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# Strategic Dual Sourcing as a Driver for Free Revealing of Innovation*

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# Strategic dual sourcing as a driver for free revealing of innovation*

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**Abstract**

This paper examines the role of dual sourcing (e.g., outside options) in vertical and horizontal relations. In a bilateral monopoly market, if either the upstream or downstream firm has outside options, the other firm could lose from seemingly positive shocks, e.g., market expansion or technology improvements. We extend this setting to a bilateral duopoly market in which each downstream firm has outside options and upstream firms can engage in cost reducing investments and generate technological spillovers. We find that each upstream firm has an incentive to *voluntarily* generate technological spillovers to its upstream rival if the downstream firms have better outside options.

**Keywords**: Dual sourcing, Outside option, Spillover, Vertical relations

**JEL Codes**: L13, O32, M11, C72

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# 1 Introduction

The management literature documents a long list of "dual sourcing." Asanuma (1985) shows that Japanese firms bring rival parts suppliers to work together in some situations, while in other situations they keep the suppliers away from each other to create competition.[1] Kamath and Liker (1994) describe how Japanese automakers would invite guest engineers from rival suppliers to compete side-by-side, to see who could come up with a better design. Dyer and Nobeoka (2000) document the practices in Toyota, which constitute of different layers within the supplier network, ranging from bilateral relations (i.e., sending Toyota's internal lean-production experts to advise suppliers), to sub-networks (i.e., establishing supplier learning groups where rival suppliers help each other study and implement the Toyota Production System), to more encompassing network structures (i.e., regular meetings within Toyota's supplier association). Subsequently, Wilhelm (2012) finds that such practices still exist today in Japanese firms and they create *not only cooperation but also competition* between suppliers within the network. Wu and Choi (2005) investigate the cases of eight buyers, and find that even a long-term buyer-supplier relationship does not prevent the buyer from finding alternative suppliers to create competition.[2] In another study, Wu et al. (2010) simulate such "co-opetition," where competing suppliers work together to meet the needs of the buyer.

The present paper examines the aforementioned phenomenon of dual-sourcing, in an extended setup of both vertical and horizontal competition. We start by considering a simple *bilateral monopoly* where a supplier sells its input to a buyer. The payment to the supplier is negotiated between the two parties,[3] but affected by the buyer's efforts to search for fringe

[1]Soucing strategies have been discussed by management researchers since Porter (1980), which views multiple sourcing as a mechanism for a firm to affect its bargaining power relative to both inside and outside suppliers, which is exactly what we rigorously model here.

[2] In the context of international trade, recently several researchers investigate the effects of bi-sourcing (make-and-buy) from home and foreign markets (Kogut and Kulatilaka, 1994; Rob and Vettas, 2003; Choi and Davidson, 2004; Mukherjee, 2008).

[3] Such negotiations are common in the literature (see Davidson, 1988; Horn and Wolinsky, 1988; Dobson and Waterson, 1997; O'Brien and Shaffer, 2005; Björnerstedt and Stennek, 2007; Inderst, 2007; Milliou and Petrakis, 2007). Recently, Iozzi and Valletti (2014) comprehensively discuss vertical relations with bilateral Nash bargaining.

suppliers. In other words, the buyer has an outside option to procure its input with, i.e., "dual sourcing."

With this simple setup, we first show that dual sourcing can affect profitability in unconventional ways. For instance, the usual sources for potential gains such as a market expansion may not benefit the supplier, opposite to what one might expect. Intuitively, as the market size rises, the buyer raises its search effort for alternative sourcing, weakening the bargaining position of the supplier. As a result, a market expansion while benefiting the downstream firm, can hurt the upstream firm. Furthermore, in the Appendix, we reverse the roles of the upstream and downstream firms, and find our basic mechanism remains robust.

We then generalize the above setup to the case of a *bilateral duopoly*, again with dual sourcing by buyers, and incorporating cost-reducing investments (e.g., R&D) by the suppliers. We find surprisingly that each supplier has an incentive to *unilaterally* generate technology spillovers to its rival for free, if its own downstream buyer can find cheap alternative sourcing. Such spillovers generate a market-size shrink, which can hurt the downstream buyer but benefit the supplier, via the bargaining mechanism described above. We show that the unilateral spillovers are strategic complements in the sense that it can induce the rival to also generate technology spillovers, and such technology spillovers can benefit both the buyers and the suppliers.

Our results provide rationale for why the Japanese "suppliers' associations" still have strong support (see Sako, 1996) from both suppliers and auto makers, even though these associations may at times generate outward spillovers to rivals. Sako finds that a supplier would typically join in several suppliers' associations and hold multiple memberships, aiming at obtaining information on production plans and solicitating suggestion for common problems such as standardization and pollution control, etc.[4] As such, the suppliers' association has been effective in diffusing innovative practices in the automobile industry. Our model supports her findings

[4] In 1990s, almost all major Japanese auto manufacturers (except Honda) have suppliers' associations, and many suppliers join multiple associations (Sako, 1996, p.651). Part suppliers that join in multiple suppliers' associations tend to be large in size and play a leading role in association activities (Sako, 1996, p. 656).

with a rigorous theory: dual sourcing by automakers can stabilize the suppliers' associations for strategic reasons.

The present paper while simple, generates novel results that match the real practices of many firms on vertically and horizontally related production networks, such as the automobile makers and parts suppliers documented in the literature. We explicitly show conventionally counterintuitive situations when the supplier may lose from a market expansion and when it may choose to give out its own technology to rivals. Our mechanism has wide applications under different circumstances, for instance, suppliers' incentives in cost reduction, quality improvement, upstream collaboration and technology spillovers, and even worker training in the labor market.

Feng and Lu (2012) also use a similar market structure as ours to examine bilateral duopoly, and show that a *simultaneous* efficiency improvement of both suppliers can harm the downstream firm although the total industry profits rise. Their results are obtained based on downstream competition and asymmetric bargaining power in each vertical chain, which are not required in our model.

Several other papers investigate cases in which downstream firms engage in R&D and endogenously determine the degree of R&D spillover.[5] Kultti and Takalo (1998) and Poyago-Theotoky (1999) discuss whether downstream duopolists generate R&D spillover after determining their investment levels. Kamien and Zhang (2000), Gil-Moltó et al. (2005), Piga and Poyago-Theotoky (2005) and Milliou (2009) discuss cases in which downstream firms noncooperatively set the degree of R&D spillover before setting investment levels.[6] Milliou (2009) shows that oligopolists prefer generating outward R&D spillover if the degree of product differentiation is high enough, a result that does not hold if the products are homogenous as in our paper. Subsequently, Milliou and Petrakis (2012) show that a vertically integrated firm

[5] De Bondt (1997) and Rockett (2012) nicely survey the literature of R&D competition.

[6] In Kamien and Zhang (2000), no firm has an incentive to generate spillover. In Gil-Moltó et al. (2005) and Piga and Poyago-Theotoky (2005), because spillover is reciprocal, firms have incentives to generate a positive degree of spillover.

chooses to fully disclose its production knowledge to the downstream rival to expand downstream production, which eventually benefits the integrated upstream sector. Their result is less likely to hold if the degree of product differentiation is low. Yoshida (2015) also shows a possibility that a downstream firm has an incentive to give its superior technology to its rival in a downstream multi-product duopoly with vertical relations. Product multiplicity is the key factor to derive his main result. And finally, De Fraja (1993), Katsoulacos and Ulph (1998), and Pacheco-de-Almeida and Zemsky (2012) investigate market environments where free revealing of technological knowledge can appear, in the context of continuous-time R&D competition.[7] In contrast, our paper provides another rationale behind such behavior, based on bargaining and outside options.

The paper proceeds as follows. Section 2 investigates a bilateral monopoly and establishes a benchmark result. Section 3 extends the benchmark model to the case of bilateral duopoly with cost-reducing activities by upstream suppliers, and examines both one-sided and cross spillovers in technology. And in the Appendix, we demonstrate the robustness of our results by reversing the roles played by the downstream and upstream firms.

