Exclusive Contracts, Innovation, and Welfare

by

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Abstract

We extend Aghion and Bolton (1987)'s classic model to analyze the equilibrium incidence and impact of exclusive contracts in a setting where research and development (R&D) drives industry performance. An exclusive contract between an incumbent supplier and a buyer arises when innovation protection and/or the incumbent's R&D ability are sufficiently pronounced. The exclusive contract generally reduces the entrant's R&D, and sometimes also reduces the incumbent's R&D. Exclusive contracts reduce welfare if patent protection for innovation or the incumbent's R&D ability is sufficiently limited. Exclusive contracts increase welfare if patent protection and the incumbent's R&D ability are both sufficiently pronounced.

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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.[3,4]

The purpose of this research is to analyze the equilibrium incidence and the impacts 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

[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] Carlton and Gertner (2003, p. 47) observe that a monopolistic supplier of a patented input in an R&D-intensive industry may sign a long-term contract with its customers just before the patent expires. By doing so, the monopolist may "... induce a potential competitor to reduce its investment in R&D" and perhaps "... deter effective generic entry." To illustrate this more general point, Monsanto, the producer of Nutrasweet, signed a long-term contract with Coke and Pepsi in 1992, shortly before the Nutrasweet patent expired. This contract served to prevent a strong potential competitor, Holland Sweetener, from becoming a major supplier of artificial sweetener in the U.S. soft drink industry (BrainMass, 2008).

industry entrant (S2) can both undertake R&D to (stochastically) develop a superior product of value $v_h > v_l$.[5] Before S1 and S2 undertake R&D, S1 and B can sign an exclusive contract. The exclusive contract specifies a damage payment (D) that B must deliver to S1 if B ultimately buys the product from S2 rather than from S1.[6] 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.[7]

S1's decision about whether to implement an exclusive contract (i.e., whether to set $D > 0$) and about the damage payment to specify in an exclusive contract reflects the following trade-off. 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 and the prevailing innovation protection are both sufficiently limited. Under these conditions, any innovation that arises stems primarily from S2's R&D, and this innovation is likely to be imitated by S1. The imitation benefits B but reduces S2's incentive to undertake R&D. An exclusive contract would further reduce S2's R&D, causing the joint surplus of S1 and B to decline, and thereby rendering an exclusive contract unprofitable for S1.

In contrast, S1 often will implement an exclusive contract when the prevailing innovation protection is more pronounced. If S1's relative R&D ability is sufficiently pronounced, S1 will rely entirely upon its own R&D for innovation, and will implement a fully excluding contract to prevent S2 from securing any of the realized industry surplus. Otherwise, S1 will set a modest damage

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

[6] The exclusive contract also specifies a lump-sum payment, L, 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. Because the lump-sum payment enables transfer payments between S1 and B, S1 will maximize its payoff by implementing the contract that maximizes the joint surplus of S1 and B.

[7] As noted below, some authors (e.g., Rasmusen et al., 1991) interpret an "exclusive contract" between a supplier and a buyer as a contract that fully excludes the buyer from purchasing the product in question from a different supplier. We adopt the broader, popular interpretation of an exclusive contract (e.g., Aghion and Bolton, 1987) as one that may also be partially excluding.

payment to ensure that S2 continues to conduct R&D, and therefore innovates and operates in the industry with positive probability.[8]

As one might expect, an exclusive contract reduces S2's unilateral incentive to engage in R&D, holding all else constant, including S1's R&D. What may be more surprising is that an exclusive contract also reduces S1's unilateral incentive to undertake R&D in our model, *ceteris paribus*. This finding contrasts with the standard view that an exclusive contract increases a supplier's incentive to undertake relationship-specific investment.[9] S1's reduced incentive for R&D arises because S1 receives D in equilibrium more often when it fails to innovate than when it innovates successfully. Therefore, as D increases, S1 anticipates a relatively higher payoff when it fails to innovate, and so is inclined to reduce its R&D investment.

The effects of exclusive contracts on the *equilibrium* R&D of industry suppliers are more subtle. S1's R&D and S2's R&D are strategic substitutes in our model. Therefore, if S2's R&D declines when an exclusive contract is implemented, S1's equilibrium R&D may increase even though the direct, unilateral effect of an exclusive contract is to reduce S1's R&D. Indeed, an exclusive contract will increase S1's equilibrium R&D investment when S1's R&D ability is sufficiently pronounced and the prevailing patent protection is sufficiently limited. An exclusive contract will always reduce the equilibrium R&D of at least one supplier in our model, and sometimes will reduce the equilibrium R&D of both suppliers.[10]

In equilibrium, B always buys the high-quality (v_h) product when it is available. Furthermore,

[8] The equilibrium exclusive contract is always partially excluding in Aghion and Bolton's (1987) model. Rasmusen et al. (1991) and Fumagalli and Motta (2006) restrict attention to fully excluding contracts. Segal and Whinston (2000a) allow partially excluding contracts, but find that fully excluding contracts always arise in equilibrium. Simpson and Wickelgren (2007) find that the equilibrium contract is not fully excluding in a setting where contract breach is permitted if the breach is accompanied by a payment that reflects the expected damage caused by the breach. These papers do not consider innovation, and so do not analyze the fundamental trade-off that S1 faces in our analysis.

