The Likelihood of Cooperation for Investment and Firm Heterogeneity*

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Abstract

This paper examines firms' incentives to cooperate regarding demand-enhancing investment when they choose their production technology non-cooperatively. The technology choice endogenously determines firm heterogeneity, which, in turn, implies a difference in the proportions of investment cost firms incur under cooperation. We show that cooperation for investment deters firms from adopting efficient technology. In addition, when production technology is strategically chosen, cooperative investment is less likely than when a firm has no opportunity to upgrade its production technology. On the contrary, the likelihood of cooperation for investment does not depend on the magnitude of a fixed cost when it is strategically determined before a firm's technology choice.

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1 Introduction

Cooperation for investment is considered to be an effective tool for firms in the market to enhance their activities or to avoid formidable investment costs. For example, infrastructure facilities have occasionally been built by consortiums. A system of high-bandwidth subsea fiber optic cables linking the United States and Japan called "Unity" has been deployed by a consortium of six international companies. The South Fuji gas pipeline was built by Tokyo Gas, Shizuoka Gas, and Teikoku Petroleum in 2006. Joint ventures for research and development can also be regarded as cooperation for investment.

It is also plausible that each member firm takes specific actions before or after the investment actually occurs in anticipation of such cooperation for investment. In fact, firms may reorganize their labor locations or governance structures to prepare for a consortium. Similarly, firms may change their production processes (i.e., process innovation) in adjusting to a joint venture because they may be better able to determine the details of contract terms under cooperative investment, such as investment cost sharing or the level of investment to which they agree. Hence, a technological change – such as an organizational or production innovation – is related to firm decisions on investment cooperation.

Examples of the relationship between investment cooperation and technology choice are found in the real business world. When Sony Corporation and Samsung Electronics Co. Ltd. jointly established S-LCD Corporation as an amorphous TFT LCD panel production company on April 26, 2004, they had previously agreed to form a coalition for this joint venture with a Memorandum of Understanding on October 28, 2003. Between the agreement and the establishment of S-LCD, Sony had been restructuring the company at an approximate cost of 33 million yen from 2003 to 2005. A portion of this restructuring process can be considered a strategic use of the technology choice for that cooperative investment. Regarding the South Gas pipeline example, Shizuoka Gas implemented gas calorie upgrades when the pipeline was built.

There is a subtle question regarding the relationship between cooperating for investment and firms' technology choices. Which decision is usually made before the other? Additionally, does the likelihood of investment cooperation depend on the timing of the two decisions? Indeed, it is apparently difficult to obtain convincing evidence on the timing of these two decisions. Therefore, in this paper, we examine the welfare implications of the relationship between the cooperative investment decision and each firm's non-cooperative choice on production technology by focusing on the timing of the two decisions.

To answer this question, we examine two scenarios. The first occurs when a firm chooses its production technology in anticipation of the opportunity to cooperate for investment with other firms; we call this *the strategic technology choice*. The other occurs when firms decide whether they will cooperate for investment in anticipation of each firm's choice of production technology and is called *strategic cooperation*.

To analyze the two scenarios, we build a simple model in which firms have an opportunity to cooperate to build a new upstream facility that has a demand-enhancing effect and a fixed investment cost. In addition, firms can choose a downstream production technology non-cooperatively; this affects the proportion of upstream investment costs each firm must incur under cooperation. The proportion of investment cost is determined by a cost-sharing rule under which neither firm disagrees on cost sharing and the investment level. Then, firms can choose their downstream technology non-cooperatively before or after conducting their cooperative investment to build a new upstream facility.

Analyzing this model, we first show that cooperation for investment deters firms from adopting an efficient technology in both scenarios. This finding results due to *the cost-sharing effect* under cooperative investment, i.e., member firms can share the burden of the investment cost. According to the cost-sharing rule under cooperation, an efficient firm must incur a larger proportion of the investment cost than an inefficient firm because the benefit generated by the investment is greater to an efficient firm than to an inefficient firm. Hence, a firm has a weak incentive to adopt efficient technology.