# 2 Bilateral Monopoly

We start with a benchmark bilateral monopoly model and demonstrate a basic result in the simplest way—a general positive shock such as a market expansion can hurt the firm with worse or even fixed outside option in negotiations, even though the shock increases the size of the total pie (rents). But, it benefits the firm that can improve its outside option.

## 2.1 The basic setting

Consider a downstream firm and an upstream firm without any production cost for simplicity, whose outputs are related in a one-to-one ratio. However, the downstream firm has an outside option: by incurring a fixed cost $F$, it can procure the input from a different source at price

[7] Harhoff et al. (2003) is a seminal work of voluntary information spillovers in the context of management. See also Pénin (2007) for a recent survey on open knowledge transfer.

$w(e)$ if negotiation with the upstream firm breaks down, where $e$ is the search effort of the downstream firm to improve the value of its outside option, at a cost of $S(e)$.[8] We assume $w'(e) < 0$, $w''(e) > 0$; and $S'(e) \geq 0$, $S''(e) > 0$.

Let us first investigate the simplest game structure: in the first stage, the downstream firm makes a search effort $e$ to improve its outside option; in the second stage, both firms bargain over the trading terms (a two-part tariff, $mq + T$, where $m$ is the wholesale price and $T$ is the fixed payment). If bargaining breaks down, the downstream firm executes its outside option at the fixed cost $F$, with a marginal cost of $w(e)$ (similar to Inderst and Valletti, 2009); finally, in the third stage, the downstream firm sets the quantity of final output. The game is solved by backward induction.

To keep the model simple and clean, we assume the search cost to be sunk, in a way similar to R&D investments in innovation models, where actual production and any price or profit negotiation occurs afterwards.[9] Let the inverse demand function in the downstream market be $p(q; a)$, where $q$ is the quantity and $a$ is a positive parameter that can shift up the demand, such as market size, income, etc.

In the last stage, the downstream firm chooses the final quantity $q$ to maximize its profits $(p(q; a) - m)q - T$, resulting in the following first-order and second-order conditions:

$$\text{F.O.C.} \qquad p(q; a) - m + p_q(q; a)q = 0,$$

$$\text{S.O.C.} \qquad 2p_q(q; a) + p_{qq}(q; a)q < 0,$$

where $p_q(q; a) = \partial p(q; a)/\partial q$ and $p_{qq}(q; a) = \partial^2 p(q; a)/\partial q^2$.

[8] The assumption concerning outside options follows that in Inderst and Valletti (2009). However, here we endogenize the price.

[9] An alternative is to let the two parties bargain first and then the downstream firm search if bargaining breaks down. In that case, however, since search begins after bargaining breaks down, delay of production occurs, which is costly to the downstream firm. In order to avoid such delay cost, the downstream firm thus chooses to search before bargaining occurs. Also, Feng and Lu (2012) assume simultaneous bargaining over output and transfer payment. In contrast, the sequential timing structure in our model clarifies what happens in each stage. Furthermore, our model formulation endogenizes the outside opportunity of the downstream firm along the lines of Inderst and Valletti (2009).

Let $q(m;a)$ denote the equilibrium quantity in which the wholesale price is $m$. Then the gross profits of the downstream and the upstream firms (excluding the search costs of the downstream firm) in the second stage are given as respectively,

$$\pi_D = [p(q(m;a);a) - m]q(m;a) - T; \quad \pi_U = mq(m;a) + T,$$

The firms' outside options are respectively,

$$\pi_D^O = [p(q(w(e);a);a) - w(e)]q(w(e);a) - F; \quad \pi_U^O = 0.$$

During bargaining, they jointly maximize[10]

$$G = \{\pi_D - \pi_D^O\}\{\pi_U - 0\}.$$

The first-order conditions $\partial G/\partial T = 0$ and $\partial G/\partial m = 0$ can be reexpressed as:

$$\begin{aligned} & \pi_D - \pi_D^O - \pi_U = 0, \\ & (\pi_D - \pi_D^O)[q(m;a) + mq_m(m;a)] - \pi_U q(m;a) \\ = \; & (\pi_D - \pi_D^O - \pi_U)q(m;a) + (\pi_D - \pi_D^O)mq_m(m;a) = (\pi_D - \pi_D^O)mq_m(m;a) = 0. \end{aligned}$$

From the above, we obtain

$$m = 0, \quad T = \frac{p(q(0;a);a)q(0;a) - [p(q(w(e);a);a) - w(e)]q(w(e);a) + F}{2}.$$

Since bargaining is efficient, the two firms set the wholesale price equal to the marginal cost of the upstream firm, i.e., $m = 0$, to maximize their joint profits first, and then, they split the overall profits through the lump-sum payment, $T$. As such, the "double marginalization" problem in a standard bilateral-monopoly situation is avoided. Expecting the bargained outcome, the profits of the two firms respectively become

$$\begin{aligned} \Pi_D(e) &= [p(q(m);a) - m]q(m;a) - T - S(e) \\ &= \frac{[p(q(0;a);a)]q(0;a) + [p(q(w(e);a);a) - w(e)]q(w(e);a) - F - 2S(e)}{2}, \\ \Pi_U(e) &= \frac{[p(q(0;a);a)]q(0;a) - [p(q(w(e);a);a) - w(e)]q(w(e);a) + F}{2}. \end{aligned}$$

[10] Matsushima and Shinohara (2014, pp. 430–1) explain a plausibility of using Nash bargaining to capture the negotiations between buyers and suppliers in the Japanese automobile industry.

Then in the first stage, the downstream firm chooses search effort, satisfying the following first-order condition,

$$\frac{\partial \Pi_D(e)}{\partial e} = 0 \Leftrightarrow -\frac{w'(e^*)q(w(e^*);a) + 2S'(e^*)}{2} = 0. \tag{1}$$

## 2.2 Market size

As promised, we now investigate how a marginal increase in parameter $a$ (e.g., market size or income) affects the equilibrium outcome. Applying the envelop theorem yields

$$\frac{2\partial \Pi_U(e^*)}{\partial a} = p_a(q(0;a);a)q(0;a) - p_a(q(w(e^*);a);a)q(w(e^*);a) + w'(e^*)q(w(e^*);a)\frac{de^*}{da}. \tag{2}$$

where $p_a \equiv \partial p(q;a)/\partial a$ and $e^*$ is the equilibrium level of search effort. Total differentiation of (1) gives

$$\frac{de^*}{da} = \frac{w'(e^*)q_a(w(e^*);a)}{-\{w''(e^*)q(w(e^*);a) + [w'(e^*)]^2 q_m(w(e^*);a) + 2S''(e^*)\}},$$

where $q_m \equiv \partial q(m,a)/\partial m$. It is easy to show $de^*/da > 0$, because the denominator is derived from the second-order condition of (1).

Let us examine (2) in detail. If $w(e^*)$ is sufficiently small (e.g., approaching zero), the first and second terms on the RHS cancel out, leaving only the third term and hence $\partial \Pi_U(e^*)/\partial a < 0$. Thus,

**Proposition 1** *An increase in the parameter $a$ decreases $\Pi_U(e^*)$ if $w(e^*)$ is sufficiently small.*

This Proposition implies that a market expansion actually harms the upstream firm, opposite to what one might conventionally think. Intuitively, as the market size rises, the downstream firm raises its search effort, which then weakens the bargaining position of the upstream firm, leading to our result.

To summarize, positive shocks such as market size increases enlarge the pie and could bring potential gains for all players. However, if some players can raise their outside options, they can take away more than the increase of the pie, leaving others worse off. Also note that the same logic applies to a setting with $n$ outside options, where the firm would use the best one of them and the rest of the options $(n-1)$ becomes irrelevant.

