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APPENDIX: EQUILIBRIUM OF THE TWO-PART TARIFF MODEL

We assume that the innovating upstream firm wants to sell its product to both downstream firms; i.e., it does not have an incentive to sell its product to only one downstream firm and refuse to supply the other:[1]

(A1) $$\Pi_{Di}(m';m) - \Pi_{Di}(m;m) < 2(\Pi_{Di}(m';m') - \Pi_{Di}(m;m')),$$

where $\Pi_{Di}(m;m')$ is the operating profit of Di (the profit of Di exclusive of the fixed fee) when Di faces a unit cost m, given that Dj faces a unit cost m'. One case, for example, where condition (A1) is always met, is when innovation is not very drastic, i.e., when m' is not very low.[2] Another example where condition (A1) is always met is when downstream products are sufficiently differentiated.[3]

As in the linear pricing game, in stage 1 U1 can negotiate an exclusive supply contract with D1 and U2 with D2. The contract specifies the fixed fee A_i^c at which Ui has the obligation to sell the upstream product to Di. Since in stage 1 Ui and Di do not know what the marginal cost of Ui will be in stage 3, they negotiate on the conservative presumption that Ui will not manage to invent the new technology, and thus its marginal cost in stage 3 will be m (c = m). If, on the other hand, Ui manages to invent the new technology, it can transform the contract that Ui and Di negotiated in stage 1 into the equivalent contract where c = m' and the fixed fee is equal to $A_i^c + \Pi_{Di}(c = m') - \Pi_{Di}(c = m)$; from the standpoint of buyer Di, the two contracts are exactly the same.

To solve for the equilibrium, we first assume that firms U2 and D2 sign an exclusive supply contract and agree on a fixed fee A_2^c.[4] Taking this decision as given, we examine whether U1 and D1 will also decide to sign a contract.

Suppose that firms U1 and D1 do not sign an exclusive supply contract. Then, the outcome of upstream price competition in stage 3 depends on the "legacy" of the prior R&D race. If no upstream supplier has invented the new technology, all upstream suppliers face a marginal cost m, and Bertrand competition drives fixed fee for firm D1 to zero.

On the other hand, if firm U2 has obtained a patent for the new technology, it practices "limit pricing" to squeeze U1 out of the market; U2 charges D1 a fixed fee Π_{D1}(m';m') - Π_{D1} (m;m'). Moreover, U2 charges D2 a fixed fee $A_2^c + \Pi_{D2}$(m';m') - Π_{D2}(m;m').

Finally, if firm U1 has obtained a patent for the new technology, it also practices "limit pricing" and charges D1 a fixed fee Π_{D1} (m';m) - Π_{D1} (m;m). U1 cannot sell to D2 because U2 is already a captive buyer; U2 and D2 signed an exclusive supply contract in stage 1.

Thus, if U1 and D1 do not sign an exclusive supply contract, U1 faces the following maximization problem in stage 2:

(A2) $$\underset{\{RU_1\}}{Max} \quad p_1(R_{U1},R_{U2})(\Pi_{Di}(m';m) - \Pi_{Di}(m;m)) - R_{U1}.$$

U2 follows the following maximization problem:

(A3) $$\underset{\{RU_2\}}{Max} \quad A_2^c + p_2(R_{U1},R_{U2})(2(\Pi_{Di}(m';m') - \Pi_{Di}(m;m'))) - R_{U2}.$$

Suppose now that in stage 1 U1 tries to "convince" D1 to sign an exclusive supply contract. We can show that there exists a contract that raises joint profits for U1 and D1 above the no-contract level. Consider the contract in which $A_1^c = 0$. Under this contract, U1's profit maximization problem in the R&D stage does not change. However, U2's incentive to invest in R&D is lower; even if U2 wins the R&D race, it will not be able to sell its product to D1. The R&D problem of U2 becomes:

(A4) $$\underset{\{RU_2\}}{Max} \quad A_2^c + p_2(R_{U1},R_{U2})(\Pi_{Di}(m';m) - \Pi_{Di}(m;m)) - R_{U2}.$$

Since Π_{Di}(m';m) - Π_{Di}(m;m) < 2(Π_{Di}(m';m') - Π_{Di}(m;m')) (see (A1)), the reaction curve of U2 shifts to the left; as in the linear pricing case, the contract leads to higher expected profits for U1.

