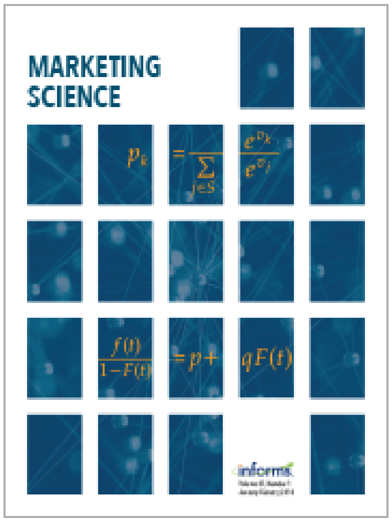

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Research Note

Channel Structure with Knowledge Spillovers

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We study two main questions in this paper: (1) How do spillovers of knowledge created by manufacturers' investments in process innovation affect channel structure and effort investment incentives? (2) What are the interactions between organizational incentives to form joint ventures and strategic alliances with competitors, and coordinate decisions vertically with downstream channel members? We focus on situations where spillovers are involuntary, firms' innovative activities are nonoverlapping, and firms benefit directly from the results of competitors' innovations. Under these conditions, we find that spillovers in process knowledge increase the likelihood of observing decentralized channel structures. Surprisingly, decentralized manufacturers invest more in process innovation than perfectly coordinated manufacturers do when spillovers are large. Moreover, in industries where large spillovers exist, horizontal cooperation among manufacturers induces higher levels of process innovation investments than channel coordination does. From a public policy perspective, however, the desirability of such cooperative arrangements among competitors depends on channel structure: joint ventures among decentralized manufacturers are more likely to meet the regulators' criteria of raising effort investments than cooperation among integrated manufacturers would be. Investment incentives are best provided when firms share their process knowledge and are buffered from subsequent price competition by independent retailers.

Key words: channel coordination; process innovation; spillovers; research joint ventures
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1. Introduction

A manufacturer makes investments in improving its production processes that reduce unit costs. The resulting improvements are copied by the competitors. The extent of such knowledge spillovers varies from industry to industry, depending on the property rights regime, ease of reverse-engineering the products, prevalence of benchmarking and best practice sharing techniques, and mobility of people within the industry. Spillovers of process knowledge alter firms' incentives to invest in process innovation and lead to a need to cooperate with competitors to internalize the horizontal externality thus created. Do spillovers also affect the need to coordinate decisions vertically with downstream channel partners when channels compete for end-customers through differentiated products? How do coordination incentives along these two dimensions interact in determining channel structure and effort investments? We study these issues in the context of two competing manufacturer-retailer channels and focus on situations where spillovers are largely involuntary, firms' innovative activities are nonoverlapping, and firms benefit directly from the results of competitors' innovations. First, we find that spillovers increase the likelihood of decentralization being an equilibrium (and more profitable) strategy to follow for manufacturers in oligopolistic markets. Intuitively, the higher the spillovers, the easier the spread of process knowledge and the less sustainable the competitive advantage of any one manufacturer because of his production efficiency, the higher the need to buffer from price competition by not coordinating the channel. Second, we show that when large degrees of knowledge spillovers exist or when manufacturers cooperate in setting their process innovation investments (but remain competitors in the output markets), decentralized manufacturers invest more in production cost reduction than coordinated manufacturers do, even with linear contracts where one may expect lower effort investments by firms in a noncoordinated channel because of the usual double marginalization problems. Third, we show that, from the perspective of a government policymaker interested in encouraging process investments in industry, channel structure is a critical factor in evaluating organizational alternatives such as research joint ventures (RJVs) that allow competitors to cooperate in *precompetitive* research efforts; joint ventures among decentralized manufacturers are more likely to lead to higher effort investments than cooperation among integrated manufacturers would be.

The marketing literature on channel coordination is well developed. Jeuland and Shugan's (1983) classic analysis of channel coordination has been extended by many authors. Choi (1991) studies different game structures in two manufacturers–one retailer setting, while Ingene and Parry (1995) analyze coordination incentives when one manufacturer sells through two competing retailers. McGuire and Staelin's (1983) well-known arguments for strategic decentralization in competing channels have been further studied by many authors as well, including Coughlan (1985), Moorthy (1988), Coughlan and Wernerfelt (1989), and Lee and Staelin (1997). Iyer (1998) studies coordination incentives when retailers compete on both price and nonprice factors; Gupta and Loulou (1998) analyze interactions between process innovation investments and product substitutability in competing channels. More recently, Raju and Zhang (2005) show how a manufacturer can coordinate a channel in the presence of a dominant retailer using quantity discounts or a menu of two-part tariffs. Arya and Mittendorf (2006) show that, in the context of durable goods, decentralization can be used by a manufacturer as a credible commitment to keep prices high in the future.[1] Our paper draws on and extends this literature by analyzing the effects of involuntary spillovers of knowledge and the incentives to horizontally coordinate investment decisions.

Industrial practice suggests that knowledge spillovers and horizontal cooperation among competitors are widespread. By their very nature, most products embody the process knowledge used in creating them, and benchmarking and reverse engineering are common tools employed by manufacturers to gain access to competitors' process knowledge.[2] Surveys show that more than 70% of the *Fortune* 500 companies use benchmarking on a regular basis, and the primary reason for undertaking benchmarking projects is to reduce costs (Elmuti 1998). Levin (1988) showed that, in high-technology industries (semiconductors, computers, communications equipment, and others), interpersonal communications and reverse-engineering are the most effective means of learning about competitors' new processes. These industries were also found to have the highest levels of spillovers and significantly higher levels of innovation than other industries, such as food processing and metal working. Levin and Reiss (1988) find that, on average, firms lower their costs by 0.45% for every doubling of their own process R&D, but the cost decline is 2.3% for every doubling in the industry pool of process R&D, with significant interindustry variations.

It is intuitively clear that existence of spillovers affects manufacturers' incentives to invest in cost reduction, because spillovers make process innovations a partial public good. Empirical studies have repeatedly demonstrated that there is a gap between private and social rates of return from R&D (Mansfield et al. 1977, Bernstein and Nadiri 1988). Scholars and policymakers have argued for a long time about the best means of alleviating that incentive gap; whereas government subsidies and stronger intellectual property rights (e.g., patents) have been used for a long time, ex ante cooperation among firms in R&D through RJVs has increasingly been accepted as the best institutional alternative for the creation of "leaky" intellectual property (Ouchi and Bolton 1988, Jorde and Teece 1990). Following a policy change by the U.S. government (National Cooperative Research Act (NCRA) of 1984, and National Cooperative Research and Production Act of 1993), RJVs have increased rapidly among firms in the same industry that remain competitors in the final product markets.[3]

An important stream of literature in economics has studied manufacturers' incentives to cooperate horizontally in the presence of knowledge spillovers. Closest in approach to our paper is d'Aspremont and Jacquemin (1988), who considered the effects of spillovers in process R&D for manufacturers competing in a Cournot fashion. Their analysis has been generalized and extended by a number of authors (Kamien et al. 1992, Suzumura 1992, Katsoulacos and Ulph 1998, Amir 2000, Banerjee and Lin 2001, Lambertini et al. 2004). This literature is primarily concerned with evaluating whether the level of R&D

[1] For other recent research on channels, see Besanko et al. (2005) and Moorthy (2005), who study channel pass-through behavior; and Liu and Zhang (2006), who study channel implications of adopting personalized pricing.

[2] Patent infringement disputes provide one measure of such activities; for example, those between Intel and AMD; GlaxoSmithKline and Genentech over the process used in making two of Genentech's anticancer drugs, and so on. Such knowledge spillovers exist at broader levels as well, such as innovations in business processes (Amazon's one-click checkout; Priceline's reverse auctions model), and new products and services (frequent flier programs).

[3] A few well-known examples include Microelectronics and Computer Technology Corporation (MCC), SEMATECH, Semiconductor Research Corp., and International 300 mm Initiative (I300I) (all in the US); JESSI and ESPRIT in Europe; VLSI and Semiconductor Leading Edge Technologies (Selete) in Japan. More than 575 research joint ventures had been registered under NCRA by the end of 1995, in many industries, including automobiles, aerospace, and telecommunications (Ham et al. 1998). Major auto assemblers have been conducting joint research under the umbrella of USCAR on a range of issues, such as composite materials and technologies for reducing emissions and enhancing fuel efficiency. Cooperation in specific projects among competitors is common (e.g., IBM and Apple to develop the PowerPC chip; Maytag and Whirlpool to research the potential of microwave technology for drying clothes).

investments made by firms with or without a research joint venture is socially efficient under different conditions. A usual conclusion from this research is that cooperation among firms raises effort investments if spillovers are above a threshold level. None of these papers analyzes the role that channel structure might play in determining firms' incentives to invest. (See §5 for a discussion of features our model shares with this literature, and some alternative possibilities for model formulation.)

Our model is outlined in the next section. Section 3 presents the main results for the case where manufacturers do not horizontally coordinate any of the decisions. Section 4 discusses the case where manufacturers may cooperate in setting their effort levels through a research joint venture. Section 5 discusses the various assumptions and limitations of our analysis and concludes with some possible directions along which this research could be extended.