**Example** Assume that $p = a - q$, $w(e) = w - e$, and $S(e) = \gamma e^2/2$, with $a$ and $\gamma$ being positive constants.[11] The second stage net profits of the two firms are then given as

$$\Pi_D(e) = \frac{1}{8}\left(a^2 + [a - w(e)]^2 - 4F\right) - S(e), \text{ and } \Pi_U(e) = \frac{1}{8}\left(a^2 + [a - w(e)]^2 + 4F\right)$$

In the first stage, the first-order condition of the downstream firm is

$$\frac{\partial \Pi_D(e)}{\partial e} = \frac{a - w - (4\gamma - 1)e}{4} = 0 \quad \rightarrow \quad e^* = \frac{a - w}{4\gamma - 1}.$$

Since the quantity under which bargaining breaks down, $(a - w(e^*))/2$, is smaller than when agreement is reached, we require $a < 4\gamma w$. Substituting $e^*$ into $\Pi_U(e)$ gives

$$\Pi_U(e^*) = \frac{[(8\gamma - 1)a - 4\gamma w](4\gamma w - a)}{8(4\gamma - 1)^2} + \frac{F}{2}.$$

The first term is positive if

$$\frac{4\gamma w}{8\gamma - 1} < a < 4\gamma w.$$

Differentiating $\Pi_U(e^*)$ with respect to $a$ yields

$$\frac{\partial \Pi_U(e^*)}{\partial a} = \frac{16\gamma^2 w - (8\gamma - 1)a}{4(4\gamma - 1)^2},$$

that is negative if and only if

$$\frac{16\gamma^2 w}{8\gamma - 1} < a < 4\gamma w,$$

under which a rise in market size $a$ *decreases* the profit of the upstream firm.

# 3 Bilateral Duopoly

In this section we extend the above benchmark model to a case of two pairs of downstream and upstream firms, denoted by $D_i$ and $U_i$ respectively ($i = 1, 2$). By doing so, we add competition to the upstream and downstream firms, forming a setup of both vertical and horizontal competition. We further show that improving one's outside option has strategic effects, which surprisingly can *hurt oneself* under certain conditions. And upstream firms, being aware of this mechanism, may give away their own technology to rivals, for free in an extreme.

[11] We assume $w(e) = w - e$ for mathematical simplicity, although $w''(e) = 0$ here.

### 3.1 The basic setting of duopoly

Just as in the benchmark, to produce a unit of the final product, firm $D_i$ needs one unit of the input produced by firm $U_i$ but not $U_j$. However, $D_i$ has outside options: it can procure the input from a different source at the price $\tilde{w}_i(e_i) = w - e_i$ if the negotiation with $U_i$ breaks down, where $e_i$ is the search effort of $D_i$, with a cost of $S(e_i)$. Simultaneously, $U_i$ engages in cost-reducing activities such as process R&D (which was absent in the benchmark case), through which it can reduce its marginal cost to $c_i(I_i) = c - I_i$, where $I_i$ is the investment of $U_i$ at a cost of $f(I_i)$. We assume $c(< w)$ to be constant to ensure an interior solution.

We then take into account technological spillovers between upstream firms, i.e., the cost-reducing effort by $U_j$ spills over to $U_i$. To obtain clear-cut results, following Milliou (2009), here we explicitly solve the game with linear demand and specific investment functions; $p = a - q_1 - q_2$, $S(e_i) = \gamma e_i^2$, and $f(I_i) = \gamma I_i^2$, where $q_i$ is the quantity supplied by $D_i$. We assume that the marginal cost of $U_i$ is $c_i(I_i, I_j) = c - I_i - rI_j$ if $U_j$ chooses to give its reduced cost to $U_i$, where $r \in [0, 1]$ is the degree of knowledge spillover.[12]

Consider the following game structure. In the first stage, each upstream firm simultaneously determines whether to unilaterally generate spillover to its upstream rival. In the second stage, each of the four firms simultaneously sinks an investment cost that determines the effort level to improve its outside option (downstream firms) or to reduce its marginal cost (upstream firms). In the third stage, observing the effort levels in the second stage, the upstream and the downstream firms on the same vertical chain negotiate over a transfer payment (a two-part tariff). The determined transfer payment is privately known in the vertical chain, but unknown to outsiders. This assumption simplifies the analysis since the Nash equilibrium wholesale price is set at the marginal cost of the upstream firm on each vertical chain.[13] If an agreement

[12] This setup of spillovers is quite different from the related literature on research joint ventures (see for instance, Amir et al., 2003; d'Aspremont and Jacquemin, 1988; and Suzumura, 1992), where firms conduct joint R&D in the first stage and then compete in the product market in the second stage.

[13] Notice the difference from a case where contract terms are used as a commitment device to foster aggressive behavior at the downstream level (e.g., Fershtman and Judd, 1987). The qualitative nature of our results would not change if contracts are observable.

is reached, the downstream firm procures its input from the upstream firm; otherwise, the downstream firm exercises its outside option. For expositional simplicity, we omit the fixed cost. Finally, in the forth stage, all downstream firms simultaneously set quantities to maximize their own profits. The game is again solved by backward induction.

We denote the gross final stage profit (excluding investments costs sunk in the second stage) on the vertical chain $i$ as $\pi_i(c_i, c_j)$, where $c_i$ and $c_j$ are respectively the marginal costs on the vertical chains $i$ and $j$, and $T_i$ as the payment from the downstream to the upstream firm when bargaining reaches an agreement. Then $\pi_i(c_i, c_j) - T_i$ is the gross profit of $D_i$, excluding investment costs already sunk in the second stage, and $T_i$ becomes the gross profit of $U_i$. Note that to obtain the net profit of each firm, the sunk cost of investment in the second stage must be subtracted from the above.

From the forth-stage game, given that the marginal cost of $D_i$ is $d_i$, as in the standard Cournot duopoly outcome, the quantity supplied by $D_i$ and the final-stage gross profit on the vertical chain $i$ are given as respectively

$$q_i(d_i, d_j) = \frac{a + d_j - 2d_i}{3}, \text{ and } \pi_i(d_i, d_j) = (q_i(d_i, d_j))^2, \quad i, j = 1, 2, \ j \neq i. \tag{3}$$

If $D_i$ and $U_i$ reach an agreement, $d_i$ is $c_i(I_i)$; otherwise, it is $\tilde{w}_i(e_i)$. Note that the functional form of $c_i(I_i)$ is replaced by $c_i(I_i, I_j)$ if $U_j$ chooses to give its reduced cost technology to $U_i$.

In the third stage, the pair $D_i$ and $U_i$ on the same vertical chain $i$ maximize the following Nash product with respect to $T$:

$$G_i = [\pi_i(c_i, c_j) - T_i - \pi_i(\tilde{w}_i, c_j)]T_i,$$

where $\pi_i(\tilde{w}_i, c_j)$ and 0 are respectively their gross profits if bargaining breaks down. Optimization gives

$$T_i^* = \frac{\pi_i(c_i, c_j) - \pi_i(\tilde{w}_i, c_j)}{2}.$$

Then substitution yields the net profits as respectively

$$\Pi_i^U = T_i^* - f(I_i) = \frac{\pi_i(c_i, c_j) - \pi_i(\tilde{w}_i, c_j)}{2} - f(I_i), \tag{4}$$

$$\Pi_i^D = \pi_i(c_i, c_j) - T_i^* - S(e) = \frac{\pi_i(c_i, c_j) + \pi_i(\tilde{w}_i, c_j)}{2} - S(e). \tag{5}$$

Similar to the discussion in the previous section, a decrease in $c_j$ reduces $q_i$, inducing $D_i$ to lower $e_i$, which decreases $\pi_i(\tilde{w}_i, c_j)$ through an increase in $\tilde{w}_i$ indirectly. Simultaneously, the decrease in $c_j$ also directly lowers both $\pi_i(c_i, c_j)$ and $\pi_i(\tilde{w}_i, c_j)$.

### 3.2 Spillover effects

In the second stage, we consider three scenarios: no upstream firm generates spillover; only one upstream firm generates spillover; both upstream firms generate spillovers.