[9] See Whinston (2006, pp. 178-197), for example, for a discussion of this issue. Spier and Whinston (1995) find that an exclusive contract induces a supplier to undertake an inefficiently large level of cost-reducing R&D in a setting where the entrant does not engage in R&D. The cost reduction secured by the substantial R&D compels the entrant to reduce the price at which it sells the product to the buyer in equilibrium, and thereby increases the joint expected surplus of the supplier and the buyer. Segal and Whinston (2000b) 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. De Meza and Selvaggi (2007) and Milliou (2008) show that exclusive contracts can affect investment decisions in other settings.

[10] Stefanadis (1997) finds that exclusive contracts reduce R&D in a setting where the R&D of (symmetric) upstream suppliers exhibit scale economies. Scale economies in R&D are not relevant in our model. Furthermore, in contrast to Stefanadis, we consider asymmetric suppliers and we do not require exclusive contracts to be fully excluding. An exclusive contract can reduce S1's R&D in our model, but only when the contract is partially excluding.

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.[11] However, an exclusive contract affects welfare through its impact on the suppliers' R&D investments. If patent protection and/or S1's R&D ability are limited, S2's R&D typically will be below the efficient level in the absence of an exclusive contract. Under these conditions, an exclusive contract tends to reduce welfare by reducing S2's R&D (and possibly also by distorting S1's R&D), 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 – even fully excluding contracts – can increase welfare in such settings by reducing R&D toward efficient levels, particularly when S1's R&D ability is relatively pronounced.[12] Thus, partially excluding contracts can reduce welfare while fully excluding contracts can increase welfare.[13]

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.[14] The proofs of all formal conclusions appear in the Appendix.

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.[15] 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

[11] This implies that the equilibrium contract in our model is *ex post* efficient. In contrast, the equilibrium contract in Aghion and Bolton's (1987) model is *ex post* inefficient and so, as Spier and Whinston (1995) observe, the contract is not renegotiation-proof.

[12] 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.

[13] Partially excluding and fully excluding contracts both can arise, and both can increase welfare in our model. In contrast, fully excluding contracts do not arise and partially excluding contracts always reduce welfare in Aghion and Bolton's (1987) model, which abstracts from R&D considerations.

[14] Section 5 also discusses additional related literature.

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

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 innovation 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.[16]

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.[17]

[16] 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.

[17] S1 will prefer not to incur the imitation costs regardless of how small these (strictly positive) costs might be. We consider settings in which S2 will not enter the market if it does not develop the new product in order to maintain

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) $v_h > \left[\frac{2}{2-\phi}\right] v_l$.

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.[18]

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.[19]

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

a meaningful distinction between the incumbent and the potential entrant. Asymmetric imitation costs constitute a convenient means to implement this distinction.

[18] We also assume that $\rho(\cdot)$ is sufficiently concave. See inequality (6) below.

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

(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.[20] 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 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. D can be viewed as a switching cost that B incurs if he purchases the high-quality product from S2. To offset this switching cost, S2 must reduce the price of its product by D below the incremental value ($v_h - v_l$) that B derives from S2's product.[21] To simplify the exposition, we assume that $D \leq v_h - v_l$ throughout the ensuing analysis.[22] 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.

[20] The concluding section discusses the changes that arise if S1 and S2 can horizontally differentiate the high-quality products they offer, and thereby soften their price competition.

[21] When he is indifferent between purchasing the high-quality product and the low-quality product, B is assumed to purchase the former. S2 can secure B's patronage by reducing its price for the high-quality product to $v_h - v_l - D$ when S1 charges a price of 0. These prices constitute the Nash equilibrium in the subgame that provides the highest joint profit to S1 and B. Furthermre, these are the only prices consistent with the subgame perfect equilibrium of the entire game that we specify below.

[22] 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.

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. S2'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 $v_h - v_l - D$.[23] S1'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:

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

S2's corresponding expected profit is:

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

[23] 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.