2. Model Specification

We present the simplest model that captures the main effects. Following the channels literature (McGuire and Staelin 1983, Shugan and Jeuland 1988, Gupta and Loulou 1998), two competing linear channels are modeled, each consisting of a manufacturer producing a single differentiated product and selling it to the final consumers through a single retailer. We assume deterministic, linear, downward-sloping demand functions[4] given by

$$q_i = M - bp_i + b\theta p_j, \quad j = 3-i,\ i = 1, 2, \tag{1}$$

where θ is a substitutability parameter: lower values of θ imply more product differentiation ($0 \le \theta < 1$).[5] The unit production cost of manufacturer i is

$$c_i = c - x_i - \gamma x_j, \quad j = 3-i,\ i = 1, 2, \tag{2}$$

where c is the unit cost if no process improvements are carried out, assumed equal for both manufacturers (assume $c < M/b$ to ensure nonzero production quantities), and x_i is the amount of unit cost reduction achieved by manufacturer i as a result of his efforts in process improvement. γ is a spillover parameter that captures the extent to which a manufacturer's investments in process innovation benefit his competitor ($0 \le \gamma \le 1$); higher values of γ imply higher levels of knowledge spillovers. We further assume decreasing returns to effort expenditures: For convenience, we represent cost of manufacturer efforts by αx_i^2, where α is some positive constant. Any convex cost function can be used instead without altering the results qualitatively.[6] The model thus extends Gupta and Loulou (1998) by incorporating the effect of involuntary knowledge spillovers.

To save space, we focus on two extreme forms of channel structure: "Integration" (I) refers to the channel being fully coordinated, "Decentralization" (D) implies fully autonomous firms. Manufacturer i in a decentralized channel charges a per unit transfer price w_i to his retailer. The profit functions are $\pi_i^M = (w_i - c_i)q_i - \alpha x_i^2$; $\pi_i^R = (p_i - w_i)q_i$ for the decentralized manufacturer and retailer, respectively, and $\pi_i^I = (p_i - c_i)q_i - \alpha x_i^2$ for the coordinated manufacturer. Our four-stage game unfolds as follows. First, manufacturers simultaneously and noncooperatively decide whether to coordinate or decentralize their own channels. The manufacturers set their effort levels and transfer prices at the second and third stages of the game, respectively. Finally, retail prices are set at the fourth stage. Intrachannel decisions are assumed to be observable to all the players.[7]

3. Results: No Horizontal Cooperation

In keeping with the channels literature, we first concentrate on vertical coordination incentives, ignoring any horizontal coordination among manufacturers. We focus on subgame-perfect equilibria of this game, which is solved by the usual backward induction method (see the appendix for details). Closed-form equilibrium expressions for all variables of interest

[4] As is well known (see Kim and Staelin 1999), such demand functions have several attractive characteristics besides mathematical tractability, and quantitative results are dependent less on linearity of demand functions and more on the slope of response functions. Most of the results in this paper rely on slope of response functions.

[5] Note that with such demand functions, changes in θ alter the industry-level price sensitivity. Thus we focus on results for a fixed level of θ only. (See Kim and Staelin 1999 and Gupta and Loulou 1998 for a discussion.)

[6] A convex R&D cost function is appropriate because most companies have limitations on the amount of capital available for R&D projects, particularly when the budget is allocated across several different product lines. Empirical studies typically support the existence of convex R&D costs. See §5 for a discussion of the interpretation of γ as spillover parameter and other limitations of this modeling approach.

[7] The above formulation implicitly assumes that the level of spillovers is independent of the degree of product substitutability. This is reasonable because our focus here is on technological spillovers at the process level, and transfer of process knowledge and technical know-how is not restricted to immediate substitutes only. As studies in benchmarking indicate, firms routinely visit and imitate processes from outside their own industries: e.g., Xerox's and Chrysler's lessons from L. L. Bean's logistics and distribution system (*BusinessWeek* 1992), or more dramatically, attempts by a number of firms to learn from pit stop teams at Formula One racing circuits to speed up the setup and changeover times in their factories. Moreover, low θ simply means that products do not directly compete in the same geographical market, even though they might be very similar. Finally, empirical studies (e.g., Bernstein and Nadiri 1988) have demonstrated significant interindustry spillovers in a range of industries, including chemicals, electrical products, and scientific instruments.

Table 1 Equilibrium Expressions Under Different Channel Structures

	Pure decentralized (DD)	Pure integrated (II)	Mixed structure: Integrated channel (ID)	Mixed structure: Decentralized channel (DI)
No horizontal cooperation				
Effort level (x_i^*)	$\frac{FL_\gamma\widetilde{M}}{\alpha JK^2T - b(1+\gamma)FL_\gamma R}$	$\frac{F_\gamma\widetilde{M}}{\alpha HT - b(1+\gamma)F_\gamma R}$	$\frac{L_\gamma[2\alpha JS - b(1-\gamma)F_\gamma Q]\widetilde{M}}{b^2(1-\gamma^2)PF_\gamma L_\gamma - 2\alpha b[F_\gamma^2 FH + L_\gamma^2] + 8\alpha^2(FH)^2}$	$\frac{F_\gamma[2\alpha FHS - b(1-\gamma)L_\gamma Q]\widetilde{M}}{b^2(1-\gamma^2)PF_\gamma L_\gamma - 2\alpha b[F_\gamma^2 FH + L_\gamma^2] + 8\alpha^2(FH)^2}$
Transfer price (w_i^*)	$\frac{MJS + 2bF^2c_i^* + b\theta Fc_j^*}{bJK}$	$c_i^*(II)$	$c_i^*(ID)$	$\frac{MS + b\theta c_i^*(ID) + bFc_i^*(DI)}{2bF}$
Retail price (p_i^*)	$\frac{2MGJS + bFNc_i^* + 2b\theta FGc_j^*}{bHJK}$	$\frac{MS + 2bc_i^* + b\theta c_j^*}{bH}$	$\frac{MJS + bNc_i^*(ID) + b\theta Fc_i^*(DI)}{2bFH}$	$\frac{MGS + b\theta Gc_i^*(ID) + bFc_j^*(DI)}{bFH}$
Output (q_i^*)	$\frac{F}{H}\frac{MJS - bLc_i^* + b\theta Fc_j^*}{JK} = \left[\frac{\alpha JK}{L_\gamma}\right]x_i^*(DD)$	$\frac{MS - bFc_i^* + b\theta c_j^*}{H} = \left[\frac{\alpha H}{F_\gamma}\right]x_{II}^*$	$\frac{MJS - bLc_i^*(ID) + b\theta Fc_i^*(DI)}{2FH} = \left[\frac{2\alpha FH}{L_\gamma}\right]x_i^*(ID)$	$\frac{MS + b\theta c_i^*(ID) - bFc_i^*(DI)}{2H} = \left[\frac{2\alpha F}{F_\gamma}\right]x_i^*(DI)$
Manufacturer profit (π_i^{M*})	$\frac{H}{bF}(q_i^*(DD))^2 - \alpha(x_i^*(DD))^2$	$\frac{1}{b}(q_i^*(II))^2 - \alpha(x_i^*(II))^2$	$\frac{1}{b}(q_i^*(ID))^2 - \alpha(x_i^*(ID))^2$	$\frac{H}{bF}(q_i^*(DI))^2 - \alpha(x_i^*(DI))^2$
Retailer profit (π_i^{R*})	$\frac{1}{b}(q_i^*(DD))^2$	–	–	$\frac{1}{b}(q_i^*(DI))^2$
Channel profit (π_i^{CH*})	$\frac{2G}{bF}(q_i^*(DD))^2 - \alpha(x_i^*(DD))^2$	$\frac{1}{b}(q_i^*(II))^2 - \alpha(x_i^*(II))^2$	$\frac{1}{b}(q_i^*(ID))^2 - \alpha(x_i^*(ID))^2$	$\frac{2G}{bF}(q_i^*(DI))^2 - \alpha(x_i^*(DI))^2$
With horizontal cooperation (only the following expressions change from above)				
Effort level ($x_{i(C)}^*$)	$\frac{(1+\gamma)FRS\widetilde{M}}{\alpha K^2T - b(1+\gamma)^2FR^2S}$	$\frac{(1+\gamma)R\widetilde{M}}{\alpha T^2 - b(1+\gamma)^2R^2}$	$\frac{RS[\alpha(\gamma X+Y) - b(1-\gamma)(1-\gamma^2)FQ^2T]\widetilde{M}}{b^2(1-\gamma^2)^2P^2FH - \alpha b[(1+\gamma^2)GZ - 4\gamma\theta A] + 4\alpha^2(FH)^2}$	$\frac{RS[\alpha(X+\gamma Y) - b(1-\gamma)(1-\gamma^2)FQ^2T]\widetilde{M}}{b^2(1-\gamma^2)^2P^2FH - \alpha b[(1+\gamma^2)GZ - 4\gamma\theta A] + 4\alpha^2(FH)^2}$
Output ($q_{i(C)}^*$)	$\frac{F}{H}\frac{MJS - bLc_i^* + b\theta Fc_j^*}{JK} = \left[\frac{\alpha K}{(1+\gamma)RS}\right]x_{i(C)}^*(DD)$	$\frac{MS - bFc_i^* + b\theta c_j^*}{H} = \left[\frac{\alpha T}{(1+\gamma)R}\right]x_{i(C)}^*(II)$	$\frac{MJS - bLc_{i(C)}^*(ID) + b\theta Fc_{i(C)}^*(DI)}{2FH} = \left[\frac{\alpha FH[2\alpha JS - b(1-\gamma)^2Q^2T]}{RS[\alpha(\gamma X+Y) - b(1-\gamma)(1-\gamma^2)FQ^2T]}\right]x_{i(C)}^*(ID)$	$\frac{MS + b\theta c_{i(C)}^*(ID) - bFc_{i(C)}^*(DI)}{2H} = \left[\frac{\alpha FT[2\alpha FS^2 - b(1-\gamma)^2KQ^2]}{RS[\alpha(X+\gamma Y) - b(1-\gamma)(1-\gamma^2)FQ^2T]}\right]x_{i(C)}^*(DI)$