#### 3.2.1 No spillover

First, we look into the case when no upstream firm generates spillover to its rival. In the investment stage, from (5) and (4), the objective functions are given as

$$\Pi_i^U = \frac{\pi_i(c_i(I_i), c_j(I_j)) - \pi_i(\tilde{w}_i(e_i), c_j(I_j))}{2} - f(I_i), \tag{6}$$

$$\Pi_i^D = \frac{\pi_i(c_i(I_i), c_j(I_j)) + \pi_i(\tilde{w}_i(e_i), c_j(I_j))}{2} - S(e_i). \tag{7}$$

The first-order conditions lead to the reaction functions:

$$I_i(I_j) = \frac{\alpha - I_j}{9\gamma - 2}, \quad e_i(I_j) = \frac{\alpha - 2\beta - I_j}{9\gamma - 2}, \tag{8}$$

where $\alpha \equiv a - c$ and $\beta \equiv w - c$. Note that $e_i(I_j)$ in (8) includes only the investment level of the rival's upstream firm $U_j$ because $D_i$'s effort is related to its outside option, $\pi_i(\tilde{w}_i(e_i), c_j(I_j))$. Solving the simultaneous equations, we have the investment levels:

$$I_i^* = \frac{\alpha}{9\gamma - 1}, \quad e_i^* = \frac{(9\gamma - 2)\alpha - 2(9\gamma - 1)\beta}{(9\gamma - 2)(9\gamma - 1)}.$$

The net profit of each firm then becomes

$$\Pi_i^{U*}(N, N) = \frac{(9\gamma - 2)\gamma\alpha^2}{2(9\gamma - 1)^2} - \frac{9\gamma^2((9\gamma - 2)\alpha - 2(9\gamma - 1)\beta)^2}{2(9\gamma - 1)^2(9\gamma - 2)^2},$$

$$\Pi_i^{D*}(N, N) = \frac{9\gamma^2\alpha^2}{2(9\gamma - 1)^2} + \frac{\gamma((9\gamma - 2)\alpha - 2(9\gamma - 1)\beta)^2}{2(9\gamma - 1)^2(9\gamma - 2)},$$

where $k$ and $l$ in $\Pi_i^{D*}(k, l)$ and $\Pi_i^{U*}(k, l)$ respectively represent the decisions of upstream firms 1 and 2 for generating spillover $(k, l = Y, N)$, with $Y$ and $N$ indicating yes and no.

### 3.2.2 One-sided spillover

Next, consider the case in which only the reduced cost of $U_1$ is spilled over to $U_2$ but not the other way around. The cost function of $U_2$ can be rewritten as $c_2(I_2, I_1) = c - I_2 - rI_1$. From (5) and (4), the objective functions of the firms are respectively

$$\Pi_1^U = \frac{\pi_1(c_1(I_1), c_2(I_2, I_1)) - \pi_1(\tilde{w}_1(e_1), c_2(I_2, I_1))}{2} - f(I_1), \tag{9}$$

$$\Pi_1^D = \frac{\pi_1(c_1(I_1), c_2(I_2, I_1)) + \pi_1(\tilde{w}_1(e_1), c_2(I_2, I_1))}{2} - S(e_1), \tag{10}$$

$$\Pi_2^U = \frac{\pi_2(c_2(I_2, I_1), c_1(I_1)) - \pi_2(\tilde{w}_2(e_2), c_1(I_1))}{2} - f(I_2), \tag{11}$$

$$\Pi_2^D = \frac{\pi_2(c_2(I_2, I_1), c_1(I_1)) + \pi_2(\tilde{w}_2(e_2), c_1(I_1))}{2} - S(e_2). \tag{12}$$

Then, the effort level of $U_1$, $I_1$, influences the outside value of $D_1$, $\pi_1(\tilde{w}_1(e_1), c_2(I_2, I_1))$, as well as the downstream profit, $\pi_1(c_1(I_1), c_2(I_2, I_1))$. The voluntary spillover generates a strategic interaction between the endogenous effort levels of $U_1$ and $D_1$, through $\pi_1(\tilde{w}_1(e_1), c_2(I_2, I_1))$. Specifically, an increase in $I_1$ decreases $c_2$, inducing $D_1$ to lower $e_1$. This effect can benefit $U_1$ especially when $\tilde{w}_1(e_1)$ is small, since the marginal effect of lowering $e_1$ on the outside profit of $D_1$ increases as its "efficiency," $\tilde{w}_1(e_1)$, improves.

In the investment stage, each firm's reaction function is obtained as respectively

$$I_1(I_2, e_1) = \frac{\alpha - r\beta - I_2 + re_1}{9\gamma - 2(1-r)}, \tag{13}$$

$$I_2(I_1) = \frac{\alpha - (1-2r)I_1}{9\gamma - 2}, \tag{14}$$

$$e_1(I_2, I_1) = \frac{\alpha - 2\beta - I_2 - rI_1}{9\gamma - 2}, \tag{15}$$

$$e_2(I_1) = \frac{\alpha - 2\beta - I_1}{9\gamma - 2}. \tag{16}$$

$e_2(I_1)$ is the same in both (16) and (8). Note that the technology spillover generates three additional effects on these reaction functions. First, the effort by $D_1$ enhances the incentive of $U_1$ to engage in cost reduction (see (13)), because the spillover allows $U_1$ to directly decrease the outside profit of $D_1$ through its own investment. Second, the effort by $U_1$ can increase the incentive of $U_2$ if the degree of spillover is large (see (14)), which is similar to that in the context of research joint ventures (e.g., d'Aspremont and Jacquemin, 1988). Finally, the effort by $U_1$ lowers the incentive of $D_1$ to increase its outside value (see (15)), similar to the reason in the first effect. Putting these all together, the spillover generates a positive impact on the efficiency of the rival upstream firm but a negative one on the downstream partner's effort to improve its outside option. The former impact hurts the technology giver while the latter one benefits it, and which effect is bigger can be explained as follows.

Solving the simultaneous equations gives:

$$\begin{aligned}
I_1^* &= \frac{(3\gamma-1)(9\gamma-2+r)\alpha - 3\gamma(9\gamma-2)r\beta}{(9\gamma-2+r)((9\gamma-1)(3\gamma-1)+3\gamma r)}, \\
I_2^* &= \frac{(3\gamma-1+r)(9\gamma-2+r)\alpha + 3\gamma(1-2r)r\beta}{(9\gamma-2+r)((9\gamma-1)(3\gamma-1)+3\gamma r)}, \\
e_1^* &= \frac{(3\gamma-1)(9\gamma-2+r)\alpha - (2(3\gamma-1)(9\gamma-1)+(12\gamma-1)r-3\gamma r^2)\beta}{(9\gamma-2+r)((9\gamma-1)(3\gamma-1)+3\gamma r)}, \\
e_2^* &= \frac{((3\gamma-1)(9\gamma-2)+3\gamma r)(9\gamma-2+r)\alpha}{(9\gamma-2)(9\gamma-2+r)((9\gamma-1)(3\gamma-1)+3\gamma r)} \\
&\qquad - \frac{(2(3\gamma-1)(9\gamma-2)(9\gamma-1)+(2-30\gamma+81\gamma^2)r+6\gamma r^2)\beta}{(9\gamma-2)(9\gamma-2+r)((9\gamma-1)(3\gamma-1)+3\gamma r)}.
\end{aligned}$$

Further substitution yields the firms' equilibrium profits, which are messy algebraically (see Appendix 2):

$$\Pi_1^{U*}(Y,N),\ \Pi_1^{D*}(Y,N),\ \Pi_2^{U*}(Y,N),\ \Pi_2^{D*}(Y,N),$$

given that the cost reduction of $U_1$ is spilled over to $U_2$.