B's expected surplus if he accepts the (D, L) contract is:[24]

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

Equations (1) and (3) imply that the joint surplus of S1 and B under contract (D, L) is:

$$\begin{aligned} J(D) = {} & v_l + r\rho(k_1(D))\,[v_h - v_l] - k_1(D) + \\ & \rho(k_2(D))\left\{[1 - r\rho(k_1(D))]\,[\theta D + [1-\theta]\,(v_h - v_l)] - r\rho(k_1(D))\,\frac{\phi}{2}\,[v_h - v_l - D]\right\}. \end{aligned} \tag{4}$$

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.[25]

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 that maximize total expected surplus, or "welfare":

$$W(k_1, k_2) = v_l + [v_h - v_l]\,\{r\rho(k_1) + \rho(k_2)\,[1 - r\rho(k_1)]\} - k_1 - k_2. \tag{5}$$

The expression in equation (5) 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 and the probability that S2 innovates successfully but S1 does not. To ensure that $W(k_1, k_2)$ is concave, we assume:

$$\rho''(k_1)\rho''(k_2)[1 - \rho(k_2)][1 - r\rho(k_1)] \;>\; r\,[\rho'(k_1)\rho'(k_2)]^2 \quad \text{for all relevant } k_1,\ k_2. \tag{6}$$

Inequality (6) will hold if $\rho(\cdot)$ is sufficiently concave.

Differentiating equation (5) reveals that the efficient k_1 and k_2, denoted k_1^* and k_2^*, satisfy:

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

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

[25] B's expected surplus in the absence of a contract with S1 is as specified in equation (3), with $D = L = 0$. Notice that S1 will implement the contract that maximizes $J(D)$, the joint surplus of S1 and B. For simplicity, we focus on the case in which S1 has all of the bargaining power in its interaction with B. The key qualitative conclusions drawn below persist under alternative bargaining structures in which B must receive more than the surplus he secures in the absence of a contract between S1 and B.

$$\rho'(k_2^*)\left[1 - r\rho(k_1^*)\right]\left[v_h - v_l\right] \;\leq\; 1, \text{ with equality if } k_2^* > 0. \tag{8}$$

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 $k_2^* = 0$).[26]

3 Primary 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.[27]

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 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:

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

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:

$$\rho'\left(k_2\right)\left[\theta - r\rho\left(k_1\right)\left(\theta - \frac{\phi}{2}\right)\right]\left[v_h - v_l - D\right] \;=\; 1. \tag{10}$$

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. In other words, 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

[26] Equations (7) and (8) and Assumption 1 imply that $0 < r_1^* < r_2^*$.

[27] 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.

expected profit is greatest under Bertrand competition.

Lemma 2 explains how reaction 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), as the damage payment (D) in an exclusive contract increases, S2's R&D always declines and S1's R&D declines whenever some patent protection is present (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, given ϕ;[28] 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., $\theta = 1$ or θ is sufficiently close to 1 and $\phi > 0$) 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 $\widetilde{r}(\phi) \in [\frac{1}{\rho'(0)[v_h - v_l]}, r_2^*]$ such that $D^e > 0$ and $k_2^e > 0$ when $r < \widetilde{r}(\phi)$, whereas $D^e > 0$ and $k_2^e = 0$ when $r \in [\widetilde{r}(\phi), r_2^n(\phi))$).*

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

Proposition 1 indicates that when innovation 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.[29] 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.[30] 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 will not always do so. When innovation protection is limited and S1's relative R&D ability is sufficiently low, the joint surplus of S1 and B will be higher when S2's innovation is not limited by an exclusive contract and when S1 simply imitates S2's innovation whenever it is able to do so. This conclusion is recorded in Proposition 2, as is the observation that S1 may decline to implement an exclusive contract even when its R&D ability is pronounced. These conclusions are illustrated in section 4.

Proposition 2. *S1 will not implement an exclusive contract (so $D^e = 0$) when innovation protection and S1's R&D ability are sufficiently limited (i.e., when θ and r are sufficiently small). S1 will sometimes decline to implement an exclusive contract even when S1 and S2 have the same R&D ability (i.e., when $r = 1$).*

In summary, an exclusive contract will not arise when innovation protection and S1's R&D ability are both sufficiently limited. In contrast, S1 and B will sign a partially excluding contract when innovation protection is pronounced but S1's R&D ability is sufficiently limited. A fully

[29] 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.

[30] 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.

excluding contract will arise in equilibrium when innovation protection and S1's R&D ability are both sufficiently pronounced.

While Propositions 1 and 2 address the equilibrium incidence and nature 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 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:[31]

$$-\rho''(k_1)\left[1 - r\rho(k_1)\right] \;\geq\; r\left[\rho'(k_1)\right]^2 \rho(k_2)\left[\frac{v_h - v_l}{v_h}\right] \quad \text{for all relevant } k_1, k_2. \tag{11}$$

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 (11) 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. 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 by supplying the efficient level of R&D (k_1^*), S1 can maximize expected surplus and ensure that S2 receives none of the surplus.[32]

An exclusive contract also will increase S1's equilibrium R&D when patent protection is limited.

