J'(0) > 0$ in this case, and so $D^e > 0$.

If $r_1^n(\phi) \leq r < r_2^n(\phi)$, then $k_1(0) \in [0, \bar{k}_1)$, where $\bar{k}_1 \equiv \arg\max_{k_1} W(k_1, 0)$. If $D = v_h - v_l$, then $k_2 = 0$ and $\rho(k_2) = 0$. Therefore, from (A9), if θ is sufficiently close to 1:

$$
\begin{aligned}
J(0) &= v_l + r\rho(k_1(0))[v_h - v_l] - k_1(0) \\
&\quad + \left\{[1 - r\rho(k_1(0))][1-\theta][v_h - v_l] - r\rho(k_1(0))\frac{\phi}{2}[v_h - v_l]\right\}\rho(k_2(0)) \\
&\leq v_l + r\rho(k_1(0))[v_h - v_l] - k_1(0) \quad \text{as } \theta \to 1 \\
&< \max_{k_1}\{v_l + r\rho(k_1)[v_h - v_l] - k_1\} = J(v_h - v_l) \leq \max_D J(D) = J(D^e).
\end{aligned} \tag{A12}
$$

The strict inequality in (A12) follows from the concavity of $v_l + r\rho(k_1)[v_h - v_l] - k_1$. (A12) implies that $D^e > 0$.

Let $\bar{D}(\phi) > 0$ denote the smallest D such that $k_2(D) = 0$, given patent protection probability ϕ. Formally:

$$
k_2(D) \begin{cases} > 0 & if \quad D < \bar{D}(\phi) \\ = 0 & if \quad D \geq \bar{D}(\phi). \end{cases} \tag{A13}
$$

At $D = \bar{D}(\phi) > 0$, $k_2^e = 0$, and thus $k_1^e = k_1(\bar{D}) = \bar{k}_1$. Since $\rho(k_2(D))_{D=\bar{D}(\phi)^-} = \rho(k_2(\bar{D}(\phi)^-)) = \rho(0) = 0$, (11) implies:

$$
J'(D)\big|_{D=\bar{D}(\phi)^-} = \{[1 - r\rho(k_1(D))][\theta D + [1-\theta](v_h - v_l)]
$$

$$-r\rho\left(k_1\left(D\right)\right)\frac{\phi}{2}\left[v_h-v_l-D\right]\}\rho'\left(k_2\left(D\right)\right)k_2'\left(D\right)_{D=\bar{D}(\phi)^-}$$

$$= \left\{\theta D+\left[1-\theta\right]\left[v_h-v_l\right]-r\rho\left(k_1\left(D\right)\right)\left[\frac{\phi}{2}\left[v_h-v_l-D\right]+\theta D+\left[1-\theta\right]\left[v_h-v_l\right]\right]\right\}\cdot$$

$$\rho'\left(k_2\left(D\right)\right)k_2'\left(D\right)_{D=\bar{D}(\phi)^-} \equiv \Phi\,\rho'\left(k_2\left(D\right)\right)k_2'\left(D\right)_{D=\bar{D}(\phi)^-},$$

where:

$$\Phi = \theta\bar{D}+\left[1-\theta\right]\left[v_h-v_l\right]-r\rho\left(k_1\left(\bar{D}\right)\right)\left[\frac{\phi}{2}\left[v_h-v_l\right]+\bar{D}\left(\theta-\frac{\phi}{2}\right)+\left[1-\theta\right]\left[v_h-v_l\right]\right]$$

$$= \bar{D}\left[\theta-\left(\theta-\frac{\phi}{2}\right)r\rho\left(\bar{k}_1\right)\right]+\left[1-\theta\right]\left[v_h-v_l\right]-r\rho\left(\bar{k}_1\right)\left[v_h-v_l\right]\left[\frac{\phi}{2}+1-\theta\right].$$

$\Phi > 0$ when $r \leq \frac{1}{\rho'(0)[v_h-v_l]}$, since $\bar{k}_1 = 0$ in this case. $\bar{D}$ is non-increasing in r, while $r\rho\left(\bar{k}_1\right)$ is increasing in r. Therefore, Φ is decreasing in r.