Using the above, we can examine whether the voluntary spillover increases the profit of $U_1$. A simple comparison leads to:[14]

**Proposition 2** *$\Pi_1^{U*}(Y,N) > \Pi_1^{U*}(N,N)$ if and only if $\beta < \beta(YN)$, where $\beta(YN)$ is $\beta$ such that $\Pi_1^{U*}(Y,N) = \Pi_1^{U*}(N,N)$. Similarly, $\Pi_2^{U*}(N,Y) > \Pi_2^{U*}(N,N)$ if and only if $\beta < \beta(YN)$.*

The threshold value of $\beta$, $\beta(YN)$, is depicted in Figure 1. $U_1$ benefits by giving its technology to the rival for free, if the above condition is satisfied. Similarly, we can numerically show

[14] In Section 3, we *explicitly* derive the threshold values in the propositions. The file is available upon request.

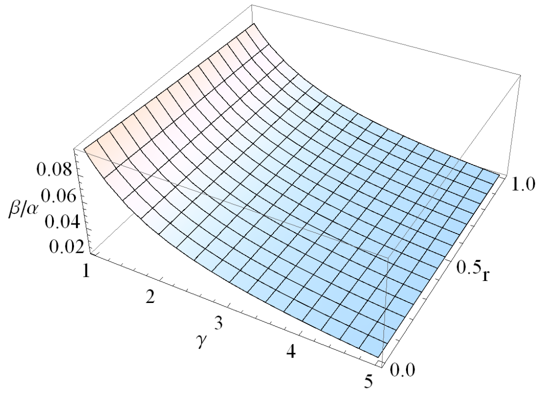



**Figure 1: Condition for voluntary spillover to benefit $U_1$**

that giving $U_1$'s technology to $U_2$ harms $D_1$.[15]

### 3.2.3 Two-sided spillovers

Finally, we examine the case when both $U_1$ and $U_2$ cross spillover, specifically, the cost function of $U_i$ is given by $c_i(I_i, I_j) = c - I_i - rI_j$ $(i, j = 1, 2,\ j \neq i)$. Except this *ex-post* cost of the upstream firms, the timing structure of the game is similar to the case under one-sided spillover just examined. From (5) and (4), the objective functions of $U_i$ and $D_i$ are given as respectively $(i, j = 1, 2$ and $j \neq i)$

$$\Pi_i^U = \frac{1}{2}\left(\pi_i(c_i(I_i, I_j), c_j(I_j, I_i)) - \pi_i(\tilde{w}_i(e_i), c_j(I_j, I_i))\right) - f(I_i), \tag{17}$$

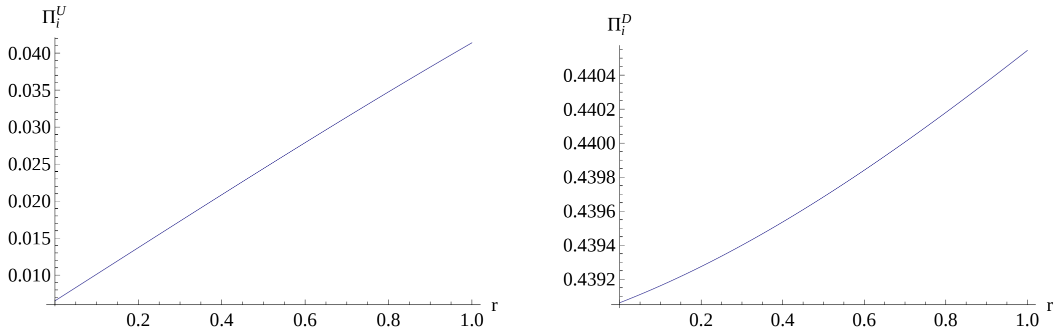
$$\Pi_i^D = \frac{1}{2}\left(\pi_i(c_i(I_i, I_j), c_j(I_j, I_i)) + \pi_i(\tilde{w}_i(e_i), c_j(I_j, I_i))\right) - S(e_i). \tag{18}$$

Rearranging the first-order conditions, $\partial\Pi_i^U/\partial I_i = 0$ and $\partial\Pi_i^D/\partial e_i = 0$, gives the following reaction functions

$$I_i(I_j, e_i) = \frac{\alpha - r\beta - (1-r)^2 I_j + re_i}{9\gamma - 2(1-r)}, \tag{19}$$

$$e_i(I_i, I_j) = \frac{\alpha - 2\beta - rI_i - I_j}{9\gamma - 2}. \tag{20}$$

[15] The *ex ante* commitment to generating technological spillovers is crucial in deriving the above results. Given that the effort levels have already been determined, normally each upstream firm does not have an incentive to give its technology to its rival upstream. For our results to hold, each upstream firm must commit to giving out its technology *before* choosing effort levels, while the size of spillovers is not so essential.




Upstream firm    Downstream firm

Note: We set $\gamma = 3$, $\alpha = 2$, and $\beta = 1/20$.

**Figure 2: The profits of the upstream and downstream firms.**

Under reciprocal spillovers, the reaction function of $U_i$ in (19) differs from that in (13). However, the reaction function of $D_i$ in (20) is the same with that in (15), because the outside profit does not depend on the inside transfer price, $c_i(I_i, I_j)$.

Solving the simultaneous equations leads to

$$
\begin{aligned}
I_i^{**} &= \frac{(9\gamma - (2-r))\alpha - 9r\gamma\beta}{(9\gamma-2)(9\gamma-1) + r + (9\gamma-1)r^2}, \\
e_i^{**} &= \frac{(9\gamma - (2-r)(1+r))\alpha - (18\gamma - (2-r)(1+r))\beta}{(9\gamma-2)(9\gamma-1) + r + (9\gamma-1)r^2}.
\end{aligned}
$$

We can explicitly solve the game and derive the equilibrium profits, which are again messy (see Appendix 2):

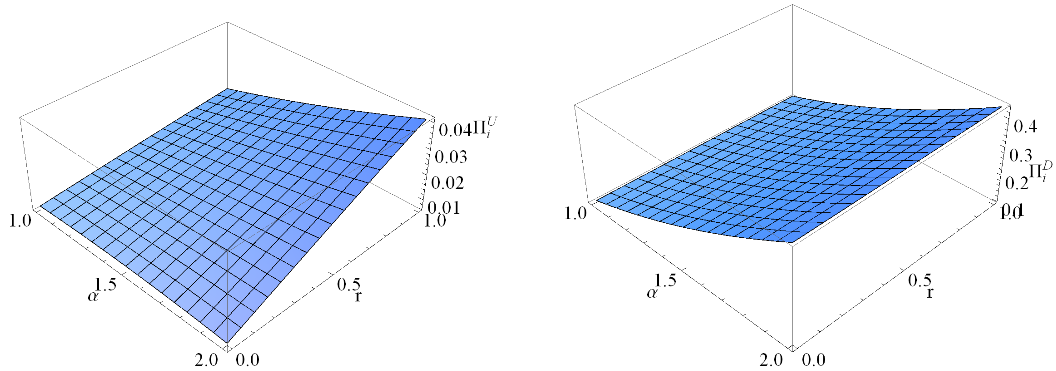
$$\Pi_i^{U*}(Y, Y),\ \Pi_i^{D*}(Y, Y).$$

Here we only show how the exogenous variables ($\alpha$ and $r$) affect the equilibrium profits.

In Figure 2, the vertical axis indicates the profit level, $\Pi_i^j$ ($j = U, D$); and the horizontal axis indicates the value of $r$. The figures show that the degree of spillovers raises firm profitability.

Since $\alpha = a - c$ and $\beta = w - c$, an increase in $\alpha$ reflects an increase in $a$, expanding the market size. As previously shown, an increase in $\alpha$ does not always improve the profitability of each upstream firm in the absence of spillovers (Figure 3).

Note that the left-hand side of Figure 3 also shows several properties: i). An increase in the market size monotonically and significantly raises the profit of each upstream firm when




Upstream firm Downstream firm

Note: We set $\gamma = 3$ and $\beta = 1/20$ to draw the figures.