The contract also leads to higher expected profits for D1. D1 prefers that U2 does not innovate; D1 makes a higher total profit in the case where no upstream firm innovates, or U1 innovates, rather than in the case where U2 innovates ($\Pi_{Di}(m;m') < \Pi_{Di}(m;m)$). Thus, the contract is beneficial to D1 because it lowers the probability of innovation by U2.

It follows that the contract increases the sum of expected profits of U1 and D1; **U1 and D1 will sign an exclusive supply contract in Stage 1, given that firms U2 and D2 will also sign a contract**. Moreover, since D1 is strictly better off with the contract when A_1^c is zero, U1 can charge a higher fixed fee and still elicit contract acceptance by D1; in our simple model, the equilibrium contract that U1 and D1 will sign (given that U2 and D2 will sign a contract with A_2^c) specifies a fixed fee $A_1^c > 0$.

By following the same procedure, we can see that U1 and D1 may or may not sign an exclusive supply contract in stage 1, given that U2 and D2 will not sign a contract. For simplicity, we set A_1^c equal to zero at first; A_1^c does not affect the sum of expected profits, but only determines the allocation of profits between U1 and D1. The analysis shows that the U1-D1 contract leads to higher expected profits for U1 because it discourages U2 from innovating. However, the effect of the contract on the expected profits of D1 is ambiguous. D1 prefers that innovation does not take place; if an upstream firm innovates, it plays the downstream firms against each other and extracts a higher fixed fee. Thus, the contract is beneficial to D1 when it lowers the probability of upstream innovation. We can show that the contract lowers the probability of innovation when certain conditions are met.[5] When those conditions are not met, the impact of the contract on $(p_1 + p_2)$ is ambiguous.

It follows that one of the Nash equilibria of the game is always foreclosure; when each pair of firms expects the other to sign the contract, the U1-D1 and U2-D2 contracts are always signed and $A_i^c > 0$ (i = 1,2). If certain conditions are met (see footnote 5), this equilibrium is unique. If they are not met, uniqueness of this equilibrium is not guaranteed; it might be possible also to have a second equilibrium where no Ui-Di contract is signed.[6]

<u>Proposition:</u> One of the Nash equilibria is always downstream foreclosure; the U1-D1 and U2-D2 contracts are signed. This equilibrium is not necessarily unique.

The idea is the same as in the linear pricing model; Ui and Di may jointly have potential gains from signing an exclusive supply contract and discouraging Uj from innovating. As in the linear pricing case, the two-part tariff model is rather simplistic and extreme; downstream firms fail to benefit from upstream innovation. In this way, however, the model can clearly illustrate the mechanism of downstream foreclosure and the possibility of joint gains by Ui and Di.

NOTES:

1. If this happened, we would have upstream, rather than downstream foreclosure.

2. To see this, notice that when m' = m, we have:

$$H = \Pi_{Di}(m';m) - \Pi_{Di}(m;m) - 2(\Pi_{Di}(m';m') - \Pi_{Di}(m;m')) = 0.$$

Also, notice that when m' = m, we have $\partial H/\partial m' > 0$; that is, at least for some values of m' a little lower than m, we have $H < 0$, and condition (A1) holds. In particular, since downstream products are differentiated (rather than homogeneous), we have:

$$\partial H/\partial m' \, (m' = m) = -\partial \Pi_{Di}(mi = m; mj = m)/\partial mi > 0.$$

3. To see the intuition of this, notice that condition (A1) always holds when the downstream products are completely differentiated, i.e., when the two downstream firms are in independent markets: $\Pi_{Di}(m') - \Pi_{Di}(m) < 2(\Pi_{Di}(m') - \Pi_{Di}(m))$. On the other hand, condition (A1) never holds when the downstream product is totally homogeneous; in this case, $\Pi_{Di}(m;m) = \Pi_{Di}(m';m') = \Pi_{Di}(m;m') = 0$.

4. Notice that in our simple model, when a Ui-Di contract is signed, A_i^c can never be strictly negative; Ui prefers not to sign a contract at all rather than offer a strictly negative A_i^c. Thus, in equilibrium we can only have $A_i^c \geq 0$. The reasoning is the same as in footnote 8 of the main paper.

5. When the total probability of innovation ($p_1 + p_2$) is concave in R_{U1} and R_{U2}, and the R&D reaction curves of U1 and U2 are concave in shape.

6. It is not possible to have asymmetric equilibria in which only one pair of firms signs an exclusive supply contract.