Notes. A variable $y_i(AB)$ refers to channel i when that channel's vertical structure is A and competing channels' is B. $F = 2-\theta^2$; $G = 3-\theta^2$; $H = 4-\theta^2$; $J = 4-2\theta^2+\theta$; $K = 4-2\theta^2-\theta$; $L = 8-9\theta^2+2\theta^4$; $N = 8-3\theta^2$; $\widetilde{M} = M-(1-\theta)bc$; $P = 1-\theta^2$; $Q = 1+\theta$; $R = 1-\theta$; $S = 2+\theta$; $T = 2-\theta$; $U = 4-3\theta^2$; $V = 4+2\theta-\theta^2$; $W = 4-2\theta-\theta^2$; $F_\gamma = 2-\gamma\theta-\theta^2$; $L_\gamma = 8-9\theta^2+2\theta^4-\gamma\theta(2-\theta^2)$ ($F_\gamma = F$ and $L_\gamma = L$ at $\gamma = 0$); $X = (2-\theta^2)(8+4\theta-3\theta^2-\theta^3)$; $Y = 32+32\theta-20\theta^2-23\theta^3+3\theta^4+4\theta^5$; $Z = 32-52\theta^2+29\theta^4-5\theta^6$; $A = (2-\theta^2)(16-15\theta^2+3\theta^4)$.

are summarized in Table 1. To ensure the existence, uniqueness, and stability of effort-level equilibria, it is assumed that $b/\alpha < 1$; that is, the cost of effort is *large enough*.[8] This assumption is not restrictive for most industrial situations (e.g., see Gupta and Loulou 1998). For expositional clarity, we focus the discussions in this paper on interactions between spillovers and substitutability, and ignore the cost reduction parameter α. Accordingly, we report most of the results here assuming $b/\alpha = 1/2$; the results hold, in general, for all $b/\alpha < 1$, $0 \le \gamma \le 1$ and $0 \le \theta < 1$.[9] Retailers' reservation profits are normalized to zero without any loss in generality. A variable $y_i(AB)$ refers to channel i when that channel's vertical structure is A and the competing channel's is B.

We first provide some intermediate results that are of interest in themselves and will also be useful in understanding the overall effects of manufacturer effort investments and spillovers on channel coordination incentives. Lemmas 1–3 generalize known results in the channels literature to include all three parameters (α, θ, and γ). All proofs are in the appendix.

Lemma 1. *When spillovers are positive, an increase in the level of cost-reducing effort by a manufacturer always reduces his own and his rival manufacturer's equilibrium retail prices in both coordinated and decentralized channels. That is, for* $\gamma > 0$, $\partial p_i^*(II)/\partial x_k < 0$; $\partial p_i^*(DD)/\partial x_k < 0$; $k = i$ *or* j, $i \ne j$.

Lemma 2. *Retail prices are higher when both channels are decentralized than when they are coordinated* ($p_i^*(DD) \ge p_i^*(II)\ \forall\, \alpha, \theta, \gamma$).

Lemma 3. *With an increase in effort investments, a coordinated channel drops its retail price more than a decentralized channel does; that is,* $|\partial p_i^*(II)/\partial x_i| \ge |\partial p_i^*(DD)/\partial x_i| \quad \forall\, \alpha, \theta, \gamma$.

Lemma 3 is a generalized version of the well-known "buffering" effect (McGuire and Staelin 1983) when spillovers are accounted for. The effect of a change in effort investments on output levels, however, depends on whether spillovers are large or small.

Lemma 4. *An increase in effort investments by a manufacturer has the following effects*:

(i) *it always increases his own equilibrium output, in both coordinated and decentralized channels* (*i.e.*, $\partial q_i^*(II)/\partial x_i \ge 0$; $\partial q_i^*(DD)/\partial x_i \ge 0$).

(ii) *it increases the rival manufacturer's output only when spillovers are above a threshold level*: $\partial q_j^*(II)/\partial x_i \ge 0$ *iff* $\gamma \ge \theta/(2-\theta^2)$; *and* $\partial q_j^*(DD)/\partial x_i \ge 0$ *iff* $\gamma \ge \theta(2-\theta^2)/(8-9\theta^2+2\theta^4)$, $j \ne i$.

An explanation for Lemma 4 is as follows. Manufacturer i's investments in cost reduction have two opposing effects on manufacturer j's output. On one hand, i's investment allows him to reduce his prices and expand output to gain market share, thus reducing j's output. However, part of that investment also benefits j through spillovers, allowing j to reduce his prices and expand output. The net effect is positive or negative depending on the extent of spillovers. When spillovers are *small*, the cost reduction achieved by manufacturer j is not enough to avoid a decrease in j's output. As spillovers rise above a certain level, the second effect dominates and leads to higher output by j. (Note that $(\partial/\partial x_i)(\sum_{i=1}^{2} q_i^*) > 0$; i.e., the total industry output always rises as a result of an increase in a manufacturer's effort investments, as production costs of both firms fall.) This leads us to an important result.

Lemma 5. *With "large" spillovers, an increase in effort investments by a manufacturer leads the competing manufacturer to also invest more* $\partial x_i(II)/\partial x_j > 0$ *iff* $\gamma > \theta/(2-\theta^2)$; *and* $\partial x_i(DD)/\partial x_j > 0$ *iff* $\gamma > \theta(2-\theta^2)/(8-9\theta^2+2\theta^4)$, $j \ne i$. *Thus the threshold level for spillovers to be "large" is dependent on the channel structure.*

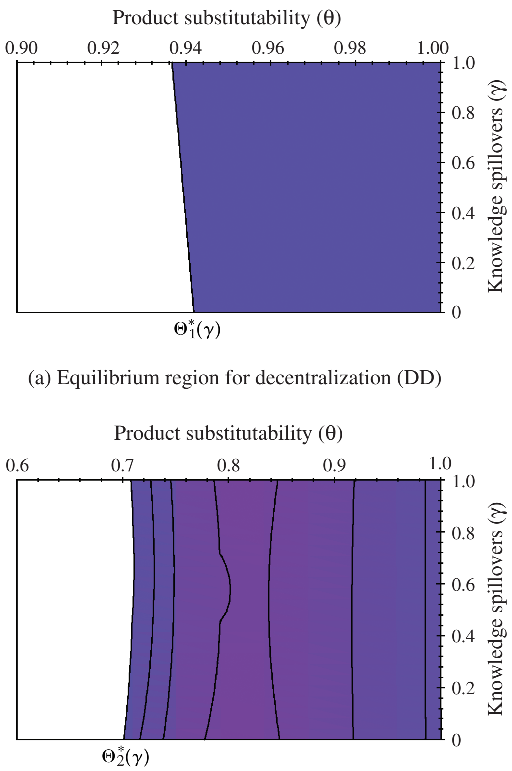
When spillovers are small, effort levels are strategic substitutes (i.e., have downward-sloping reaction curves) but are strategic complements (i.e., have upward-sloping reaction curves) when spillovers exceed a threshold level. Thus, with large spillovers a firm raises its investments as the competitor raises his. This might sound counterintuitive, as one could expect large spillovers to create a situation whereby firm j could choose to free-ride on firm i's investments. However, a little reflection and Lemma 4 show this intuition to be false. When spillovers are small, the cost reduction achieved by the competitor as a result of an increase in a firm's effort is not enough to avoid reducing the competitor's profits—the lower cost firm gains market share at the expense of the higher cost firm. When spillovers are large enough, both firms expand output, total industry equilibrium profits increase, and the competitor's market share does not decline significantly. Consequently, the competitor also raises his effort investment.

By using these results, we can establish the net effect of spillovers on equilibrium channel strategies of competing manufacturers. Parts (a) and (b) of the following result generalize the well-known "strategic decentralization" argument to situations, where manufacturers' marginal production costs are not constant and imperfect intellectual property rights lead to

[8] It could be argued that spillovers are more important when cost of effort is high. Thus the assumption poses no loss in generality.

[9] Readers interested in exploring the interactions between spillovers (γ), substitutability (θ), and ease of cost reduction (α) can do so using Tables 1 and 2. All equilibrium and profit-dominance conditions rely only on these three parameters.

Figure 1 **Equilibrium Channel Structures Without Horizontal Cooperation** ($b/\alpha = 1/2$)



(a) Equilibrium region for decentralization (DD)

(b) Profit dominance region: Π(DD) > Π(II)

involuntary knowledge spillovers. Part (c) shows that larger spillovers make decentralization more likely as an equilibrium strategy by rational, profit-maximizing manufacturers.[10]

Proposition 1. (a) *Channel coordination by both manufacturers* (*II*) *is always an equilibrium strategy. Decentralization* (*DD*) *is an equilibrium strategy when the manufacturers' products are highly substitutable* (*i.e.*, $\theta \geq \Theta_1^*(\gamma)$) (*see Figure* 1).

(b) *Whenever decentralization* (*DD*) *is an equilibrium, it generates higher profits than channel coordination*: $\pi_i^M(DD) > \pi_i^M(II)$ *iff* $\theta > \Theta_2^*(\gamma)$, *where* $\Theta_2^*(\gamma) < \Theta_1^*(\gamma) \forall \gamma$ (*see Figures* 1(a) *and* 1(b)).

(c) *The threshold value of product differentiation parameter* (θ) *for the decentralized channel strategy to be an equilibrium declines in the level of knowledge spillovers. As spillovers increase, the decentralized equilibrium becomes more likely* (*see Figure* 1(a)).

The general conditions characterizing these equilibria and profit dominance relations are summarized in Table 2. Figure 1 illustrates the parameter regions where the above result holds. The role of product substitutability in this result is well understood; we thus focus on the effect of knowledge spillovers. The result can be understood intuitively as follows. A manufacturer makes investments in production cost reduction, hoping to translate his lower costs into lower prices and capture market share from competitors. However, as spillovers increase, his investments also reduce his competitors' costs and makes them tougher, his willingness to lower prices to capture market share is reduced because he expects his competitors to match price decreases. Hence it becomes more attractive to buffer from price competition by not coordinating the channel. In other words, having access to competitors' process improvements provides a conduit for manufacturers to lower their unit costs, while decentralization provides a buffer from price competition. Costless exchange of production improvement ideas among competing manufacturers can thus effectively substitute for lost channel efficiency. This notion is further explored in the following result, which shows that lack of channel coordination does not lead to lower effort investments by manufacturers in industries where cross-channel spillovers are large.