If $r_2^n\left(\phi\right) < r_2^*$, then $\bar{D}\left(\phi\right) = 0$ at $r_2^n\left(\phi\right)$. If $\Phi \geq 0$ at $r_2^n\left(\phi\right)$, then $\Phi > 0$ for all $\bar{D}\left(\phi\right) > 0$, or equivalently, for all $r < r_2^n\left(\phi\right)$. Consequently, $J'\left(D\right)|_{D=\bar{D}(\phi)-} < 0$ since $\rho'\left(k_2\left(D\right)\right)k_2'\left(D\right)|_{D=\bar{D}(\phi)^-} < 0$. Therefore, $D < \bar{D}\left(\phi\right)$ if and only if $r < r_2^n\left(\phi\right)$. If $\Phi < 0$ at $r_2^n\left(\phi\right)$, then, since $\bar{k}_1 = 0$ if $r \leq \frac{1}{\rho'(0)[v_h-v_l]}$ and since Φ is monotonic in r, there will be some $\widetilde{r}\left(\phi\right) \in (\frac{1}{\rho'(0)[v_h-v_l]},\, r_2^n\left(\phi\right)]$ such that $\Phi = 0$ if $r = \widetilde{r}\left(\phi\right)$, with $\Phi < 0$ and $J'\left(D\right)|_{D=\bar{D}(\phi)^-} < 0$ if $r < \widetilde{r}\left(\phi\right)$.

If $r_2^n\left(\phi\right) \geq r_2^*$, $W(\cdot)$ is maximized when $k_2 = 0$ if $r = r_2^*$. Therefore, $J\left(D\right)$ must be maximized at $D = \bar{D}\left(\phi\right)$, and so $J'\left(D\right)|_{D=\bar{D}(\phi)^-} \geq 0$. It follows that $\Phi|_{D=\bar{D}(\phi)^-} \leq 0$, since $\rho'\left(k_2\left(D\right)\right)k_2'\left(D\right)|_{D=\bar{D}(\phi)^-}$ ≤ 0. Hence, there exists some $\widetilde{r}\left(\phi\right) \in (\frac{1}{\rho'(0)[v_h-v_l]},\, \min\left\{r_2^*, r_2^n\left(\phi\right)\right\}]$ such that $D^e < \bar{D}\left(\phi\right)$ if and only if $r < \widetilde{r}\left(\phi\right)$. ■

Proof of Proposition 2.

See Table 2. ■

Proof of Proposition 3.

(i) If an exclusive contract arises in equilibrium (so $D^e > 0$), both reaction functions $R_1(\cdot)$ and $R_2(\cdot)$ shift down. Consequently, $k_1^e < k_1^n$ and/or $k_2^e < k_2^n$. From Table 5, $k_1^e < k_1^n$ and $k_2^e < k_2^n$ when $r = 0.5$ or $r = 0.8$.

(ii) If an exclusive contract arises in equilibrium (so $D^e > 0$), then $k_2^n > 0$. If $D^e = \bar{D}\left(\phi\right)$, then $k_2^e = 0 < k_2^n$. If $D^e < \bar{D}\left(\phi\right)$, then $k_2^e > 0$. If $k_1^e = 0$ in this case, then, from (9), any increase in D^e above 0 will reduce k_2^e. Consequently, the proof is complete if $\frac{dk_2}{dD} < 0$ when $k_1 > 0$ and $k_2 > 0$

satisfy (8) and (9). Totally differentiating (8) and (9) with respect to D yields:

$$\left[\frac{\partial^2 \pi_1}{\partial k_1^2}\right]\frac{dk_1}{dD} + \left[\frac{\partial^2 \pi_1}{\partial k_1 \partial k_2}\right]\frac{dk_2}{dD} - r\rho'(k_1)\,\rho(k_2)\,\frac{\phi}{2} \;=\; 0; \text{ and} \tag{A14}$$

$$\left[\frac{\partial^2 \pi_2}{\partial k_2^2}\right]\frac{dk_2}{dD} + \left[\frac{\partial^2 \pi_2}{\partial k_2 \partial k_1}\right]\frac{dk_1}{dD} - \rho'(k_2)\left[\theta - r\rho(k_1)\left(\theta - \frac{\phi}{2}\right)\right] \;=\; 0. \tag{A15}$$