Then, we show that cooperative investment is less likely to occur in the case of strategic technology choice (i.e., the production technology is strategically chosen before the decision to cooperate for investment) than in the case in which a firm cannot upgrade its production technology. Moreover, firm heterogeneity is less likely to occur under investment cooperation. By contrast, the likelihood of cooperation for investment does not depend on the magnitude of the fixed investment cost for strategic cooperation (i.e., when the cooperative investment decision is strategically determined before a firm's technology choice). These results indicate that one of the two decisions actually relates to the other and is used as a strategic device for the other decision. In particular, a firm's technology choice is used to affect the likelihood of cooperation for the strategic technology choice. By contrast, investment cooperation can affect a firm's incentive to adopt an efficient production technology in addition to the incentive benefit of sharing the investment cost burden.

Many studies examine the performance of cooperative investments; see for example, Katz (1986), Kamien et al. (1992), Suzumura (1992) and Choi (1993). Chen and Ross (2003) examine the characteristics of strategic alliances and joint ventures. Ghosh and Morita (2006) examine the relationship between cooperative investment for product innovation and market competition by assuming that cooperation for product innovation reduces product differentiation. These studies examine how cooperative behavior regarding investments contributes to social benefits by comparing cooperative investment with non-cooperative investment, but the decision on cooperation for investment is nonetheless taken as given in these studies.

Regarding a firm's technology choice, Mills and Smith (1996) and Elberfeld (2003) analyze firms' incentives to adopt an efficient technology and show the occurrence of endogenous firm heterogeneity in oligopolies. These two papers do not examine the relationship of cooperative investment and firms' non-cooperative technology choices.

The most relevant studies are Lin and Saggi (2002) and Bourreau and Doğan (2010).

These researchers examine a link between product R&D and process R&D. Lin and Saggi analyze whether cooperative product R&D enhances process R&D by assuming that process innovation increases the degree of horizontal product differentiation. They take a decision on cooperation as given. In the setting of Bourreau and Doğan, cooperation for product innovation has the benefit of sharing investment costs, while its disadvantage is that it induces fierce competition by reducing the degree of horizontal product differentiation. Then, the degree of cooperation is endogenously determined in the researchers' model. In contrast to the researchers' setting, we assume that investment for product innovation has only a demand-enhancing effect. We then analyze the issue regarding when cooperation for investment is likely to occur when firms have a non-cooperative choice to improve their production technology.[1] In particular, we focus on the timing of these two decisions and indicate the possibility of firm heterogeneity that occurs endogenously in equilibrium.

The remainder of this paper is structured as follows. Section 2 presents the model. Section 3 provides three benchmarks, i.e., the two equilibria when the decision to cooperate for investment and firms' non-cooperative technology choices do not interact (two separate cases) and the second-best optimum. Section 4 characterizes the equilibrium for the strategic technology choice, and the equilibrium for strategic cooperation is examined in Section 5. Section 6 discusses the robustness of our qualitative results. Concluding remarks are in Section 7.

2 The Model

To examine the relationship between the likelihood of cooperation and firms' non-cooperative technology choices, we consider a duopoly model with the opportunity to invest in a new

[1] The literature on group or network formation is related to our research in that cooperation is endogenously determined; see for example, Deroian and Gannon (2006), Goyal (2007), Goyal and Joshi (2003), and Jackson (2008).

facility in the context of vertically related sectors.[2]

There are two vertically related sectors in a market: an *upstream* sector and a *downstream* sector. The two sectors are required to supply services to consumers in the market. Two firms, firm 1 and firm 2, want to build a new upstream facility to upgrade the quality of their services or to extend the deployment of the upstream facility to a new region. In other words, the investment for a new upstream facility has a demand-enhancing effect on the service. The investment cost to build a new upstream facility is represented by $F(\theta) = \widetilde{F} + f(\theta)$ where $\widetilde{F}$ is a constant and $f(0) = 0$, $f'(\theta) > 0$, and $f"(\theta) > 0$. $\widetilde{F}$ represents a fixed facility cost, whereas $f(\theta)$ represents a variable portion of the investment cost at investment level θ. θ reflects the magnitude of a demand-enhancing effect, as shown herein. For analytical tractability, we use a specific form of $f(\theta) = k\theta^2/2$ to derive the explicit solution in the following analysis. Here, $k\,(> 0)$ represents the efficient parameter of the investment technology.