[31] Condition (11) is similar, but not equivalent, to condition (6), which ensures $W(k_1, k_2)$ is concave. Both conditions hold when $\rho(\cdot)$ is sufficiently concave, as in the examples presented in section 4.

[32] Notice also that a fully excluding contract will reduce S2's R&D (to zero) and increase S1's R&D.

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 equilibrium R&D increases.[33]

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 (i.e., $r \leq \hat{r}_1$ for some $\hat{r}_1 \geq r_1^n(\phi)$).*

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 (5)), 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.

[33] In principle, an exclusive contract could increase S2's equlibrium R&D and reduce S1's equilibrium R&D. However, we have not been able to identify a setting in which $k_2^e > k_2^n$.

To understand conclusion (iii) in Proposition 4, note that if S1's relative R&D ability is sufficiently limited, S1 will undertake no R&D in the absence of an exclusive contract (so $k_1^n = 0$). 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. As the discussion of Table 1 in section 4 reveals, an exclusive contract also can reduce welfare when S1's ability is sufficiently pronounced that it will undertake R&D in the absence of an exclusive contract (i.e., when $r > r_1^n(\phi)$, so that $k_1^n > 0$).

Proposition 5 points out that although an exclusive contract often will reduce welfare, an exclusive contract also can 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 (i.e., $r \in [r_2^*, r_2^n(\phi))$). In this setting, an exclusive contract will increase welfare by reducing S2's R&D to its efficient level.[34] (The discussion of Table 3 in section 4 points out that an exclusive contract also can increase welfare when $r < r_2^*$, and so $k_2^* > 0$.)

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 imply that S1 will implement an exclusive contract that reduces welfare when ϕ or r is sufficiently small, but will implement an exclusive contract that increases welfare when ϕ and r are both sufficiently large. The propositions also provide the following conclusion.

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

[34] 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.

4 Additional Findings.

Further conclusions about the incidence and effects of exclusive contracts can be drawn if additional structure is introduced that admits explicit solutions to equations (9) and (10). In particular, the equilibrium effects of exclusive contracts can be identified even when the sufficient conditions employed in Propositions 1 – 5 do not hold. 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. For convenience, we set $v_l = 1$ and define $\Delta v \equiv v_h - v_l$.

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 ability ($r = 1$), trade secret protection is perfect ($\phi_t = 1$), and $\Delta v = 2$. Table 1 reports how equilibrium R&D (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 R&D (k_i^e), welfare (W^e), and damage payment (D^e) vary with ϕ when exclusive contracts are permitted. In addition, the table records the equilibrium changes in R&D ($\Delta k_i \equiv k_i^e - k_i^n$ for $i = 1, 2$) and welfare ($\Delta W \equiv W^e - W^n$) that arise when exclusive contracts are feasible.

ϕ	k_1^n	k_2^n	W^n	D^e	k_1^e	k_2^e	W^e	Δk_1	Δk_2	ΔW
0.00	0.1655	0.1655	1.0533	0.1485	0.2138	0.0717	1.0495	0.0483	−0.0938	−0.0038
0.25	0.1808	0.1704	1.0531	0.1761	0.2206	0.0713	1.0495	0.0398	−0.0991	−0.0036
0.50	0.1959	0.1773	1.0525	0.2061	0.2273	0.0702	1.0493	0.0314	−0.1071	−0.0032
0.75	0.2112	0.1859	1.0513	0.2381	0.2337	0.0685	1.0491	0.0225	−0.1174	−0.0022
1.00	0.2272	0.1960	1.0494	0.2717	0.2396	0.0665	1.0488	0.0124	−0.1295	−0.0006

Table 1. Effects of Patent Protection ($r = 1$; $\phi_t = 1$; $\Delta v = 2$).

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., $\Delta W < 0$) in the present setting by increasing S1's investment further above the efficient level (i.e., $k_1^e > k_1^n$).

S1 always implements a partially excluding contract in this setting in order to capture some

of the surplus that arises from S2's innovation.[35] The positive damage payment ($D^e > 0$) that S1 implements reduces S2's R&D and welfare (i.e., $k_2^e < k_2^n$ and $W^e < W^n$).[36] 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.[37]

Next consider how equilibrium outcomes vary as the prevailing trade secret protection varies. Table 2 explores this issue in a setting with imperfect patent protection ($\phi = 0.5$),[38] where S1 and S2 have identical R&D abilities ($r = 1$) and where $\Delta v = 5$.