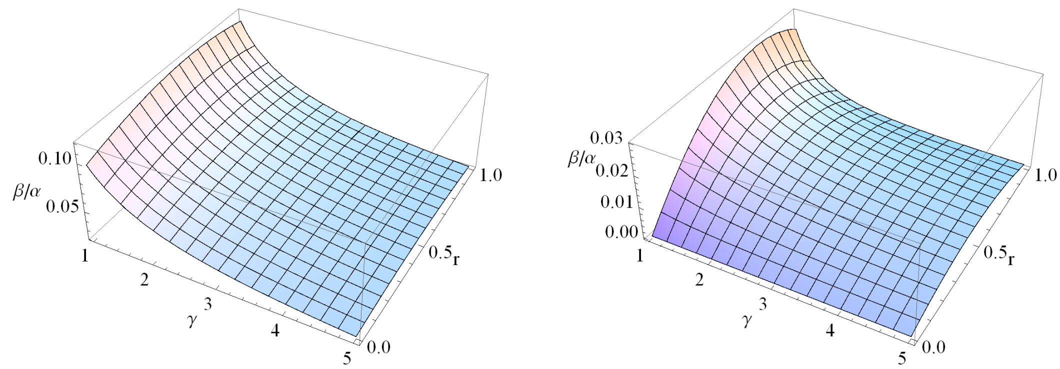
**Figure 3: The profits of the upstream and downstream firms.**

the degree of spillovers is large enough, because the outside option of $D_i$ decreases with the degree of spillovers. ii). The spillover effect is more significant on the upstream firms than the downstream firms, caused by the former firms' investment to lower the outside option of the latter firms. iii). The spillover effect on the rival's efficiency is magnified, when the downstream firm also has a stronger incentive to raise its own option value. In turn, an increase in $r$ enhances the incentive of each upstream firm to engage in cost-reducing activity, raising their profits.

We can explicitly derive the threshold value of $\beta$ (denoted as $\beta(YY)$) at which $U_i$'s profit when both upstream firms generate spillovers equals that when only $U_j$ generates spillover. A simple comparison gives:

**Proposition 3** $\Pi_1^{U*}(Y,Y) > \Pi_1^{U*}(N,Y)$ *if and only if* $\beta < \beta(YY)$*, where* $\beta(YY)$ *is* $\beta$ *such that* $\Pi_1^{U*}(Y,Y) = \Pi_1^{U*}(N,Y)$*. Similarly,* $\Pi_2^{U*}(Y,Y) > \Pi_2^{U*}(Y,N)$ *if and only if* $\beta < \beta(YY)$*.*

The threshold value $\beta(YY)$, and the difference between $\beta(YY)$ and $\beta(YN)$ are summarized in Figure 4. From these threshold values, the decisions of the upstream firms depend on the exogenous values $\beta/\alpha$ and $r$. As $\beta/\alpha$ rises, the incentive of each downstream firm to increase its search effort becomes weaker, which in turn lowers the incentive of each upstream firm for technology spillovers.




$\beta(YY)$ $\beta(YY) - \beta(YN)$

**Figure 4: The conditions that upstream firms generate spillovers.**

### 3.3 Endogenous spillover effects

So far we have examined either one-way or two-way but exogenous giveaway of upstream technology.

In the first stage, each upstream firm $U_i$ unilaterally determines whether to generate technological spillover to its rival upstream firm $U_j$.[16] Depending on the threshold values of $\beta$, we find:

**Proposition 4** *(i). If $\beta < \beta(YY)$, both $U_1$ and $U_2$ voluntarily generate spillovers; (ii). If $\beta > \beta(YN)$, no upstream firm voluntarily generates spillover; and (iii). If $\beta(YN) < \beta < \beta(YY)$, multiple equilibria exist.*

Figure 5 shows, under high parameter values of $\beta/\alpha$, neither upstream firm is willing to give its technology out; Under intermediate values, both firms can either generate technology spillovers to the rival or not at all, i.e., multiple equilibria exist; Under low values of the same parameter ratio, each upstream firm has incentives to generate spillover in equilibrium.

The logic can be understood as follows. As in the monopoly case, a lower $\beta/\alpha$ enhances the incentives of the downstream firms to increase their search efforts, which induces each upstream firm to generate spillovers to mitigate its downstream partner's incentive to search. Figure 6

[16] It can be straightforwardly shown that $U_j$ does not have an incentive to refuse the unilateral spillover.

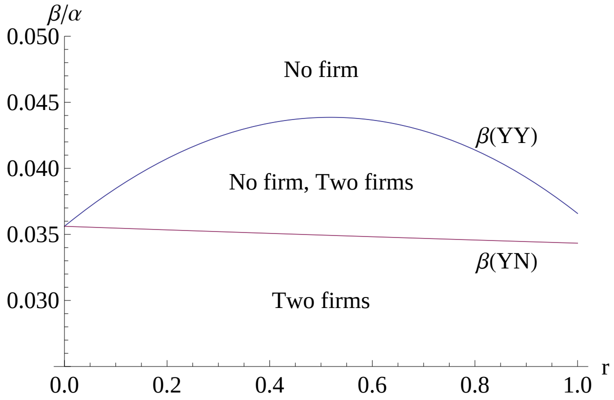
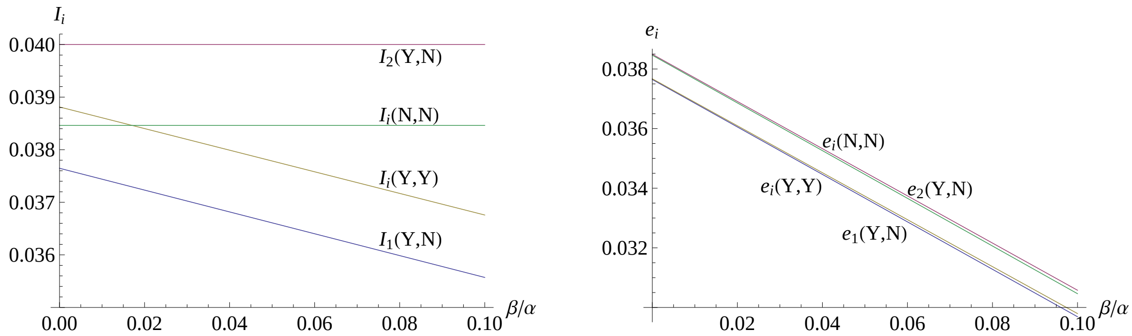



**Figure 5: Endogenous determination of spillover effects** $(\gamma = 3)$

shows that the investment of a spillover-generating upstream firm and that of a downstream firm are negatively correlated with $\beta/\alpha$.

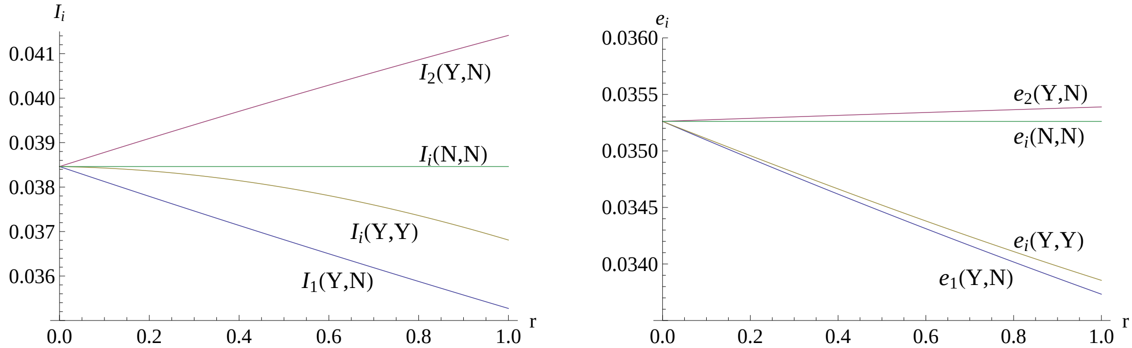



(Investment levels: upstream) (Investment levels: downstream)

**Figure 6: The equilibrium investment levels** $(\gamma = 3,\ r = 1/2)$

| | |
|---|---|
| $(Y, Y)$: | Both upstream firms generate spillovers. |
| $(Y, N)$: | Only $U_1$ generates spillover. |
| $(N, N)$: | No upstream firm generates spillover. |
| Note: | $e_2(Y, N) > e_i(N, N) > e_i(Y, Y) > e_1(Y, N)$ |

Note that investment spillover is a key reason for multiple equilibria under intermediate values of $\beta/\alpha$. In Figure 5, the lower line indicates the threshold value of $\beta/\alpha$ for which $U_i$ has incentives to generate spillover given that $U_{-i}$ does not generate spillover. As in (14), generating unilateral spillovers increases the rival upstream's investment since it raises the rival's quantity (see also the difference between $I_1(Y,N)$ and $I_2(Y,N)$ in Figure 7), diminishing the incentive for unilateral spillover. The negative effect is stronger as the degree of spillover increases. However, the negative effect is *almost* canceled out by the decrease in the downstream partner's investment (see $e_1(Y,N)$ in Figure 7), which is shown by the gentle slope of the lower line in Figure 5.