The utility of a representative consumer is represented by the following quadratic function:

$$U(q_1, q_2, q_0) = (V + \theta)(q_1 + q_2) - \frac{1}{2}\left(q_1^2 + 2q_1q_2 + q_2^2\right) + q_0,$$

where V is the basic willingness to pay for the service; q_i $(i = 1, 2)$ is the quantity served by firm i,[3] and q_0 is a numeraire good. Here, we assume that the services provided by the two firms are perfect substitutes, and the level of upstream investment θ reflects the magnitude of the demand-enhancing effect. Then, the inverse demand function for good i is given by

$$p_i = (V + \theta) - q_i - q_j \qquad i,\ j = 1, 2, \text{ and } i \neq j.$$

Since building a new upstream facility includes a fixed cost $\widetilde{F}$, it is possible that firms 1 and 2 have an incentive to own the facility jointly to share the investment cost. When

[2] The context of vertically related sectors is not essential for the analysis in this paper. The context is used only to make the analysis relevant to the examples introduced in Section 1.

[3] In broadband markets and in energy markets, such as electricity and gas markets, the quantity may be deemed to be the number of customers served by downstream firms.

a new upstream facility's ownership is shared by firms 1 and 2, this ownership is called *joint ownership*. Under joint ownership, the two firms cooperatively determine the level of demand-enhancing investment θ, and each must incur a portion of the investment cost $F(\theta)$ based on a cost-sharing rule. Any cost-sharing rule should satisfy the following equation.

$$s_1 + s_2 = 1, \tag{1}$$

where s_i $(i = 1, 2)$ is the share of the investment cost that firm $i\,(= 1,\ 2)$ incurs. There are several candidates for the cost-sharing rules. In our analysis, we use *the unanimity sharing rule*. The unanimity sharing rule is defined as the rule under which no firm disagrees regarding its share of investment cost and associated investment level. In other words, under the unanimity sharing rule, each firm's profit is maximized by that investment level with its share of the investment cost. As shown in Section 4, there are two reasons that we use this rule: the first is that it achieves the joint-profit maximizing investment; the second is that the cost share reflects each firm's marginal benefit generated from demand-enhancing investment. The details of the unanimity sharing rule used in this paper and the procedure for its derivation are explained in Section 4 below.

Moreover, each firm in our model has an opportunity to choose its downstream production technology. We suppose that there are two alternative production technologies, called *new* and *old*. The old technology is the status quo technology, which is represented by a constant marginal cost c^o. Conversely, we represent the new technology as a lower marginal cost $c\,(< c^o)$ that is adopted by incurring an investment cost f. We assume that a firm's technology choice from these two alternatives is made non-cooperatively.

Then, under the joint ownership of a new upstream facility, the profit of firm i depends on its technology choice downstream. When firm i chooses the old technology (hereafter called *the old-technology firm*), its profit is represented by

$$\pi_i = (p - c^o)\, q_i - s_i F(\theta)\,.$$

When firm i chooses the new technology (hereafter called *the new-technology firm*), its profit is represented by

$$\pi_i = (p - c)\, q_i - s_i F(\theta) - f.$$

We examine two scenarios. The first involves *the strategic technology choice.* In this scenario, we analyze the situation in which a firm can use its downstream technology choice as a strategic device by anticipating the occurrence of joint ownership for cooperative upstream investment. Hence, in the first stage, both firms 1 and 2 choose their downstream production technologies non-cooperatively by anticipating the opportunity to have joint ownership with the associated investment determined in the second stage, and the downstream competition determined in the third stage. Then, in the second stage, each firm determines whether it cooperates in joint ownership of a new upstream facility. If both firms agree to cooperate, the new upstream facility is owned by them and they cooperatively determine the investment level θ and each firm's share of investment cost, s_1 and s_2. By contrast, if at least one of the firms does not agree to cooperate, each firm should invest in the facility alone. This situation is called *a non-cooperative investment regime.* We should recognize that, when examining a non-cooperative investment regime, the degree of spillovers generated from the two firms' investment affects each firm's incentive to invest in an upstream facility. In this paper, we restrict our focus to a *full-spillover case.* In the full-spillover case, the level of investment by a firm fully benefits another firm's demand enhancement. The reason for the adoption of the full-spillover case is that it is instructive and useful when we compare the investment level under a non-cooperative investment regime with joint ownership and with the social optimum as well.[4] Then, in the third stage, firms 1 and 2 compete in a Cournot competition.