Proposition 2. *Decentralized manufacturers invest more in process improvement efforts than coordinated ones do* (*i.e.*, $x_i(DD) \geq x_i(II)$) *if spillovers are above a threshold level defined by* $f(\theta)$, *where*

$$f(\theta) = \frac{(2-\theta^2)(32+16\theta-40\theta^2-23\theta^3+10\theta^4+6\theta^5)}{\theta(48+32\theta-48\theta^2-31\theta^3+11\theta^4+7\theta^5)}, \quad \theta \neq 0,$$

is a convex decreasing function of θ.[11]

Equilibrium effort levels are illustrated in Figure 2(a) for different channel structures. Note that for $\gamma = 1$ (maximum spillovers), the condition reduces to $\theta > 0.708$ and for $\gamma = 0$ (no spillovers), it is never satisfied, implying that $x_i^*(DD) < x_i^*(II) \forall \theta$ $(\theta \neq 1)$ – in agreement with the existing literature on effort reduction in decentralized channels (Jeuland and Shugan 1983, Gupta and Loulou 1998). In Gupta and Loulou (1998), effort investments are assumed to be completely appropriable by the manufacturer making the investments. With no spillovers, manufacturer's effort investments incur only a vertical externality, and decentralization always decreases investments. Spillovers, however, create a horizontal externality as well. The combined effect on effort investment incentives then depends on the interplay between the level of product substitutability, level of

[10] All equilibrium results are presented here with respect to manufacturers maximizing their own profits. Similar results hold when employing a *channel profits* criterion.

[11] Recalling the caveat on interpretation of θ (see footnote 5), we do not analyze the behavior of $f(\theta)$. Note instead that, for any given value of θ, $f(\theta)$ is well defined, and we can compare any variable of interest across channels.

Table 2 Equilibrium and Profit Dominance Conditions

	Equilibrium conditions		Profit dominance conditions
	(DD)	(II)	($\pi^*_{DD} > \pi^*_{II}$)
No horizontal cooperation	$(2-\theta^2)\Delta_{71}(\Delta_1)^2 - \Delta_8(\Delta_{41})^2(\Delta_{42})^2 > 0$	$\Delta_5(\Delta_1)^2 - \Delta_{61}(\Delta_{21})^2(\Delta_{22})^2 > 0$	$(2-\theta^2)\Delta_{71}(\Delta_{21})^2 - \Delta_5(\Delta_{41})^2 > 0$
With horizontal cooperation	$(2-\theta^2)(\Omega_3)^2 - (2+\theta)\Omega_{21}\Omega_9 > 0$	$(\Omega_3)^2 - (2+\theta)\Omega_1\Omega_{81} > 0$	$(2+\theta)(2-\theta^2)\Omega_1 - \Omega_{21} > 0$

where:

$$
\begin{aligned}
\Delta_1 &= b^2(1-\gamma^2)(1-\theta^2)(2-\gamma\theta-\theta^2)(8-9\theta^2+2\theta^4-\gamma\theta(2-\theta^2))\\
&\quad -2b\alpha((2-\theta^2)(4-\theta^2)(2-\gamma\theta-\theta^2)^2\\
&\qquad +(8-9\theta^2+2\theta^4-\gamma\theta(2-\theta^2))^2)+8\alpha^2(2-\theta^2)^2(4-\theta^2)^2\\
\Delta_{21} &= \alpha(2-\theta)(4-\theta^2)-b(1+\gamma)(1-\theta)(2-\gamma\theta-\theta^2)\\
\Delta_{22} &= 2\alpha(2+\theta)(2-\theta^2)(4-\theta^2)\\
&\quad -b(1-\gamma)(1+\theta)(8-9\theta^2+2\theta^4-\gamma\theta(2-\theta^2))\\
\Delta_{41} &= \alpha(2-\theta)(4-2\theta^2+\theta)(4-2\theta^2-\theta)^2\\
&\quad -b(1+\gamma)(1-\theta)(2-\theta^2)(8-9\theta^2+2\theta^4-\gamma\theta(2-\theta^2))\\
\Delta_{42} &= 2\alpha(2+\theta)(4-2\theta^2+\theta)-b(1-\gamma)(1+\theta)(2-\gamma\theta-\theta^2)\\
\Delta_5 &= \alpha(4-\theta^2)^2-b(2-\gamma\theta-\theta^2)^2\\
\Delta_{61} &= 4\alpha(2-\theta^2)(4-\theta^2)-b(2-\gamma\theta-\theta^2)^2\\
\Delta_{62} &= 8\alpha(2-\theta^2)(3-\theta^2)-b(2-\gamma\theta-\theta^2)^2\\
\Delta_{71} &= \alpha(4-\theta^2)(4-2\theta^2+\theta)^2(4-2\theta^2-\theta)^2\\
&\quad -b(2-\theta^2)(8-9\theta^2+2\theta^4-\gamma\theta(2-\theta^2))^2\\
\Delta_{72} &= 2\alpha(3-\theta^2)(4-2\theta^2+\theta)^2(4-2\theta^2-\theta)^2\\
&\quad -b(2-\theta^2)(8-9\theta^2+2\theta^4-\gamma\theta(2-\theta^2))^2\\
\Delta_8 &= 4\alpha(2-\theta^2)^2(4-\theta^2)^2-b(8-9\theta^2+2\theta^4-\gamma\theta(2-\theta^2))^2
\end{aligned}
$$

$$
\begin{aligned}
\Omega_1 &= \alpha(2-\theta)^2-b(1+\gamma)^2(1-\theta)^2\\
\Omega_{21} &= \alpha(2-\theta)(4-2\theta^2-\theta)^2-b(1+\gamma)^2(1-\theta)^2(2+\theta)(2-\theta^2)\\
\Omega_{22} &= 2\alpha(3-\theta^2)(4-2\theta^2-\theta)^2-b(1+\gamma)^2(1-\theta)^2(2+\theta)^2(2-\theta^2)\\
\Omega_3 &= b^2(1-\gamma^2)^2(1-\theta^2)^2(2-\theta^2)(4-\theta^2)\\
&\quad -b\alpha((1+\gamma^2)(3-\theta^2)(32-52\theta^2+29\theta^4-5\theta^6)\\
&\qquad -4\gamma\theta(2-\theta^2)(16-15\theta^2+3\theta^4))+4\alpha^2(2-\theta^2)^2(4-\theta^2)^2\\
\Omega_4 &= 2\alpha(2+\theta)(4-2\theta^2+\theta)-b(1-\gamma)^2(1+\theta)^2(2-\theta)\\
\Omega_5 &= 2\alpha(2+\theta)^2(2-\theta^2)-b(1-\gamma)^2(1+\theta)^2(4-2\theta^2-\theta)\\
\Omega_6 &= \alpha(\gamma(2-\theta^2)(8+4\theta-3\theta^2-\theta^3)\\
&\quad +(32+32\theta-20\theta^2-23\theta^3+3\theta^4+4\theta^5))\\
&\quad -b(1+\gamma)(1-\gamma)^2(1+\theta)^2(2-\theta)(2-\theta^2)\\
\Omega_7 &= \alpha(2-\theta^2)(8+4\theta-3\theta^2-\theta^3)\\
&\quad +\gamma(32+32\theta-20\theta^2-23\theta^3+3\theta^4+4\theta^5))\\
&\quad -b(1+\gamma)(1-\gamma)^2(1+\theta)^2(2-\theta)(2-\theta^2)\\
\Omega_{81} &= \alpha(2-\theta)^3(2-\theta^2)(\Omega_5)^2-b(1-\theta)^2(2+\theta)(\Omega_7)^2\\
\Omega_{82} &= 2\alpha(2-\theta)^2(2-\theta^2)(3-\theta^2)(\Omega_5)^2-b(1-\theta)^2(2+\theta)^2(\Omega_7)^2\\
\Omega_9 &= \alpha(2-\theta)^2(2-\theta^2)^2(\Omega_4)^2-b(1-\theta)^2(\Omega_6)^2
\end{aligned}
$$

spillovers, and the channel structure. In particular, high spillovers across manufacturers and high substitutability between their products makes decentralized manufacturers invest more than perfectly coordinated ones do (see Figure 2(b) for the range in which this is true). Given our discussions so far, this result is easy to understand when spillovers are large. Competing manufacturers increase their investments in cost reduction in response to an increase by the rival when spillovers are large (Lemma 5). Moreover, decentralization blunts the intensity of competition between manufacturers. In particular, a small change in the level of cost-reducing effort leads to a larger change in equilibrium output produced (or, a larger decline in prices) by a coordinated manufacturer than a decentralized one (Lemma 3). This buffering is stronger the higher the product substitutability. Thus, when spillovers are large and product substitutability is high, decentralized manufacturers invest more in effort than coordinated manufacturers because (a) an increase in effort levels by their competitors makes them increase their own effort and (b) they are shielded from downstream competition by independent retailers. In other words, the benefits of lower costs attained through process improvements are not competed away because of the presence of independent retailers as buffers, giving manufacturers stronger incentives to invest in cost reduction.[12]

To further compare our results with Gupta and Loulou (1998), we look at how equilibria vary with the ease of production cost reduction (α). With no spillovers ($\gamma = 0$), Result 2 in Gupta and Loulou (1998) is reproduced: As innovation gets cheaper, the equilibrium range for decentralization declines. This result is interpreted as a trade-off between efficiency and strategic incentives in choosing the optimal channel structure; as it becomes cheaper to reduce costs, the *efficiency penalty* of not coordinating channel decisions gets stronger because decentralized manufacturers invest less. With larger spillovers, however, Proposition 2 implies that this trade-off might no longer hold: As decentralized manufacturers invest more than coordinated ones, the channel efficiency loss is smaller. It can be confirmed that with large spillovers, decentralization is obtained as an equilibrium outcome over a *larger* range of product substitutability as α declines. Thus, presence of spillovers can lead to qualitatively different results from those without spillovers.