(Investment levels: upstream) (Investment levels: downstream)

**Figure 7: The equilibrium investment levels** ($\gamma = 3$, $\beta/\alpha = 1/25$)

| | |
|---|---|
| $(Y,Y)$: | Both upstream firms generate spillovers. |
| $(Y,N)$: | Only $U_1$ generates spillover. |
| $(N,N)$: | No upstream firm generates spillover. |

Next, the threshold value of $\beta/\alpha$ for which $U_i$ has an incentive to generate spillover given that $U_{-i}$ generates spillover too, can be reflected by the upper curve in Figure 5, which is concave and shows the changes in the reactions of the upstream firms through spillovers. Given that its rival generates spillovers, a firm's own spillover causes two effects: (i) the rival's free riding on the investment and (ii) the loss of its aggressive investment through unilaterally receiving spillovers. The free-riding effect is weaker than when only one upstream firm generates spillover (compare (19) with (14)), which increases its incentive for generating spillover. As a result, the threshold value of $\beta/\alpha$ rises above than when no upstream firm generates spillover, leading to multiple equilibria. This effect, while positive, is however partially canceled out by the latter loss which increases with the degree of spillovers (see (14)), shifting down the upper curve of $\beta/\alpha$ for a higher $r$ in Figure 5.

Further, the above results are obtained based on the assumption that the downstream firms' efforts are independent from each other (i.e., $e_i$ does not influence the outside option of $D_j$ $(i, j = 1, 2,\ j \neq i)$). If on the contrary, $e_i$ also improves the outside option of $D_j$, then each upstream firm has a stronger incentive to generate positive spillovers, just to mitigate the efforts of the downstream firms.

Finally, we check whether the voluntary spillover benefits the downstream firms. Simple calculations lead to:

**Proposition 5** $\Pi_i^{D*}(Y, Y) > \Pi_i^{D*}(N, N)$ *if and only if* $\beta < (9\gamma - 2)\alpha/((1 + r)(9\gamma - 1))$.

Note here the upper bound of $\beta$ is higher than $\beta(YY)$, which implies the downstream firms benefit from such voluntary spillovers from the upstream firms.

# 4 Discussion

The above results may explain the following stylized facts. "Mr. Toyoda was instrumental in forging a technology tie-up agreement between Denso and Bosch" (Anderson, 2010, p.94). The relationships among autoparts suppliers Denso and Bosch, and major automakers Ford, Mitsubishi and Toyota are perhaps good examples. Denso originated as a parts division of Toyota, spun off from Toyota in 1949 and initially supplied parts only to Toyota, gradually developed other sales channels and now provides parts to all major automakers in the world (e.g., Ford, General Motors, Honda, Mazda, Mitsubishi, except Nissan). Interestingly, Denso also has licensing and joint venture relationships with its direct rival, Bosch, in Europe and the U.S., the aim of which was to share technology and gain economies of scale and scope. Similarly, Suzuki (1993) finds that there are two types of R&D spillovers in the Japanese electrical machinery industry, one among members *within a keiretsu* group such as NEC and the other between members of *different keiretsu* groups (e.g., between members of NEC and Fujitsu), although the former is more significant than the latter. These horizontal and vertical relationships match very well the settings we have examined above.

Furthermore, our results suggest that giving up patents can spur innovation and increase profits in the industry, which might explain the recent surprise moves by Tesla and Toyota to give up patents. On June 13, 2014, electric carmaker Tesla announced it was giving up its patents "to the open source movement." Perhaps surprisingly, its stock price has skyrocketed since then. And even more surprisingly, on January 5, 2015, Toyota too announced it would make 5,680 patents related to fuel cell drive systems available, as a means to help other automakers build fuel cell cars. While standardization competition for fuel systems is rumored to be one reason for them to open their innovation outcomes to the public, our paper shows that the more fundamental reason lies in the possibility that they could grab the biggest share of the enlarged pie through different bargaining arrangements.

# 5 Conclusion

This paper has investigated how dual sourcing influences profitability in buyer-suppler relationships, and especially as an alternative to overcoming trading frictions. Under a bilateral monopoly, if the buyer easily finds alternate suppliers, we find that a market size expansion actually harms the supplier, opposite to what one might conventionally think.

We then apply the mechanism behind this result to bilateral duopoly with cost-reducing investments by the suppliers, and find that each supplier has an incentive to *unilaterally* generate technology spillovers to its rival if its buyer's cost to lower the outside wholesale price is small. Such a free spillover generates a market size shrink, which can benefit the supplier via the mechanism aforementioned.

Our mechanism can have wide applications in various situations, such as in suppliers' incentives in cost reduction, quality improvement, upstream collaboration, technology spillovers and labor training, which remain as interesting topics for future research.

We have abstracted from commitment issues and strategic competition among suppliers, by modelling the second source as a purely competitive 'fringe'. The wholesale price set by outside fringe suppliers is negatively correlated to the degree of frictions. Chatain and Zemsky

(2011) formulate frictions as a result of probabilistic randomness in the matching of buyers and suppliers. In their terminology, a lower wholesale price in the present model (set by outside suppliers) would represent a lower friction level from the viewpoint of buyers.

Emons (1996), Shy and Stenbacka (2003), Beladi and Mukherjee (2012) and Stenbacka and Tombak (2012) investigate buyers' decisions on bi-sourcing.[17] In our model, since buyers have options to procure inputs from potential outside suppliers, they continue dual sourcing and find alternative suppliers.

[17] In the management literature, it is well established that manufacturers are willing to outsource in the absence of suppliers' cost advantage, because outsourcing mitigates market competition (Cachon and Harker, 2002; Arya et al., 2008; Liu and Tyagi, 2011).

# 6 Appendix 1: Reversing the Roles of the Up- and Downstream Firms

In Appendix 1, we switch the roles of the upstream and the downstream firms in the basic model, and show a similar result when the upstream (instead of the downstream) firm has better outside options.

Again assume the two firms' outputs are related by a one-to-one ratio, with the upstream firm's marginal cost being constant at $c$. As its outside option, the upstream firm can supply a final product directly, of quality $v(e)$, if negotiation with the downstream firm breaks down, where $e$ is its effort to improve the value ($v'(e) > 0$ and $v''(e) < 0$), at a cost of $S_U(e)$ with $S'_U(e) \geq 0$ and $S''_U(e) > 0$.

The game structure is as follows: in the first stage, the upstream firm makes an effort $e$ to improve its outside options; in the second stage, both firms bargain over the trading terms; finally, in the third stage, the downstream firm sets the quantity of final output. The game is solved by backward induction as before.

As in the benchmark, when the upstream firm uses a two-part tariff contract, it sets the wholesale price at its marginal cost, $c$. The fixed payment from the downstream firm to the upstream firm is $T_d$. In an abstract form, the gross profit of the downstream firm is $\pi_d(c)$, where $\pi'_d(c) < 0$ and $\pi''_d(c) > 0$.