Conversely, the second scenario is called *strategic cooperation.* In this scenario, in the first stage, each of the two firms determines whether it will cooperate in joint ownership by

[4] If we examine the opposite, i.e., the no-spillover case, firm heterogeneity in the social optimum totally disappears, because our model has a symmetric structure and the optimal level of investment must be derived for each firm in the social optimum.

anticipating the opportunity to choose its own downstream technology. Here, we assume that each firm's proportional cost and the level of upstream investment are determined based on the firm's production technology, which is chosen in the second stage. In the second stage, both firms 1 and 2 choose their downstream production technologies non-cooperatively. Firms 1 and 2 compete in a Cournot competition in the third stage.

We define $v \equiv V - c^o$ and $\Delta c \equiv c^o - c$. Using these definitions, we make the following assumptions for analytical simplicity.

Assumptions

$$\text{(i) } v > \Delta c \text{ and (ii) } k > 2.$$

Assumption (i) implies that the basic willingness to pay is sufficiently large that the old-technology firms can be active in a market. Assumption (ii) allows us to restrict our focus to the interior solutions of firms' profit-maximizing investments in the following analysis.

3 Three Benchmarks: Two Separate Decisions and the Second-Best Optimum

In this section, we prepare two benchmarks in which the decision to cooperate for investment and firms' non-cooperative technology choice do not interact. In other words, both firms have only one decision in each benchmark: one is the case in which they make a decision on cooperation for investment without an opportunity to upgrade their production technologies, while the other is the case in which each firm decides whether it upgrades its technology or not without an opportunity to invest in a new upstream facility. As a third benchmark, moreover, we characterize the second-best optimum in our model.

Suppose that the decision regarding investment cooperation is made by assuming that each firm's technology is old and that Cournot competition occurs in the last stage.

First, we characterize the upstream investment in a non-cooperative investment regime.

In the third stage, firms 1 and 2 each chooses a quantity that maximizes its profit, given an investment level θ. We then obtain the following equilibrium production for firm i.

$$q_i^* = \frac{1}{3}\left((V + \theta_1 + \theta_2) - 2c_i + c_j\right), \quad i, j = 1, 2, \, i \neq j, \tag{2}$$

where $c_i \in \{c^o, \ c\}$. When both firms' production technologies are old (i.e., $c_1 = c_2 = c^o$), (2) becomes $q_i^* = (v + \theta_1 + \theta_2)/3$. Then, we obtain a firm's profit-maximizing investment and the associated profit in a non-cooperative investment regime as follows:

$$\theta_i^{*noo} = \frac{2v}{9k-4} \left(= \theta_j^{*noo}\right) \text{ and } \pi_i^{*noo} = \frac{k(9k-2)v^2}{(9k-4)^2} - \widetilde{F}, \ \ i = 1, \ 2. \tag{3}$$

Next, we characterize the investment level under joint ownership for cooperative investment, which is called *a cooperative investment regime*. In a cooperative investment regime, the two firms cooperatively determine the level of demand-enhancing investment, and each must incur investment costs based on a cost-sharing rule. As discussed in Section 2 above, we use *the unanimity sharing rule*, which is defined as the rule under which no firm disagrees on its share of investment cost and the associated investment level. In other words, under the unanimity sharing rule, each firm's profit is maximized by that investment level associated with its proportion of the investment costs. We defer the characterization of the unanimity sharing rule with different production technologies to the next section. However, it is easy to verify that, when both firms' production technologies are old ($c_1 = c_2 = c^o$), the unanimity sharing rule in this benchmark is characterized as

$$s_1^{oo} = s_2^{oo} = \frac{1}{2} \text{ and } \theta^{*oo} = \frac{4v}{9k-4}.$$

Then, the associated profit under the cooperative investment regime is

$$\pi_i^{*oo} = \frac{1}{9}\left(v + \theta^{*oo}\right)^2 - \frac{1}{2}\left(\frac{1}{2}k\left(\theta^{*oo}\right)^2 + \widetilde{F}\right). \tag{4}$$

We now examine each firm's decision regarding whether they agree to cooperate for investment under joint ownership when each firm's technology is old. Comparing π_i^{*noo} and π_i^{*oo}, we verify that there is a threshold level of a fixed cost $\widetilde{F}^{oo}$ above (below) which each firm agrees (disagrees) to cooperate for investment with $c_1 = c_2 = c^o$.

Next, we examine the second benchmark in which each firm decides whether it adopts a new technology or not without an opportunity to invest in a new upstream facility. In fact, the analysis regarding firm's technology choice is the same as in Mills and Smith (1996), as is shown below.