One implication of these results is that the level of spillovers can be an important factor in predicting the likelihood of observing decentralized channels. Industries such as electronics, semiconductors, and

[12] Note that when products are almost homogenous, Proposition 2 holds even in a range where level of spillovers is not large enough to induce strategic complementarity between effort level variables. Effectively, in such cases, the combined effect of being buffered from price competition (through decentralization) and having some benefits from competitor's effort investments (through spillovers) is enough to lead decentralized manufacturers to invest more in cost reduction; integrated manufacturers have less incentive to invest when product market competition is intense because the benefits of their investments are competed away.

Figure 2a **Equilibrium Manufacturer Effort Levels Under different Channel Structures with Large Knowledge Spillovers** ($M/b = 1$, $b/\alpha = 1/2$, $c = 1/2$, $\gamma = 1$)

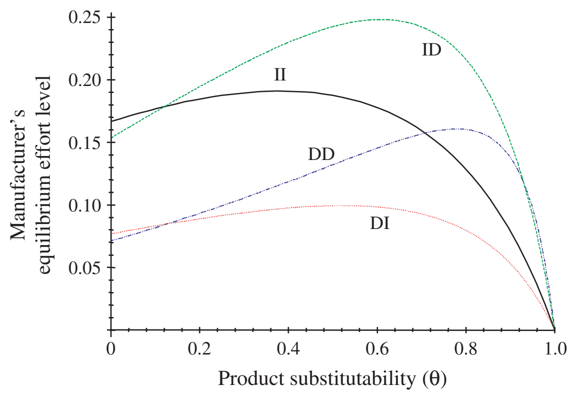
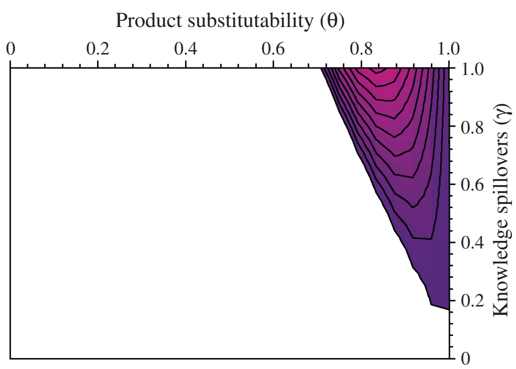


Figure 2b **Region Where Manufacturers' Effort Investments Are Higher Under (DD)**



telecommunications may have lower levels of α compared to industries with more mature technologies, such as automobiles and farm equipment. However, these industries also differ in the level of technological spillovers (Levin and Reiss 1988). Ceteris paribus, decentralized channels are more likely in competitive industries where production costs fall rapidly and manufacturers copy each other's technical advances quickly.

4. Vertical and Horizontal Cooperation

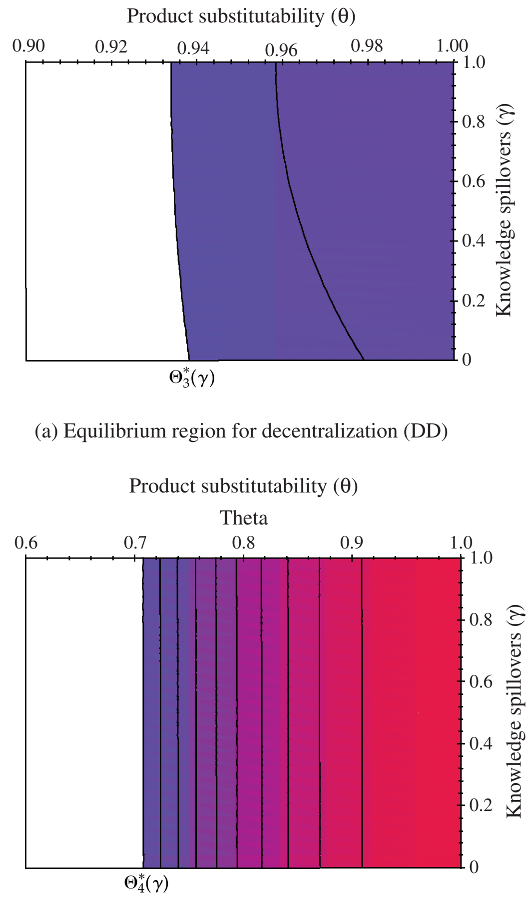
As discussed earlier, cooperation among competing manufacturers through alliances and joint ventures, in the presence of horizontal externalities such as knowledge spillovers, is an increasingly common occurrence. RJVs vary widely in the way they are organized and coordinated. Two broad types by structure include research corporations as a freestanding body with their own facilities (e.g., MCC, SEMATECH); and an administrative body that coordinates research conducted at the member firms' own facilities (e.g., Semiconductor Research Corp., Plastics Recycling Foundation) (Evan and Olk 1990). In our model, horizontal cooperation in process investments can be captured in two ways, reflecting the two broad types observed in industry. First, cooperation could imply that manufacturers coordinate their R&D budgets to maximize their joint profits while setting investment levels; but the level of spillovers remains unchanged, implying that the organizational setup of the RJV dictates that the firms carry out research separately at their own facilities, though the firms take into account the effect of their R&D on the profits of all the firms. Thus, spillover level is not affected because the firms do not share their private information and experiences on R&D projects beyond the level of spillovers that exists in that particular industry because of reasons discussed in the introduction.[13] Joint profit maximization assumes that bargaining and enforcement are costless, so side payments between firms (such as profit-sharing agreements) could always be implemented that would ensure that firms choose investment levels that are jointly optimal (e.g., Coughlan and Wernerfelt 1989). Alternatively, one could also argue that only the most efficient ventures would survive in a competitive environment, giving firms the incentive to act jointly. Such arrangements are usually referred to as "cooperative R&D agreement," "R&D Cartel" (Kamien et al. 1992), or "secretariat RJV" (Vonortas 1997).

The second cooperative arrangement entails complete sharing of process knowledge in addition to setting the investment levels cooperatively. That is, firms pool their resources (capital, people, expertise, proprietary technologies, and processes) under the umbrella of an RJV, create independent facilities, and carry out most of the R&D jointly. This arrangement is referred to as an "RJV Cartel" (Kamien et al. 1992), or simply as a "joint lab." We report most of the results here only for the first case, which is more general as the second is achieved by exogenously setting $\gamma = 1$. We use the term *RJV* generically to refer to any of these arrangements. The reader is reminded to refer to §5 for a discussion of various assumptions imposed in our model that may limit applicability of these results.

The game is played as follows. At the second stage, manufacturers form an *RJV* and decide on x_i to $\text{Max} \sum_{i=1}^{2} \pi_i^M$. The subsequent stages remain the

[13] In many cases, a firm's participation in an RJV does not guarantee access to results of R&D, which could be sold or licensed to individual members for a fee. For example, SEMATECH's equipment projects mostly take place at individual member's own facilities, rather than at the consortium's common facility, and the firms typically own any project-related intellectual property (Ham et al. 1998). Using data from joint venture filings under NCRA, Majewski and Williamson (2002) provide several examples and discuss different governance mechanisms used by firms in an RJV to manage access to intellectual property rights over output of the RJV.

Figure 3 **Equilibrium Channel Structures with Horizontal Cooperation** ($b/\alpha = 1/2$)



same as before.[14] Closed-form expressions appear in Table 1, and equilibrium and profit dominance conditions are in Table 2. The following proposition summarizes the equilibrium results, which are very similar to those obtained in the previous section.

Proposition 3. (a) (II) *is always an equilibrium.* (DD) *is an equilibrium iff the level of product substitutability is above a threshold* $\Theta_3^*(\gamma)$ (*see Figure* 3(a)).

(b) *Whenever* (DD) *is an equilibrium, it generates higher profits for manufacturers than* (II): $\pi_{i(C)}^M(DD) > \pi_{i(C)}^M(II)$ *iff* $\theta > \Theta_4^*(\gamma)$, *and* $\Theta_4^*(\gamma) < \Theta_3^*(\gamma)\ \forall \gamma$ (*see Figures* 3(a) *and* (b)).

(c) *Higher spillovers make decentralization more likely* (*see Figure* 3(a)).

Comparing Propositions 1 and 3, we note a few points. As is readily apparent, the nature of equilibria is very similar with or without horizontal cooperation, with minor differences in threshold values. This suggests that strategic commitment effects of decentralization in a channel are much *stronger* than the horizontal cooperation effects. However, the level of spillovers remains an important determinant of the equilibrium channel structure, even though a joint venture among manufacturers internalizes the horizontal externality induced by involuntary knowledge spillovers. One implication is that manufacturers in highly competitive markets with strong knowledge spillovers in process innovations might find it better to forgo channel coordination in favor of joint ventures with competitors. Thus, managers have a new set of strategic alternatives to consider: Coordination decisions along these two dimensions are not independent.

From a government policy perspective, an important question of interest is which institutional arrangements lead to higher process investments and close the gap between social and private incentives to invest. Existing research on spillovers has tended to focus only on horizontal cooperation among manufacturers while ignoring the vertical structure of the firms (see the introduction). The following result examines the effect of channel structure on process investments.

Proposition 4. (a) *For a given equilibrium channel structure, horizontal cooperation leads to higher effort investments than non-cooperation if and only if the spillovers are "large." The threshold level of spillovers, however, depends on the channel structure. Specifically,*

(i) $x_{i(C)}^*(DD) > x_{i(N)}^*(DD)$ *iff* $\gamma > \theta(2-\theta^2)/(8-9\theta^2+2\theta^4)$ *and*

(ii) $x_{i(C)}^*(II) > x_{i(N)}^*(II)$ *iff* $\gamma > \theta/(2-\theta^2)$.