On the other hand, its outside option is when the upstream firm directly enters the downstream market and supplies the final product, with a gross profit of $\pi_o(c, v)$, where $\partial\pi_o(c, v)/\partial c < 0$ and $\partial^2\pi_o(c, v)/\partial c^2 > 0$; that is, an increase in $c$ diminishes the gross profit, at a decreasing rate. But the converse holds for quality, $\partial\pi_o(c, v)/\partial v > 0$ and $\partial^2\pi_o(c, v)/\partial v^2 > 0$. The cross partial derivative is $\partial^2\pi_o(c, v)/\partial c\partial v < 0$.

Thus, $T_d$ is chosen to satisfy

$$\pi_d(c) - T_d = T_d - \pi_o(c, v).$$

Then the firms' net profits in the second stage are respectively

$$\begin{aligned}\Pi_D &= \frac{\pi_d(c) - \pi_o(c, v(e))}{2}, \\ \Pi_U &= \frac{\pi_d(c) + \pi_o(c, v(e))}{2} - S_U(e).\end{aligned}$$

And in the first stage, the upstream firm's maximization problem leads to:

$$\frac{\partial \pi_o(c, v(e))}{\partial v} \cdot v'(e) - 2S'_U(e) = 0.$$

Total differential of the above yields

$$\left[\frac{\partial^2 \pi_o(c, v(e))}{\partial v^2} \cdot (v'(e))^2 + \frac{\partial \pi_o(c, v(e))}{\partial v} \cdot v''(e) - 2S''_U(e)\right] de + \left[\frac{\partial \pi_o(c, v(e))}{\partial c \partial v} \cdot v'(e)\right] dc = 0,$$

which gives $de/dc < 0$, since the terms in the first brackets are the second-order conditions and negative, and the last term in the second brackets is also negative.

Finally, we examine how the upstream firm's marginal cost affects the downstream firm's profit.

$$\begin{aligned}\frac{2d\Pi_D}{dc} &= \pi'_d(c) - \frac{\partial \pi_o(c, v(e))}{\partial c} - \frac{\partial \pi_o(c, v(e))}{\partial v} \cdot v'(e)\frac{de}{dc} \\ &= \underbrace{\pi'_d(c)}_{(-)} \underbrace{- \frac{\partial \pi_o(c, v(e))}{\partial c}}_{(+)} \underbrace{- 2S'_U(e)\frac{de}{dc}}_{(+)}.\end{aligned}$$

If the third term is strong enough, the sign of $d\Pi_D/dc$ becomes positive. That is, the efficiency improvement of the upstream firm can harm the downstream firm, even though it generates a bigger pie, analogous to the result in the basic model.

# 7 Appendix 2: The Equilibrium Profits in Section 3

The equilibrium profits under the two scenarios of spillovers in Section 3 can be explicitly written as follows.

**One-sided spillover** The equilibrium profits of the firms are respectively,

$$
\begin{aligned}
&\Pi_1^{U*}(Y,N)\\
=&\frac{9\gamma^2[(3\gamma-1)(9\gamma-(2-r))\alpha-r(6\gamma-1-3\gamma r)\beta]^2}{2(9\gamma-(2-r))^2((3\gamma-1)(9\gamma-1)+3\gamma r)^2}\\
&-\frac{9\gamma^2[(3\gamma-1)(9\gamma-(2-r))\alpha-(2(3\gamma-1)(9\gamma-1)+(12\gamma-1)r-3\gamma r^2)\beta]^2}{2(9\gamma-(2-r))^2((3\gamma-1)(9\gamma-1)+3\gamma r)^2}\\
&-\frac{\gamma[(3\gamma-1)(9\gamma-(2-r))\alpha-3r(9\gamma-2)\gamma\beta]^2}{(9\gamma-(2-r))^2((3\gamma-1)(9\gamma-1)+3\gamma r)^2},
\end{aligned}
$$

$$
\begin{aligned}
&\Pi_1^{D*}(Y,N)\\
=&\frac{\gamma(9\gamma-2)[(3\gamma-1)(9\gamma-(2-r))\alpha-(2(3\gamma-1)(9\gamma-1)+(12\gamma-1)r-3\gamma r^2)\beta]^2}{2(9\gamma-(2-r))^2((3\gamma-1)(9\gamma-1)+3\gamma r)^2}\\
&+\frac{9\gamma^2[(3\gamma-1)(9\gamma-(2-r))\alpha-r(6\gamma-1-3\gamma r)\beta]^2}{2(9\gamma-(2-r))^2((3\gamma-1)(9\gamma-1)+3\gamma r)^2},
\end{aligned}
$$

$$
\begin{aligned}
&\Pi_2^{U*}(Y,N)\\
=&\frac{\gamma(9\gamma-2)[((3\gamma-1)(9\gamma-2)+3(4\gamma-1)r+r^2)\alpha+3(1-2r)r\gamma\beta]^2}{2(9\gamma-(2-r))^2((3\gamma-1)(9\gamma-1)+3\gamma r)^2}\\
&-\frac{9\gamma^2}{2(9\gamma-2)^2(9\gamma-(2-r))^2((3\gamma-1)(9\gamma-1)+3\gamma r)^2}\times\\
&\quad\big\{((9\gamma-2)^2(3\gamma-1)+(9\gamma-2)(6\gamma-1)r+3\gamma r^2)\alpha\\
&\qquad\qquad-(2(3\gamma-1)(9\gamma-1)(9\gamma-2)+(81\gamma^2-30\gamma+2)r+6\gamma r^2)\beta\big\}^2,
\end{aligned}
$$

$$
\begin{aligned}
&\Pi_2^{D*}(Y,N)\\
=&\frac{\gamma}{2(9\gamma-2)(9\gamma-(2-r))^2((3\gamma-1)(9\gamma-1)+3\gamma r)^2}\times\\
&\quad\big\{((9\gamma-2)^2(3\gamma-1)+(9\gamma-2)(6\gamma-1)r+3\gamma r^2)\alpha\\
&\qquad\qquad-(2(3\gamma-1)(9\gamma-1)(9\gamma-2)+(81\gamma^2-30\gamma+2)r+6\gamma r^2)\beta\big\}^2\\
&+\frac{9\gamma^2[((3\gamma-1)(9\gamma-2)+3(4\gamma-1)r+r^2)\alpha+3(1-2r)r\gamma\beta]^2}{2(9\gamma-(2-r))^2((3\gamma-1)(9\gamma-1)+3\gamma r)^2}.
\end{aligned}
$$

**Two-sided spillovers** The equilibrium profits of the firms are respectively,

$$\begin{aligned}
\Pi_i^{U*}(Y,Y) &= \frac{9\gamma^2[(9\gamma-2+r+r^2)\alpha - r(1+r)\beta]^2}{2((9\gamma-1)(9\gamma-2)+r+(9\gamma-1)r^2)^2} \\
&\quad - \frac{9\gamma^2[(9\gamma-2-r+r^2)\alpha - (2(9\gamma-1)-r+r^2)\beta]^2}{2((9\gamma-1)(9\gamma-2)+r+(9\gamma-1)r^2)^2} \\
&\quad - \frac{\gamma[(9\gamma-2+r)\alpha - 9r\gamma\beta]^2}{((9\gamma-1)(9\gamma-2)+r+(9\gamma-1)r^2)^2}, \\
\Pi_i^{D*}(Y,Y) &= \frac{\gamma(9\gamma-2)[(9\gamma-2-r+r^2)\alpha - (2(9\gamma-1)-r+r^2)\beta]^2}{2((9\gamma-1)(9\gamma-2)+r+(9\gamma-1)r^2)^2} \\
&\quad + \frac{9\gamma^2[(9\gamma-2+r+r^2)\alpha - r(1+r)\beta]^2}{2((9\gamma-1)(9\gamma-2)+r+(9\gamma-1)r^2)^2}.
\end{aligned}$$

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