ϕ_t	k_1^n	k_2^n	W^n	D^e	k_1^e	k_2^e	W^e	Δk_1	Δk_2	ΔW
≤ 0.5	0.6600	0.2963	2.1110	0.0	0.6600	0.2963	2.1110	0.0	0.0	0.0
0.6	0.6476	0.3974	2.1663	0.5332	0.6545	0.3247	2.1290	0.0069	−0.0727	−0.0373
0.7	0.6392	0.4733	2.1923	1.0893	0.6524	0.3249	2.1292	0.0132	−0.1484	−0.0631
0.8	0.6331	0.5322	2.2034	1.5226	0.6508	0.3250	2.1294	0.0177	−0.2072	−0.0740
0.9	0.6287	0.5794	2.2064	1.8696	0.6495	0.3251	2.1295	0.0208	−0.2543	−0.0769
1.0	0.6254	0.6179	2.2050	2.1537	0.6485	0.3251	2.1296	0.0231	−0.2928	−0.0754

Table 2. Effects of Trade Secret Protection ($r = 1$; $\phi = 0.5$; $\Delta v = 5$).

Table 2 illustrates the conclusion drawn in Proposition 2. When innovation protection is limited (i.e., when $\phi = 0.5$ and $\phi_t \leq 0.5$ in Table 2), S1 chooses not to implement an exclusive contract, and imitates S2's innovation whenever possible.[39] As trade secret protection increases, S1 becomes less likely to successfully imitate S2's innovation. Consequently, S1 implements a partially excluding contract to capture a portion of the surplus that arises from S2's innovation. S1 increases the damage payment in the contract as ϕ_t increases, in part because S1 becomes less concerned with

[35] Notice that the assumptions in Proposition 1 are satisfied in the setting of Table 1 ($\theta = 1$ and $1 = r < r_2^n(\phi)$, since $k_2^n > 0$). Also notice that $1 = r > r_1^n(\phi)$ (since $k_1^n > 0$) for all values of ϕ in Table 1. Therefore, the identified welfare reduction ($W^e < W^n$) illustrates conclusion (iii) of Proposition 4.

[36] 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 $r = 1$ and $\Delta v = 2$.

[37] 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.

[38] $\phi < 1$ 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.

[39] S1 will not implement an exclusive contract when θ and r are small (recall Proposition 2). Table 2 illustrates that S1 also may decline to implement an exclusive contract when θ and r are moderate (e.g., $\theta = 0.5$ and $r = 1$).

limiting S2's R&D unduly as the trade secret protection that S2 enjoys increases.[40]

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

Next consider how equilibrium outcomes vary as the relative R&D abilities of S1 and S2 change. Table 3 considers a setting where $\phi = \phi_t = 1$ and $\Delta v = 2$. The table illustrates the conclusion in Proposition 1 that when $\theta = 1$, S1 will implement a partially excluding contract when r is small (e.g., $r \leq 1.2$) and a fully excluding contract when r is large (e.g., $r \geq 1.5$).[41] Table 3 also illustrates the conclusions drawn in Propositions 4 and 5. In particular, when r is small (e.g., when $r \leq 1$ here), S1 will implement an exclusive contract that reduces welfare.[42] In contrast, when patent protection and S1's relative R&D ability are pronounced (e.g., when $\phi = 1$ and $r = 1.2$ or $r = 1.5$), S1 will implement an exclusive contract that increases welfare.[43]

r	k_1^n	k_2^n	W^n	D^e	k_1^e	k_2^e	W^e	Δk_1	Δk_2	ΔW
0.10	0.0	0.2500	1.0417	0.2763	0.0	0.1298	1.0320	0.0	−0.1202	−0.0097
0.50	0.0	0.2500	1.0417	0.2763	0.0	0.1298	1.0320	0.0	−0.1202	−0.0097
0.80	0.0277	0.2445	1.0389	0.2697	0.0388	0.1242	1.0298	0.0111	−0.1203	−0.0091
1.00	0.2272	0.1960	1.0494	0.2717	0.2396	0.0665	1.0488	0.0124	−0.1295	−0.0006
1.20	0.3603	0.1495	1.1037	0.2845	0.3744	0.0045	1.1125	0.0141	−0.1450	+0.0088
1.50	0.4936	0.0787	1.2346	0.1539	0.5000	0.0	1.2500	0.0064	−0.0787	+0.0154
2.00	0.6250	0.0	1.5208	0.0	0.6250	0.0	1.5208	0.0	0.0	0.0

Table 3. Effects of Relative R&D Abilities ($\phi = 1;\ \phi_t = 1;\ \Delta v = 2$).

Table 3 also reveals that the equilibrium damage payment (D^e) can vary non-monotonically with r. In the setting of Table 3, 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

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

[41] When $r = 2$, $r \geq r_2^n(\phi)$ and $k_2^n = 0$ even when $D = 0$.