(A15) implies:

$$\frac{dk_1}{dD} \;=\; \frac{\rho'(k_2)\left[\theta - r\rho(k_1)\left(\theta - \frac{\phi}{2}\right)\right] - \left[\frac{\partial^2 \pi_2}{\partial k_2^2}\right]\frac{dk_2}{dD}}{\frac{\partial^2 \pi_2}{\partial k_2 \partial k_1}}. \tag{A16}$$

Substituting (A16) into (A14) provides:

$$\frac{\partial^2 \pi_1}{\partial k_1^2}\left[\frac{\rho'(k_2)\left[\theta - r\rho(k_1)\left(\theta - \frac{\phi}{2}\right)\right] - \frac{\partial^2 \pi_2}{\partial k_2^2}\frac{dk_2}{dD}}{\frac{\partial^2 \pi_2}{\partial k_2 \partial k_1}}\right] + \left[\frac{\partial^2 \pi_1}{\partial k_1 \partial k_2}\right]\frac{dk_2}{dD} - r\rho'(k_1)\,\rho(k_2)\,\frac{\phi}{2} \;=\; 0$$

$$\Leftrightarrow \quad \frac{dk_2}{dD}\left\{\left[\frac{\partial^2 \pi_1}{\partial k_1 \partial k_2}\right]\left[\frac{\partial^2 \pi_2}{\partial k_2 \partial k_1}\right] - \left[\frac{\partial^2 \pi_1}{\partial k_1^2}\right]\left[\frac{\partial^2 \pi_2}{\partial k_2^2}\right]\right\}$$

$$= \;\left[\frac{\partial^2 \pi_2}{\partial k_2 \partial k_1}\right] r\rho'(k_1)\,\rho(k_2)\,\frac{\phi}{2} - \left[\frac{\partial^2 \pi_1}{\partial k_1^2}\right]\rho'(k_2)\left[\theta - r\rho(k_1)\left(\theta - \frac{\phi}{2}\right)\right]$$

$$\Leftrightarrow \quad \frac{dk_2}{dD} \;=\; -\,\frac{\left[\frac{\partial^2 \pi_2}{\partial k_2 \partial k_1}\right] r\rho'(k_1)\,\rho(k_2)\,\frac{\phi}{2} - \left[\frac{\partial^2 \pi_1}{\partial k_1^2}\right]\rho'(k_2)\left[\theta - r\rho(k_1)\left(\theta - \frac{\phi}{2}\right)\right]}{\left[\frac{\partial^2 \pi_1}{\partial k_1^2}\right]\left[\frac{\partial^2 \pi_2}{\partial k_2^2}\right] - \left[\frac{\partial^2 \pi_1}{\partial k_1 \partial k_2}\right]\left[\frac{\partial^2 \pi_2}{\partial k_2 \partial k_1}\right]}. \tag{A17}$$

(5) ensures $\left[\frac{\partial^2 \pi_1}{\partial k_1^2}\right]\left[\frac{\partial^2 \pi_2}{\partial k_2^2}\right] - \left[\frac{\partial^2 \pi_1}{\partial k_1 \partial k_2}\right]\left[\frac{\partial^2 \pi_2}{\partial k_2 \partial k_1}\right] > 0$. Therefore, (A17) implies that $\frac{dk_2}{dD} < 0$ if and only if:

$$\left[\frac{\partial^2 \pi_2}{\partial k_2 \partial k_1}\right] r\rho'(k_1)\,\rho(k_2)\,\frac{\phi}{2} - \left[\frac{\partial^2 \pi_1}{\partial k_1^2}\right]\rho'(k_2)\left[\theta - r\rho(k_1)\left(\theta - \frac{\phi}{2}\right)\right] \;>\; 0. \tag{A18}$$