(b) *The equilibrium effort levels are the highest when manufacturers share all the costs and benefits of their efforts* (*i.e., manufacturers maximize joint profits when making investment decisions and* γ *is set to* 1) *regardless of the equilibrium vertical industry structure* (*i.e.,* $x_{i(C)}^*(k)\,|_{\gamma=1} \geq x_{i(N)}^*(k)\,\forall\,\theta$, $k = II$ *or* DD).

This result may be counterintuitive, as one could expect large spillovers and cooperation among manufacturers to reduce their incentives to invest. However, as discussed before (see Lemma 5), that intuition turns out to be false. Large spillovers induce strategic complementarity between effort levels, and horizontal cooperation allows manufacturers to fully internalize the profit externality generated by spillovers. Low spillovers, on the other hand, imply strategic substitutability, and horizontal cooperation under these conditions would provide the firms an incentive to limit their effort investments. This is in agreement with the existing literature on R&D cooperation (see d'Aspremont and Jacquemin 1988); our result generalizes to different equilibrium channel structures. In

[14] We use the letter C to qualify a variable for the case when manufacturers cooperate at the investment stage, and N to refer to noncooperation (e.g., $x_{i(C)}(DD)$ refers to effort investments by manufacturer i when manufacturers cooperate in setting investment levels and both firms are decentralized; $x_{i(N)}(DD)$ refers to the same variable when manufacturers do not cooperate).

particular, the result shows that the threshold level of spillovers required in an industry for cooperation to raise R&D investments is dependent on the channel structure of the firms: at any given level of product substitutability, a relatively larger level of spillovers are required to induce strategic complementarity between effort levels if manufacturers are integrated than if they are decentralized (because $\theta(2-\theta^2)/(8-9\theta^2+2\theta^4) < \theta/(2-\theta^2)\ \forall\,\theta$). That is, joint ventures among decentralized manufacturers are more likely to meet the regulators' criteria of raising effort investments than those among integrated manufacturers would be, ceteris paribus. Combining Propositions 2 and 4, we have the following.

Corollary. (i) $x^*_{i(C)}(DD) > x^*_{i(N)}(DD) > x^*_{i(N)}(II)$ *iff* $\gamma > \theta(2-\theta^2)/(8-9\theta^2+2\theta^4)$ *for any* $\theta \geq 0.869$.

(ii) *With perfect spillovers* ($\gamma = 1$), $x^*_{i(C)}(DD) \geq x^*_{i(N)}(II)\ \forall\,\theta$.

That is, in markets with no intellectual property protection and perfect knowledge spillovers, horizontal cooperation among decentralized manufacturers is likely to generate higher effort investments than channel coordination would.

5. Conclusion, Limitations, and Future Research

In this paper, we have presented a simple model to explore interactions among firm incentives to coordinate decisions along two dimensions: vertically with channel partners and horizontally with competitors, when involuntary spillovers exist in the knowledge created by manufacturers' investments in process innovations. Our main results show that decentralization is more likely if, in addition to being in a highly competitive market, firms' investments in process efficiency are not completely appropriable: large spillovers make decentralization more likely. With large spillovers, decentralized manufacturers in oligopolistic markets invest more in process innovation than integrated manufacturers do. Our results also suggest that firms' channel structure can be an important determinant in formulation of government policies that encourage RJVs among competitors to stimulate investments in innovative activities. Joint ventures among decentralized manufacturers in highly competitive markets are more likely to raise effort investments than those among integrated manufacturers would be.

These results, however, are subject to several caveats reflecting the assumptions we have imposed in our model. We discuss these assumptions and limitations below. Relaxing some of these assumptions might indeed lead to different results. Further research along these lines can provide richer insights into the interactions between horizontal and vertical coordination incentives in oligopolistic markets.

1. *Nature of Innovation and Spillovers*. The model assumes that: (a) innovation occurs at the process level and benefits apply to reduction in production costs; (b) knowledge spillovers *within* an industry are more significant than interindustry spillovers; (c) spillovers across manufacturers in an industry are exogenously determined, though the extent of such spillovers varies depending on industry conditions; (d) investments required by manufacturers to access their competitors' process knowledge are negligible compared to investments in their own innovative activities; (e) spillovers occur at the R&D output level (i.e., manufacturers benefit directly from the results of innovative activities carried out by competitors), and there is a sufficient degree of nonoverlap in these activities that benefits can be taken as additive.

(1.a) reflects the empirical observation that process knowledge spillovers are common across a range of industries. Government policies that encourage cooperation among competitors in R&D have focused mainly on this category, usually referred to as *precompetitive* R&D, implying that firms may cooperate in developing new processes and technologies, but remain competitors in exploiting that technology to produce and sell products in the market. Thus the model applies to industries such as computers, electronics, automobiles, and heavy equipment where manufacturers carry out most of the innovation in the channel. Excluded from this are industries such as books, music, and groceries where retail innovation can play an important role. A worthwhile extension of our model would be to explore the effects of retailer efforts in provision of services for the products such as advertising, promotion, and store displays (see Jeuland and Shugan 1983) that might generate positive spillovers for competing channels and could have demand side effects instead of cost effects. In particular, consideration of retailers' decision to add or drop products (see Bergen et al. 1996) is likely to lead to new and significant insights.

(1.b) implies that our analysis is more relevant for industries such as chemicals and mechanical engineering that rely mostly on knowledge generated within the industry, but not for others such as textiles that seem to borrow most of their technological inputs from outside the industry (e.g., suppliers and clients; see Lambertini et al. 2004). Banerjee and Lin (2001) study incentives to form vertical joint ventures when an upstream supplier's innovation benefits downstream producers. Analysis of both horizontal and vertical spillovers along with channel effects requires a more complex model than the one studied here but would be worthwhile.

(1.c) reflects empirical evidence that levels of spillovers differ across industries depending on the ease of reverse engineering competitive products and "inventing around" (when patents and intellectual property laws do not provide adequate protection), mobility of people within and across industries, as well as knowledge disseminated through consultants, scientific conferences, and other formal and informal networks (Levin 1988). While firms can, in principle, endogenously choose how much of their knowledge to share with competitors by, for example, choosing between different research designs (Katsoulacos and Ulph 1998), it is not clear empirically how much control firms have over the level of spillovers (see Lambertini et al. 2004), precisely because of the prevalence of factors that make an innovation a partial public good. Nevertheless, it would be interesting to see the effects of endogenous determination of spillovers on channel coordination incentives.

(1.d) restricts the application of our results to situations where firms are not actively deciding how to allocate their research dollars between activities aimed at enhancing their own innovative capability versus those improving their "absorptive capacity," i.e., a firm's ability to identify, assimilate and exploit knowledge generated by other firms (Cohen and Levinthal 1989). Thus our model is similar in spirit to literature in cooperative R&D that implicitly assumes that firms are symmetric in their capabilities and knowledge (d'Aspremont and Jacquemin 1988, Kamien et al. 1992, Suzumura 1992, and others), and our results contrast and extend those in this stream. A parallel stream of literature adopts the resource-based view that sees a firm as a portfolio of core competencies, and argues that the primary objective of firms in forming alliances is to access complementary knowledge and skills of other firms (see Kamien and Zhang 2000 and Sakakibara 2003 for a discussion and analysis of spillovers along these lines without channel considerations). Such "learning effects" tend to dominate when "technological heterogeneity" of firms participating in a consortium is high (see Sakakibara 2002, 2003), as seems to be the case for most Japanese government-sponsored R&D consortia. In contrast, learning effects and complementary knowledge tend to play a lesser role in consortia such as SEMATECH with a narrow range of industry participants, or in joint ventures among established firms in oligopolies to which the results of this paper are immediately more relevant.

(1.e) is a crucial assumption, and indeed, relaxing this assumption is likely to alter the results. The assumption is less restrictive for industries with a small number of competitors that face strong spillovers and have good knowledge of others' research activities (say, technology companies located close to each other). An alternative formulation, following Kamien et al. (1992), would be to model spillovers in research *inputs* (expenditures) and a given R&D production function that links these inputs to the amount of cost reduction obtained by a firm. See Amir (2000) for a discussion of differences in expected results between these two modeling choices; Hauenschild (2003), however, shows that those differences are negligible and the effects in some cases are reversed if one considers uncertainty in R&D projects. In any case, one must consider which model better captures the reality in the industry being studied before applying any of the conclusions.

2. *Nature of Joint Ventures*. The model assumes that firms in a joint venture (a) maximize joint profits while setting their R&D investment levels and (b) might or might not take steps to voluntarily increase information sharing beyond what is already available through other means.

(2.a) is discussed in §4. An analysis of interactions between various forms of channel contracts and different governance mechanisms within a joint venture (such as different agreements regarding cost and profit sharing, and intellectual property rights) would certainly contribute to a better understanding of organizational design. Oxley (1997) and Sampson (2004) provide a detailed discussion of such governance mechanisms within RJVs.

(2.b) reflects assumption (1.c) above and is a critical assumption as well for the results in this paper to hold. The assumption states that spillovers exist in an industry because of several factors (as discussed in the introduction), which are largely out of a firm's control. For an industry under consideration, this existing level of spillovers is commonly known and can be operationalized as a parameter γ, $0 \leq \gamma \leq 1$. This, together with assumption (1.e), implies that for each x dollars of unit cost reduction achieved by a firm i because of i's investments in process innovation, i's competitors enjoy a cost reduction of γx without making any investments. Moreover, it is assumed that formation of a joint venture does not eliminate factors contributing to the level of involuntary spillovers in the industry. Firms in a joint venture may choose to simply coordinate their R&D investments without altering the level of information sharing, or commit to perfect information sharing as well. As in Kamien et al. (1992), this way of modeling helps us separate the firm incentives to cooperate with competitors from the effects of sharing information. However, a more general model would explicitly consider firms' choice of the level of information sharing in a joint venture, which along with analysis of different governance mechanisms within a joint venture, is likely to lead to alternative specifications of how firms benefit from spillovers, and possibly very different results.