[42] Notice that $r > r_1^n(\phi)$ (since $k_1^n > 0$) when $r = 0.8$ or $r = 1.0$ in the setting of Table 3, and so the setting illustrates conclusion (iii) in Proposition 4.

[43] $k_2^* = 0.0114$ when $r = 1.2$ in the setting of Table 3. Therefore, since the exclusive contract increases welfare when $r = 1.2$, this setting illustrates Proposition 5.

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.

Notice from the second and third rows of data in Table 3 that an increase in industry R&D ability (r) can reduce welfare. This welfare reduction reflects two considerations. First, the increase in r (from 0.5 to 0.8) stimulates additional R&D investment, which already exceeds efficient levels due to the prevailing strong innovation protection. Second, the increase in r diverts R&D from the firm with the greatest to the firm with the least R&D ability (i.e., from S2 to S1).

An exclusive contract does not reduce the R&D of both S1 and S2 in any of the settings in Tables 1 – 3. To verify that an exclusive contract can reduce the R&D of both suppliers as conclusion (i) in Proposition 3 indicates, consider the setting of Table 4. The setting is identical to that in Table 3 except the social value of innovation is larger (i.e., $\Delta v = 5$).

r	k_1^n	k_2^n	W^n	D^e	k_1^e	k_2^e	W^e	Δk_1	Δk_2	ΔW
0.10	0.0	0.7000	1.8167	2.4417	0.0	0.4137	1.6800	0.0	−0.2863	−0.1367
0.50	0.3180	0.6860	1.8101	2.4153	0.3062	0.3934	1.6950	−0.0118	−0.2926	−0.1151
0.80	0.5747	0.6632	2.0091	2.3981	0.5719	0.3530	1.9220	−0.0028	−0.3102	−0.0871
1.00	0.6603	0.6481	2.1956	2.3831	0.6604	0.3277	2.1304	+0.0001	−0.3204	−0.0652
1.20	0.7156	0.6937	2.3840	2.4044	0.7203	0.2915	2.3557	+0.0047	−0.4022	−0.0283
1.50	0.7746	0.6067	2.7319	2.4390	0.7807	0.2314	2.7251	+0.0061	−0.3753	−0.0068
2.00	0.8320	0.5563	3.3223	2.6031	0.8453	0.0724	3.4171	+0.0133	−0.4839	+0.0948

Table 4. Effects of Relative R&D Abilities ($\phi = 1$; $\phi_t = 1$; $\Delta v = 5$).

The increased value of innovation in the setting of Table 4 provides S2 with 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. The large damage payment reduces the unilateral incentive to undertake R&D for both S1 and S2. (Recall Lemma 3). When S1's R&D ability is relatively moderate ($r = 0.5$ or $r = 0.8$) in the setting of Table

4, the exclusive contract that S1 implements reduces the equilibrium R&D of both suppliers.[44]

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 always reduces the R&D of at least one industry supplier, and can reduce the R&D of both suppliers. An exclusive contract reduces welfare if patent protection or the incumbent's (relative) R&D ability is sufficiently limited. In contrast, an exclusive contract increases welfare if patent protection and the incumbent's R&D ability are both sufficiently pronounced.

The key considerations and trade-offs that arise in our basic model persist in alternative settings, with appropriate modification. Consider, for instance, a setting that parallels the model developed above except that S1 and S1 can implement horizontal product differentiation when both firms produce the high-quality product.[45] The product differentiation reduces 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*. If the increased R&D that typically arises in the presence of product differentiation raises R&D above efficient levels, then exclusive contracts that reduce equilibrium R&D can increase welfare.

Elastic (downward-sloping) demand also can 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, B's surplus increases by more than the seller's profit declines as the sales price is reduced (due to the reduction in deadweight loss). Consequently, S2 can secure B's patronage with a positive, and thus profitable, price. The relevant price ensures that B receives the same surplus from: (i) purchasing from S1 at the price that secures profit D for S1; and (ii) purchasing from S2 at a lower price and paying D to S1.

[44] Notice that $k_2^e < k_2^n$ whenever S1 implements an exclusive contract ($D^e > 0$) in the settings of Tables 1 – 4. This observation illustrates conclusion (ii) in Proposition 3 since it is readily verified that inequality (11) holds in the present setting whenever $r \leq 2$.

[45] 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 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).[46] 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 with S1 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. In such

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

cases, the exclusive contract can harm consumers in addition to reducing welfare by distorting innovation incentives.

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, 2009, 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.

Appendix

<u>Proof of Lemma 1</u>.

Differentiating (9) 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 (10) 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, an interior equilibrium is unique and stable if $R_1(\cdot)$ is more steeply sloped than $R_2(\cdot)$ in k_1-k_2 space. From (9), (10), (A1), and (A2), this will be the case if:

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

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

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

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

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 (6). ■

Proofs of Lemmas 2-3.