Differentiating (8) and (9) reveals that (A18) holds if and only if:

$$-r\rho''(k_1)\left\{[1-\rho(k_2)]\,[v_h - v_l] + \rho(k_2)\,\frac{\phi}{2}\,[v_h - D]\right\}\rho'(k_2)\left[\theta - r\rho(k_1)\left(\theta - \frac{\phi}{2}\right)\right]$$

$$> \;\rho'(k_2)\,r\rho'(k_1)\left[\theta - \frac{\phi}{2}\right][v_h - v_l - D]\,r\rho'(k_1)\,\rho(k_2)\,\frac{\phi}{2}$$

$$\Leftrightarrow \quad -\rho''(k_1)\left\{[1-\rho(k_2)]\,[v_h - v_l] + \rho(k_2)\,\frac{\phi}{2}\,[v_h - D]\right\}\left[\theta - r\rho(k_1)\left(\theta - \frac{\phi}{2}\right)\right]$$

$$> \; r\left[\rho'(k_1)\right]^2\left[\theta - \frac{\phi}{2}\right][v_h - v_l - D]\,\rho(k_2)\,\frac{\phi}{2}. \tag{A19}$$

(A19) holds if ϕ is sufficiently small.

Since

$$-\rho''(k_1)\left\{[1-\rho(k_2)][v_h-v_l]+\rho(k_2)\frac{\phi}{2}[v_h-D]\right\}\left[\theta-r\rho(k_1)\left(\theta-\frac{\phi}{2}\right)\right]$$

$$> \; -\rho''(k_1)\left\{[1-\rho(k_2)]\frac{\phi}{2}[v_h-D]+\rho(k_2)\frac{\phi}{2}[v_h-D]\right\}\left[\theta-r\rho(k_1)\left(\theta-\frac{\phi}{2}\right)\right]$$

$$= \; -\rho''(k_1)\frac{\phi}{2}[v_h-D]\left[\theta-r\rho(k_1)\left(\theta-\frac{\phi}{2}\right)\right] \;\geq\; -\rho''(k_1)\frac{\phi}{2}[v_h-D][\theta-r\rho(k_1)\theta],$$

(A19) also holds if:

$$-\rho''(k_1)[v_h-D][\theta-r\rho(k_1)\theta] \;\geq\; r\left[\rho'(k_1)\right]^2\left[\theta-\frac{\phi}{2}\right][v_h-v_l-D]\rho(k_2). \quad \text{(A20)}$$

(A20) holds if:

$$-\rho''(k_1)[1-r\rho(k_1)] \;\geq\; r\left[\rho'(k_1)\right]^2\rho(k_2)\left[\frac{v_h-v_l-D}{v_h-D}\right]. \quad \text{(A21)}$$

(A21) holds when (10) holds, since $\frac{v_h-v_l-D}{v_h-D}<\frac{v_h-v_l}{v_h}$ for all $D>0$.

(iii) First suppose that $r\geq r_2^*$. If an exclusive contract arises in equilibrium (so $D^e>0$), then $k_2^n>0$, and so $r<r_2(\phi)$. But since $r\geq r_2^*$, total surplus is maximized if $k_2=0$. Consequently, the joint surplus of S1 and B is maximized if $k_2=0$. Therefore, S1 will set $D^e\geq\bar{D}(\phi)$, and so $k_2^e=0<k_2^n$ and $k_1^e=k_1^*>k_1^n$.

Next suppose that $r>r_1^n(\phi)$, so $k_1^n>0$. (A6) implies that $\frac{dR_1(k_2)}{dD}\to 0$ as $\phi\to 0$. In contrast, (A8) implies that $\frac{dR_2(k_1)}{dD}<0$, even as $\phi\to 0$. Therefore, since $R_1(k_2)$ is downward-sloping (from Lemma 1), $k_1^e>k_1^n$ when ϕ is sufficiently small. ■

Proof of Proposition 4.

To prove conclusions (i) and (iii), suppose $r\leq r_1^n(\phi)$ or $\phi=0$ and $\theta=1$. Then $k_1^n=k_1^*$ and $k_2^n=k_2^*$. Furthermore, from Proposition 3, $k_i^e<k_i^n$ for at least one i under an exclusive contract. Therefore, $W(k_1^e,k_2^e)<W(k_1^n,k_2^n)=W(k_1^*,k_2^*)$ by the concavity of $W(\cdot)$.