The equilibrium Cournot quantities and the associated profits depend on the state of firms' production technologies determined in the first stage. In particular, when two firms choose a new technology, they are

$$\widehat{q}_i^{cc} = \frac{1}{3}\left(v + \Delta c\right), \; \widehat{\pi}_i^{cc} = \left(\widehat{q}_i^{cc}\right)^2 - f.$$

When two firms choose an old technology,

$$\widehat{q}_i^{oo} = \frac{1}{3}v, \; \widehat{\pi}_i^{oo} = \left(\widehat{q}_i^{oo}\right)^2.$$

When firm i chooses an old technology, and the rival firm chooses a new technology,

$$\widehat{q}_i^{oc} = \frac{1}{3}\left(v - \Delta c\right), \; \widehat{\pi}_i^{oc} = \left(\widehat{q}_i^{cc}\right)^2.$$

When firm i chooses a new technology, and the rival firm chooses an old technology,

$$\widehat{q}_i^{co} = \frac{1}{3}\left(v + 2\Delta c\right), \; \widehat{\pi}_i^{co} = \left(\widehat{q}_i^{co}\right)^2 - f.$$

Then, we examine a technology-choice game in the first stage. Representing the number of firms that adopt a new technology by l, firm heterogeneity (i.e., $l^* = 1$) occurs if and only if $\widehat{\pi}_i^{oc} \geq \widehat{\pi}_i^{cc}$ and $\widehat{\pi}_i^{co} \geq \widehat{\pi}_i^{oo}$. $\widehat{\pi}_i^{oc} \geq \widehat{\pi}_i^{cc}$ is rewritten as $f \geq f^{\underline{M}}$ where $f^{\underline{M}} \equiv (4/9)\, v\Delta c$, while $\widehat{\pi}_i^{co} \geq \widehat{\pi}_i^{oo}$ is rewritten as $f \leq f^{\overline{M}}$ where $f^{\overline{M}} \equiv (4/9)\,(v + \Delta c)\,\Delta c$. Hence, $l^* = 1$ occurs if and only if $f^{\underline{M}} \leq f \leq f^{\overline{M}}$. Moreover, we obtain that $l^* = 2$ occurs if and only if $f < f^{\underline{M}}$. Similarly, $l^* = 0$ occurs if and only if $f > f^{\overline{M}}$.

The equilibria in the two separate cases are shown in Figure 1.

(Insert Figure 1 around here.)

In the first benchmark, cooperative investment occurs when the fixed facility cost $\widetilde{F}$ is larger than $\widetilde{F}^{oo}$. In other words, as the fixed facility cost is large, the benefit of cost sharing in a cooperative investment regime overcomes the benefit of full spillovers in a non-cooperative investment regime. In the second benchmark, firm heterogeneity (i.e., $l^* = 1$) occurs in the range between $f^{\underline{M}}$ and $f^{\overline{M}}$.

We can also characterize the second-best optimum in our model. Here, we define *the second-best optimum* as that situation in which the level of upstream investment and the number of new-technology firms are chosen from a welfare perspective, assuming Cournot competition between firms 1 and 2.[5]

Social welfare is defined by

$$SW \equiv CS\left(q_1^*\left(\theta\right), q_2^*\left(\theta\right)\right) + \sum\nolimits_{i=1}^{2} \pi_i^*\left(q_1^*\left(\theta\right), q_2^*\left(\theta\right)\right) - \left(\frac{1}{2}k\theta^2 + \widetilde{F}\right),$$

where $CS\left(.\right)$ represents consumer surplus, and $\pi_i^*\left(.\right)$ is firm i's profit under Cournot competition. Using this social welfare function, we can derive the investment and the number of new-technology firms in the second best optimum. Refer to Appendix A for the derivation.

The range of firm heterogeneity in the second-best optimum is also depicted in Figure 1 with the thresholds of the dotted lines at $f^{\overline{H}}$ and $f^{\underline{H}}$. Hence, we ensure that both firms

[5] We derive the second-best investment level under the assumption of a full spillover of a demand-enhancing effect.

have less incentive to adopt new technology in the second benchmark than they do in the second best. In addition, the investment level for an upstream facility in the first benchmark is smaller than those associated with the number of new-technology firms in the second best optimum.