3. *Uncertainty and Dynamics*. The paper essentially abstracts from the dynamic process of knowledge creation and dissemination and focuses instead on the outcome of that process. Moreover, it is assumed that there is no uncertainty in the outcome of the innovation process. Both these assumptions are clearly abstractions of reality. The resulting simplicity allows us to analyze the strategic implications of the innovation outcome being less than fully appropriable, on other firm decisions such as channel structure and pricing, which are also treated as static. Understanding and modeling the dynamics of the innovation process would be highly useful for exploring the learning motivation for firms to join research consortia to which we alluded to above. The assumptions limit our model's applicability to innovative activities such as process improvements which tend to be more predictable as opposed to, say, investments in drug discovery by pharmaceutical companies or biotechnology firms.

4. *Channel Structure*. The paper assumes two competing manufacturer-retailer channels where the retailer carries only one manufacturer's products. This is done primarily to compare our results with those in the literature (McGuire and Staelin 1983, Gupta and Loulou 1998). These results could be further generalized by considering alternative channel structures such as a common retailer for competing manufacturers, a single manufacturer distributing its products through multiple retailers, and retailers carrying multiple brands.

5. *Symmetry*. The current model treats firms as symmetric and limits itself to symmetric equilibria, primarily for analytical tractability. Consideration of asymmetry in some parameters, particularly in spillovers, is likely to lead to new and/or different insights, although the current model does not allow us to speculate on differences in expected results. See Amir and Wooders (2000) for an analysis of asymmetric spillovers without channel considerations.

Finally, an empirical illustration would be very useful. While there are many empirical studies of process knowledge spillovers in the economics literature (Bernstein and Nadiri 1988, Cockburn and Griliches 1988, Levin 1988), as well as of the decentralization effects in channels literature (Coughlan 1985), no studies exist that jointly examine spillover effects with channel structure decisions. Using data from 312 Japanese firms, Sakakibara (2002) shows that weak competition and appropriability conditions in an industry lead to higher rates of participation by firms in R&D consortia. It would certainly be worthwhile to explore the joint effects of industry-level factors (such as competitive intensity and degree of appropriability) and strategic firm decisions (such as channel structure and alliance formation).

Appendix

1. Summary of the Solution Procedure

(a) No Horizontal Cooperation. Following the standard solution procedure by backward induction, we have the following for the pure decentralized case (DD): The fourth stage Nash equilibrium retail prices, given w_i and c_i are

$$p_i^* = \frac{M(2+\theta)+2bw_i+b\theta w_j}{b(4-\theta^2)}. \quad j=3-i,\ i=1,2. \tag{3}$$

At the third stage, manufacturers take the retailers' decision rules into account while setting their wholesale prices, yielding the equilibrium wholesale prices, given c_i, $i = 1, 2$, as

$$w_i^* = \frac{M(2+\theta)(4-2\theta^2+\theta)+2b(2-\theta^2)^2c_i+b\theta(2-\theta^2)c_j}{b(4-2\theta^2+\theta)(4-2\theta^2-\theta)}, \quad j=3-i,\ i=1,2.$$

Substitution gives retail prices and quantities as functions only of the manufacturers' unit cost of production c_i and c_j, as follows:

$$p_i^* = \frac{\left\{\begin{array}{l}2M(2+\theta)(3-\theta^2)(4-2\theta^2+\theta)+b(2-\theta^2)(8-3\theta^2)c_i\\ \quad +2b\theta(2-\theta^2)(3-\theta^2)c_j\end{array}\right\}}{b(4-\theta^2)(4-2\theta^2+\theta)(4-2\theta^2-\theta)}, \quad i=1,2$$

$$q_i^* = \left(\frac{2-\theta^2}{4-\theta^2}\right)\left[\frac{M(2+\theta)(4-2\theta^2+\theta)-b(8-9\theta^2+2\theta^4)c_i+b\theta(2-\theta^2)c_j}{(4-2\theta^2+\theta)(4-2\theta^2-\theta)}\right], \quad i=1,2.$$

Using these expressions, the second-stage manufacturer profits as functions of c_i, $i=1,2$, can be written as $\pi_i^M = (1/b)[(4-\theta^2)/(2-\theta^2)](q_i^*)^2-\alpha(x_i)^2$.

The second-stage reaction functions in effort-level space are

$$x_i(x_j) = \frac{ASJ[M-b(1-\theta)c]+Ab(\gamma L-\theta F)x_j}{[\alpha-bA(L-\gamma\theta F)]},$$

where $A=(2-\theta^2)(8-9\theta^2+2\theta^4-\gamma\theta(2-\theta^2))/((4-\theta^2)\cdot(4-2\theta^2+\theta)^2(4-2\theta^2-\theta)^2)\geq 0$; $S=(2+\theta)>0$; $J=(4-2\theta^2+\theta)>0$; $L=(8-9\theta^2+2\theta^4)$; $F=(2-\theta^2)$, so $L-\gamma\theta F\geq 0\ \forall\theta,\ \gamma$. Second-order conditions for manufacturers' profit maximization require $\alpha/b>A(L-\gamma\theta F)$, or $b/\alpha<8$. Moreover, $\alpha-bA(L-\gamma\theta F)>0$ as long as $b/\alpha<8$ (i.e., as long as second-order conditions hold). Thus we have downward-sloping reaction functions in effort levels under the condition

$$\gamma<\frac{\theta(2-\theta^2)}{(8-9\theta^2+2\theta^4)}. \tag{4}$$

That is, effort-level decision variables are strategic substitutes as long as spillovers are not large in the sense that Condition (4) is satisfied. Stability conditions require that the reaction functions cross *correctly*. For Nash equilibrium in effort levels, stability is ensured by the condition $|\partial x_i/\partial x_j|<1$. Thus, for the (DD) case, stability requires that for small γ (Condition 4), $b/\alpha<8$; for large γ, $b/\alpha<4$.

Similar calculations for the pure integrated case (II) reveal the reaction functions in effort levels to be

$$x_i(x_j) = \frac{JS[M-b(1-\theta)c]+bJ(\gamma F-\theta)x_j}{\alpha-bJF_\gamma},$$

where $J=(2-\gamma\theta-\theta^2)/(4-\theta^2)^2\geq 0$; $S=(2+\theta)$; $F_\gamma=2-\gamma\theta-\theta^2\geq 0$ $\forall\theta$, γ. Second-order conditions require $\alpha/b>JF_\gamma$ or $b/\alpha<4$, which implies that the denominator $\alpha-bJF_\gamma>0$. Coefficient of x_j is positive as long as $\gamma F-\theta=\gamma(2-\theta^2)-\theta>0$. Thus we have downward-sloping reaction functions if

$$\gamma<\frac{\theta}{(2-\theta^2)}. \tag{5}$$

For small γ (condition 5), stability requires $\alpha/b>(1-\gamma)\cdot J(2-\theta^2+\theta)$ or $b/\alpha<3.8$. For large γ, stability requires $\alpha/b>(1+\gamma)J(2-\theta^2-\theta)$ or $b/\alpha<2$.

(b) Horizontal Cooperation in Effort Investments. The last two stages of the game are the same as above. At the second stage, manufacturers set their R&D levels to maximize joint profits ($T=\pi_1^M+\pi_2^M$). The major differences in determination of the second-stage equilibrium in R&D levels in this case are summarized below.

For the pure decentralized structure (DD), the first-order conditions for joint profit maximization lead to the following reaction functions:

$$x_i(x_j)=\frac{(A+A')SJ[M-(1-\theta)bc]+[A(\gamma L-\theta F)+A'(L-\gamma\theta F)]bx_j]}{\alpha-b[A(L-\gamma\theta F)+A'(\gamma L-\theta F)]}, \tag{6}$$

where

$$A'=\frac{(2-\theta^2)(\gamma(8-9\theta^2+2\theta^4)-\theta(2-\theta^2))}{(4-\theta^2)(4-2\theta^2+\theta)^2(4-2\theta^2-\theta)^2},$$

and all other expressions are as defined above. Second-order conditions require $\alpha/b>A'(D-\gamma E)+F(\gamma D-E)$ or $b/\alpha<4$. Here, the denominator is always positive under the second-order conditions, and it is easy to check that the sign of the coefficient of x_j depends on the sign of the term $(\gamma L-\theta F)$. Thus, under the condition

$$\gamma<\frac{\theta(2-\theta^2)}{(8-9\theta^2+2\theta^4)}, \tag{7}$$

we have downward-sloping reaction functions, as in the case of no R&D cooperation.

Stability conditions are as follows. For small γ (condition 7), stability requires $\alpha/b>(1-\gamma)^2Z(L+\theta F)^2$ or $b/\alpha<6.7$ (approximately), where $Z=(2-\theta^2)/((4-\theta^2)(4-2\theta^2+\theta)^2(4-2\theta^2-\theta)^2)$. For large γ, stability requires $\alpha/b>(1+\gamma)^2Z(L-\theta F)^2$ or $b/\alpha<2$.

For pure integrated structure (II), the reaction functions at the second stage are given by

$$x_i(x_j)=\frac{(J+J')S[M-(1-\theta)bc]+(J(\gamma F-\theta)+J'F_\gamma)bx_j}{\alpha-b(JF_\gamma+J'(\gamma F-\theta))}, \tag{8}$$

where $J'=(\gamma(2-\theta^2)-\theta)/(4-\theta^2)^2$ and all other expressions are as defined above. Second-order conditions require $\alpha/b>JF_\gamma+J'(\gamma F-\theta)$ or $b/\alpha<2$. It is easy to check that, as in case (a) above, we have downward-sloping reaction functions if

$$\gamma<\frac{\theta}{(2-\theta^2)}. \tag{9}$$

For small γ (Condition 9), stability requires $\alpha/b>((1-\gamma)\cdot(1+\theta)/(2+\theta))^2$ or $b/\alpha<2.2$ (approximately). For large γ, stability requires $\alpha/b>((1+\gamma)(1-\theta)/(2-\theta))^2$ or $b/\alpha<1$. Similar calculations can be done for the mixed structures as well.