Differentiating (9) 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:

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

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

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

Differentiating (10) 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.

Differentiating $J(D)$ from (4) provides:

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

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, (12) implies:

$$J'(0) \;=\; \theta\rho(k_2(0)) + [1-\theta][v_h - v_l]\,\rho'(k_2(0))\,k_2'(0)\,. \tag{A10}$$

The expression in (A10) will be strictly positive when θ is sufficiently close to 1. Therefore, $J'(0) > 0$ in this case, and so $D^e > 0$.

If $r_1^n(\phi) \le r < r_2^n(\phi)$, 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 (4), if θ is sufficiently close to 1:

$$\begin{aligned} J(0) \;&=\; v_l + r\rho(k_1(0))[v_h - v_l] - k_1(0) \\ &\quad + \left\{[1 - r\rho(k_1(0))][1-\theta][v_h - v_l] - r\rho(k_1(0))\frac{\phi}{2}[v_h - v_l]\right\}\rho(k_2(0)) \\ &\le\; v_l + r\rho(k_1(0))[v_h - v_l] - k_1(0) \quad \text{as } \theta \to 1 \\ &<\; \max_{k_1}\{v_l + r\rho(k_1)[v_h - v_l] - k_1\} \;=\; J(v_h - v_l) \;\le\; \max_D J(D) \;=\; J(D^e)\,. \end{aligned} \tag{A11}$$

The strict inequality in (A11) follows from the concavity of $v_l + r\rho(k_1)[v_h - v_l] - k_1$. (A11) 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:

$$k_2(D) \begin{cases} > 0 & if \quad D < \bar{D}(\phi) \\ = 0 & if \quad D \ge \bar{D}(\phi)\,. \end{cases} \tag{A12}$$

At $D = \bar{D}(\phi) > 0$, $k_2^e = 0$, and thus $k_1^e = k_1(\bar{D}) = \bar{k}_1$. Since $\rho(k_2(D))_{D=\bar{D}(\phi)^-} = \rho\left(k_2\left(\bar{D}(\phi)^-\right)\right) = \rho(0) = 0$, (12) implies:

$$\begin{aligned} J'(D)\big|_{D=\bar{D}(\phi)^-} \;&=\; \{[1 - r\rho(k_1(D))][\theta D + [1-\theta](v_h - v_l)] \\ &\quad - r\rho(k_1(D))\frac{\phi}{2}[v_h - v_l - D]\}\rho'(k_2(D))\,k_2'(D)_{D=\bar{D}(\phi)^-} \\ &=\; \Phi\rho'(k_2(D))\,k_2'(D)\big|_{D=\bar{D}(\phi)^-}\,, \end{aligned}$$

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

Notice that $\Phi|_{D=\bar{D}(\phi)^-} > 0$ when $r \le \frac{1}{\rho'(0)[v_h - v_l]}$, since $\bar{k}_1 = k_1(\bar{D}) = 0$ in this case. Furthermore, $\Phi|_{D=\bar{D}(\phi)^-}$ is decreasing in r since $\bar{D}$ is non-increasing in r and $r\rho(\bar{k}_1)$ is increasing in r.

$r_2^n(\phi) \ge r_2^*$ since $\theta = 1$ or $\phi > 0$ and $\theta \to 1$, by assumption. If $r \ge r_2^*$, then $W(\cdot)$ is

maximized when $k_2 = 0$. Therefore, if $r \geq r_2^*$, then $J(D)$ must be maximized at $D = \bar{D}(\phi)$, and so $J'(D)|_{D=\bar{D}(\phi)^-} \geq 0$. Consequently, $\Phi|_{D=\bar{D}(\phi)^-} \leq 0$ if $r \geq r_2^*$, since $\rho'(k_2(D))\, k_2'(D)|_{D=\bar{D}(\phi)^-} \leq 0$. Hence, there exists some $\widetilde{r}(\phi) \in (\frac{1}{\rho'(0)[v_h - v_l]}, r_2^*]$ such that $\Phi|_{D=\bar{D}(\phi)^-} > 0$ and so $J'(D)|_{D=\bar{D}(\phi)^-} < 0$ or $D^e < \bar{D}(\phi)$ if and only if $r < \widetilde{r}(\phi)$. ■

Proof of Proposition 2.

$k_1 = 0$ and $k_1'(D) = 0$ when r is sufficiently small. Furthermore, $k_2^n > 0$ from Assumption 1 and $k_2'(D) < 0$ for $D < \bar{D}$ from Lemma 3. Therefore, (12) implies that when θ and r are sufficiently small:

$$J'(D) \;=\; \theta\rho(k_2(D)) + \rho'(k_2(D))\, k_2'(D)\{[\theta D + [1-\theta](v_h - v_l)]\} \;\leq\; 0 \quad \text{for } D \;\leq\; \bar{D}.$$

Hence $D^e = 0$.