To prove conclusion (ii), suppose $r>r_1^n(\phi)$. Then $r<r_2^n(\phi)$ when an exclusive contract arises in equilibrium. If, in addition, $\theta<1$ and $\phi>0$ is sufficiently small, it is readily shown that $k_1^n>k_1^*$ and $k_2^n<k_2^*$. Furthermore, $k_1^e>k_1^n$ and $k_2^e<k_2^n$ from Proposition 3.

Since $k_1^e>k_1^n>k_1^*$ and $k_2^e<k_2^n<k_2^*$, there exists an $\alpha_1\in(0,1)$ such that $k_1^n=\alpha_1k_1^*+[1-\alpha_1]k_1^e$. If $\alpha_1k_2^*+[1-\alpha_1]k_2^e\equiv\tilde{k}_2^n\leq k_2^n$, then, with $k_1^n>k_1^*$, (7) and (9) imply that k_2^n is inefficiently low when $\theta < 1$ and ϕ is sufficiently small. Consequently, $\tilde{k}_2^n \leq k_2^n$ (weakly) further reduces $W(\cdot)$. From the strict concavity of $W(\cdot)$:

$$W\left(k_1^n, k_2^n\right) \;\geq\; W\left(k_1^n, \tilde{k}_2^n\right) \;>\; \alpha_1 W\left(k_1^*, k_2^*\right) + \left[1-\alpha_1\right] W\left(k_1^e, k_2^e\right)$$
$$>\; \alpha_1 W\left(k_1^e, k_2^e\right) + \left[1-\alpha_1\right] W\left(k_1^e, k_2^e\right) \;=\; W\left(k_1^e, k_2^e\right).$$

If $\tilde{k}_2^n > k_2^n$, then there exists an $\alpha_2 \in (0,1)$ with $\alpha_2 < \alpha_1$ such that $\alpha_2 k_2^* + [1-\alpha_2]\, k_2^e = k_2^n$. Then $\alpha_2 k_1^* + [1-\alpha_2]\, k_1^e \equiv \tilde{k}_1^n > k_1^n$. Consequently, (6) and (8) imply that for given $k_2^n < k_2^*$, k_1^n is (weakly) above the level of k_1 that maximizes $W(\cdot)$ when ϕ is sufficiently close to 0. Therefore, $\tilde{k}_1^n > k_1^n$ (further) reduces $W(\cdot)$. From the strict concavity of $W(\cdot)$:

$$W\left(k_1^n, k_2^n\right) \;>\; W\left(\tilde{k}_1^n, k_2^n\right) \;>\; \alpha_2 W\left(k_1^*, k_2^*\right) + \left[1-\alpha_2\right] W\left(k_1^e, k_2^e\right)$$
$$>\; \alpha_2 W\left(k_1^e, k_2^e\right) + \left[1-\alpha_2\right] W\left(k_1^e, k_2^e\right) \;=\; W\left(k_1^e, k_2^e\right). \quad \blacksquare$$

Proof of Proposition 5.

When $\phi \to 1$, $\theta \to 1$ and $r_2^n(0) \to r_2^* < r_2^n(\phi)$. If $r_2^* < r < r_2^n(\phi)$ in this case, then $W(\cdot)$ will be maximized when $k_2 = k_2^* = 0 < k_2^n$ and $k_1 = k_1^* > k_1^n$. It follows that the joint surplus of S1 and B also will be maximized under an exclusive contract with $D^e = \bar{D}(\phi) > 0$, so that $k_2^e = 0 = k_2^*$ and $k_1^e = k_1^*$. Consequently, this will be the equilibrium outcome. The concavity of $W(\cdot)$ implies that this equilibrium exclusive contract increases welfare. Therefore, when $\phi \to 1$, there exists some $\hat{r}_2 \leq r_2^* < r_2^n(\phi)$ such that $D^e > 0$ and $W(k_1^e, k_2^e) > W(k_1^n, k_2^n)$ if $r \in (\hat{r}_2, r_2^n(\phi))$. Table 4 demonstrates that $\hat{r}_2 < r_2^*$ in plausible settings. $\blacksquare$

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