To have meaningful results in all cases, $b/\alpha<1$ is assumed throughout.

2. Proofs

Proof of Lemma 1. From Table 1, we have: For channel structure (II), equilibrium retail price $p_i^*=(MS+2bc_i^*+b\theta c_j^*)/bH$, where $c_i^*=c-x_i^*-\gamma x_j^*$. Taking derivative wrt x_i and x_j, respectively, yields

$$\frac{\partial p_i^*(II)}{\partial x_i}=-\frac{(2+\gamma\theta)}{4-\theta^2}<0\quad\forall 0\leq\theta<1,\ 0\leq\gamma\leq 1;$$

$$\frac{\partial p_i^*(II)}{\partial x_j}=-\frac{(2\gamma+\theta)}{4-\theta^2}<0\quad\forall 0\leq\theta<1,\ 0\leq\gamma\leq 1.$$

For (DD): $p_i^*=(2MGJS+bFNc_i^*+2b\theta FGc_j^*)/(bHJK)$. Thus

$$\frac{\partial p_i^*(DD)}{\partial x_i}=-\frac{(2-\theta^2)(8-3\theta^2+2\gamma\theta(3-\theta^2))}{(4-\theta^2)(4-2\theta^2+\theta)(4-2\theta^2-\theta)}<0\quad\forall 0\leq\theta<1,\ 0\leq\gamma\leq 1$$

$$\frac{\partial p_i^*(DD)}{\partial x_j}=-\frac{(2-\theta^2)(\gamma(8-3\theta^2)+2\theta(3-\theta^2))}{(4-\theta^2)(4-2\theta^2+\theta)(4-2\theta^2-\theta)}<0\quad\forall 0\leq\theta<1,\ 0<\gamma\leq 1.\quad\square$$

Proof of Lemma 2. Using expressions from Table 1 and simplifying, we get

$$\begin{aligned}
&p_i^*(DD)-p_i^*(II)\\
&=\big(((2+\theta)^2(2-\theta)^2(4-2\theta^2+\theta)(4-2\theta^2-\theta)-\delta\theta(1+\gamma)(1-\theta^2)\\
&\quad\cdot(2-\theta^2)(2\theta(3-\theta^2)+\gamma(8-3\theta^2)))(M/b-c(1-\theta))\big)\\
&\quad\cdot\big(((2-\theta)(4-\theta^2)-\delta(1+\gamma)(1-\theta)(2-\gamma\theta-\theta^2))\\
&\quad\cdot((2-\theta)(4-2\theta^2+\theta)(4-2\theta^2-\theta)^2\\
&\quad-\delta(1+\gamma)(1-\theta)(2-\theta^2)(8-9\theta^2+2\theta^4-\gamma\theta(2-\theta^2)))\big)^{-1},
\end{aligned}$$

where $b/\alpha=\delta$. It can be checked that the right-hand side of the above equation is nonnegative for $c<M/b$, $0\leq\theta<1$, $0\leq\gamma\leq 1$, $b/\alpha<1$. $\square$

Proof of Lemma 3.

$$\begin{aligned}
&\left|\frac{\partial p_i^*(II)}{\partial x_i}\right|-\left|\frac{\partial p_i^*(DD)}{\partial x_i}\right|\\
&=\frac{(2+\gamma\theta)}{(4-\theta^2)}-\frac{(2-\theta^2)(8-3\theta^2+2\gamma\theta(3-\theta^2))}{(4-\theta^2)(4-2\theta^2+\theta)(4-2\theta^2-\theta)}\\
&=\frac{16-20\theta^2+5\theta^4+\gamma\theta(4-7\theta^2+2\theta^4)}{(4-\theta^2)(4-2\theta^2+\theta)(4-2\theta^2-\theta)}\geq 0\quad\forall 0\leq\theta<1,\ 0\leq\gamma\leq 1.\quad\square
\end{aligned}$$

Proof of Lemma 4.

(i) Using expressions from Table 1 and taking derivatives

$$\frac{\partial q_i^*(II)}{\partial x_i}=\frac{b(2-\gamma\theta-\theta^2)}{(4-\theta^2)}\geq 0\quad\forall 0\leq\theta<1,\ 0\leq\gamma\leq 1$$

$$\frac{\partial q_i^*(DD)}{\partial x_i}=\frac{b(2-\theta^2)(8-9\theta^2+2\theta^4-\gamma\theta(2-\theta^2))}{(4-\theta^2)(4-2\theta^2+\theta)(4-2\theta^2-\theta)}\geq 0\quad\forall 0\leq\theta<1, 0\leq\gamma\leq 1$$

(ii) $\partial q_i^*(II)/\partial x_j=(b/(4-\theta^2))(\gamma(2-\theta^2)-\theta)$, which is ≥ 0 iff $\gamma\geq\theta/(2-\theta^2)$.

$$\frac{\partial q_i^*(DD)}{\partial x_j}=\frac{b(2-\theta^2)}{(4-\theta^2)(4-2\theta^2+\theta)(4-2\theta^2-\theta)}\cdot(\gamma(8-9\theta^2+2\theta^4)-\theta(2-\theta^2)),$$

which is ≥ 0 iff $\gamma\geq\theta(2-\theta^2)/(8-9\theta^2+2\theta^4)$. $\square$

Proof of Lemma 5. Reaction functions in effort-level variables in the second-stage game are derived above. As shown there, $\partial x_i(DD)/\partial x_j > 0$ iff $\gamma > \theta(2-\theta^2)/(8-9\theta^2+2\theta^4)$ and $\partial x_i(II)/\partial x_j > 0$ iff $\gamma > \theta/(2-\theta^2)$. □

Proof of Proposition 1. (i) (II) is an equilibrium if no manufacturer has an incentive to unilaterally decentralize, i.e., $\pi_i^{M^*}(II) > \pi_i^{M^*}(DI)$ $\forall i$. By using the expressions in Table 1 and rearranging, we get the condition shown in Table 2 for (II) to be an equilibrium. As is apparent, these conditions depend only on three parameters: θ, γ, and b/α. Numerical studies show that the condition is always satisfied in the relevant range of parameters ($0 \le \theta < 1$, $0 \le \gamma \le 1$; $0 \le b/\alpha < 1$). Restricting discussions to interactions between θ and γ, we assume $b/\alpha = 1/2$. An implicit plot of the condition shows that the condition is always satisfied (any mathematical software such as Maple or Mathematica can be used for this purpose).

(ii) (DD) is an equilibrium if $\pi_i^{M^*}(DD) > \pi_i^{M^*}(ID)$ $\forall i$, which leads to the condition summarized in Table 2. A plot of the condition with $b/\alpha = 1/2$ shows the range of θ and γ in which the condition holds (the shaded area in Figure 1(a) shows this region).

A similar procedure is followed to prove the rest of the claims in this proposition, as well as those in Proposition 3.

Proof of Proposition 2. Using expressions from Table 1, rearranging, and simplifying, we get $x_i^*(DD) > x_i^*(II)$ if $(2-\theta^2)(4-\theta^2)(8-9\theta^2+2\theta^4-\gamma\theta(2-\theta^2)) > (2-\gamma\theta-\theta^2)(4-2\theta^2+\theta)(4-2\theta^2-\theta)^2$ or if

$$\gamma > f(\theta) = \frac{(2-\theta^2)(32+16\theta-40\theta^2-23\theta^3+10\theta^4+6\theta^5)}{\theta(48+32\theta-48\theta^2-31\theta^3+11\theta^4+7\theta^5)}, \quad \theta \neq 0.$$

One can easily confirm that $(d/d\theta)f(\theta) < 0$ for all $0 < \theta < 1$, and $(d^2/d\theta^2)f(\theta) > 0$ for all $0 < \theta < 1$. □

Proof of Proposition 4. Using expressions from Tables 1 and 3 $x_{i(C)}^*(DD) > x_{i(N)}^*(DD)$ if

$$\begin{aligned}
&\frac{(1+\gamma)(1-\theta)(2+\theta)(2-\theta^2)(M-b(1-\theta)c)}{\alpha(2-\theta)(4-2\theta^2-\theta)^2 - b(1+\gamma)^2(1-\theta)^2(2+\theta)(2-\theta^2)} \\
&\quad > ((2-\theta^2)(8-9\theta^2+2\theta^4-\gamma\theta(2-\theta^2))(M-b(1-\theta)c)) \\
&\quad \cdot (\alpha(2-\theta)(4-2\theta^2+\theta)(4-2\theta^2-\theta)^2 - b(1+\gamma)(1-\theta) \\
&\quad \cdot (2-\theta^2)(8-9\theta^2+2\theta^4-\gamma\theta(2-\theta^2)))^{-1}
\end{aligned}$$

or if $\alpha(2-\theta)(4-2\theta^2-\theta)^2(\gamma(8-9\theta^2+2\theta^4)-\theta(2-\theta^2)) > 0$, which is true as long as $\gamma > \theta(2-\theta^2)/(8-9\theta^2+2\theta^4)$. (It can be checked that the denominators in the above expressions are positive in the relevant parameter ranges.)

Similarly, $x_{i(C)}^*(II) > x_{i(N)}^*(II)$ if

$$\frac{(1+\gamma)(1-\theta)(M-b(1-\theta)c)}{\alpha(2-\theta)^2 - b(1+\gamma)^2(1-\theta)^2} > \frac{(2-\gamma\theta-\theta^2)(M-b(1-\theta)c)}{\alpha(2+\theta)(2-\theta)^2 - b(1+\gamma)(1-\theta)(2-\gamma\theta-\theta^2)}$$

or if $\alpha(2-\theta)^2(\gamma(2-\theta^2)-\theta) > 0$, which is true as long as $\gamma > \theta/(2-\theta^2)$.

Putting $\gamma = 1$ in the above comparisons proves the second part. □

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