Table 2 (when $r = 1$ and $\theta = 0.5$) reveals that D^e can be 0 when $r = 1$. ■

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 $k_2^e < k_2^n$. Furthermore, from Table 4, both $k_1^e < k_1^n$ 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 $D^e = \bar{D}(\phi)$, then $k_2^e = 0 < k_2^n$. If $D^e < \bar{D}(\phi)$, then $k_2^e > 0$. If $k_1^e = 0$ in this case, then, from (10), 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 (9) and (10). Totally differentiating (9) and (10) with respect to D yields:

$$\left[\frac{\partial^2 \pi_1}{\partial k_1^2}\right]\frac{dk_1}{dD} + \left[\frac{\partial^2 \pi_1}{\partial k_1 \partial k_2}\right]\frac{dk_2}{dD} - r\rho'(k_1)\,\rho(k_2)\,\frac{\phi}{2} \;=\; 0; \;\text{ and} \tag{A13}$$

$$\left[\frac{\partial^2 \pi_2}{\partial k_2^2}\right]\frac{dk_2}{dD} + \left[\frac{\partial^2 \pi_2}{\partial k_2 \partial k_1}\right]\frac{dk_1}{dD} - \rho'(k_2)\left[\theta - r\rho(k_1)\left(\theta - \frac{\phi}{2}\right)\right] \;=\; 0. \tag{A14}$$

(A14) implies:

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

Substituting (A15) into (A13) provides:

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

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

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

$$\Leftrightarrow \quad \frac{dk_2}{dD} \;=\; -\frac{\left[\frac{\partial^2\pi_2}{\partial k_2\partial k_1}\right] r\rho'(k_1)\rho(k_2)\frac{\phi}{2} - \left[\frac{\partial^2\pi_1}{\partial k_1^2}\right]\rho'(k_2)\left[\theta - r\rho(k_1)\left(\theta-\frac{\phi}{2}\right)\right]}{\left[\frac{\partial^2\pi_1}{\partial k_1^2}\right]\left[\frac{\partial^2\pi_2}{\partial k_2^2}\right] - \left[\frac{\partial^2\pi_1}{\partial k_1\partial k_2}\right]\left[\frac{\partial^2\pi_2}{\partial k_2\partial k_1}\right]}. \tag{A16}$$

(6) 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, (A16) implies that $\frac{dk_2}{dD} < 0$ if and only if:

$$\left[\frac{\partial^2\pi_2}{\partial k_2\partial k_1}\right] r\rho'(k_1)\rho(k_2)\frac{\phi}{2} - \left[\frac{\partial^2\pi_1}{\partial k_1^2}\right]\rho'(k_2)\left[\theta - r\rho(k_1)\left(\theta-\frac{\phi}{2}\right)\right] \;>\; 0. \tag{A17}$$

Differentiating (9) and (10) reveals that (A17) holds if and only if:

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

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

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

$$> \; r\left[\rho'(k_1)\right]^2\left[\theta-\frac{\phi}{2}\right][v_h - v_l - D]\,\rho(k_2)\frac{\phi}{2}. \tag{A18}$$

(A18) holds if ϕ is sufficiently small.

Since

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

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

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

(A18) also holds if:

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

(A19) holds if:

$$-\rho''(k_1)\left[1-r\rho(k_1)\right] \;\geq\; r\left[\rho'(k_1)\right]^2\rho(k_2)\left[\frac{v_h-v_l-D}{v_h-D}\right]. \tag{A20}$$

(A20) holds when (11) 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 $W(\cdot)$. Furthermore, for the setting in Table 3 with $r = 0.8$ or $r = 1.0$, there exists an $\hat{r}_1 > r_1^n(\phi)$ such that $W(k_1^e, k_2^e) < W(k_1^n, k_2^n)$ when $r < \hat{r}_1$.

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 ϕ 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 $k_1^n = \alpha_1 k_1^* + [1-\alpha_1]k_1^e$. If $\alpha_1 k_2^* + [1-\alpha_1]k_2^e \equiv \tilde{k}_2^n \leq k_2^n$, then, with $k_1^n > k_1^*$, (8) and (10) 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 $W(\cdot)$:

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

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, (7) and (9) 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 $W(\cdot)$:

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

Proof of Proposition 5.

When $\phi \to 1$, it must be true that $\theta \to 1$ and $r_2^* < r_2^n(\phi)$. 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 3 demonstrates that $\hat{r}_2 < r_2^*$ in plausible settings. $\blacksquare$

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