4 Strategic Technology Choice

We now examine those cases in which the firms' two types of investment decisions interact. In this section, we examine the strategic technology choice. In this case, firms non-cooperatively choose their production technologies in the first stage, anticipating the opportunity to cooperate for investment. Then, in the second stage, each firm makes a decision regarding whether it agrees to cooperate for investment, given firms' production technologies.

4.1 Equilibria in the choice of investment regimes

First, we examine the subgames in the second stage. Given firms' technology choices, we must compare two investment regimes in four possible states of production technologies chosen by two firms. In subsections 4.1.1 and 4.1.2, we prepare firms' profits and the associated investment levels for each of the possible states of production technologies in each of the two investment regimes. In subsection 4.1.3, we then characterize firms' incentives to cooperate for investment.

4.1.1 Non-cooperative investment regime

In a non-cooperative investment regime, the equilibrium profits and the associated investment levels – taking firms' downstream technologies as given – are derived as follows.

$$
\begin{aligned}
\pi_i^{*ncc} &= \frac{k\left(9k-2\right)}{\left(9k-4\right)^2}\left(v+\Delta c\right)^2 - f - \widetilde{F},\ \theta_i^{*ncc} = \frac{2\left(v+\Delta c\right)}{9k-4}\left(=\theta_j^{*ncc}\right), \\
\pi_i^{*noo} &= \frac{k\left(9k-2\right)v^2}{\left(9k-4\right)^2} - \widetilde{F},\ \theta_i^{*noo} = \frac{2v}{9k-4}\left(=\theta_j^{*noo}\right), \\
\pi_i^{*noc} &= \frac{\left(9k-2\right)\left(3kv-\left(3k-2\right)\Delta c\right)^2}{9k\left(9k-4\right)^2} - \widetilde{F},\ \theta_i^{*noc} = \frac{2\left(3kv-\left(3k-2\right)\Delta c\right)}{3k\left(9k-4\right)}, \\
\pi_i^{*nco} &= \frac{\left(9k-2\right)\left(3kv+2\left(3k-1\right)\Delta c\right)^2}{9k\left(9k-4\right)^2} - f - \widetilde{F},\ \theta_i^{*nco} = \frac{2\left(3kv+2\left(3k-1\right)\Delta c\right)}{3k\left(9k-4\right)}.
\end{aligned}
$$

4.1.2 Cooperative investment regime

To derive the equilibrium profits and the investment levels in a cooperative investment regime, we first characterize the unanimity sharing rule with different downstream technologies under the joint ownership of an upstream facility.

The unanimity sharing rules Under the unanimity sharing rule, each firm's profit is maximized by the investment with the associated cost share that the firm must incur. The following lemma characterizes the unanimity sharing rule and the investment level in our model specification. Moreover, in the lemma, we ensure that the unanimity sharing rule achieves the investment that maximizes the joint profits of all firms; $\theta^* = \arg\max\ \Pi \equiv \sum_{i=1}^{2} \pi_i$.

Lemma 1 *In the specification of our model, the unanimity sharing rule and the associated investment level are characterized as follows.*

$$
\begin{aligned}
s_i^* &= \frac{3\left(V-2c_i+c_j\right)k-2\left(c_j-c_i\right)}{3k\left(2V-\left(c_1+c_2\right)\right)}, \qquad i=1,2,\ i\neq j, \\
\theta^* &= \frac{2\left(2V-\left(c_1+c_2\right)\right)}{9k-4}.
\end{aligned}
$$

Then, the unanimity sharing rule achieves the investment that maximizes the joint profits of all firms.

Proof. See Appendix B. ■

There is an item that should be noted regarding Lemma 1. A new-technology firm, which has a lower marginal cost than an old-technology firm, must incur a larger proportion of the upstream investment cost than an old-technology firm. This finding can be verified by

$$\begin{aligned} & s_1^* - s_2^* \\ = \; & \frac{(c_2 - c_1)(9k - 4)}{3k(2V - (c_1 + c_2))}. \end{aligned}$$

Therefore, $s_1^* \geq (<)\, s_2^*$ if and only if $c_2 \geq (<)\, c_1$, because the marginal benefit generated by the upstream investment to a firm with a low marginal cost (a new-technology firm) is greater than that to a firm with a high marginal cost (an old-technology firm). Hence, a firm that obtains a higher marginal benefit should pay a larger share of the investment cost than a firm reaping a lower benefit. In this respect, the unanimity sharing rule is reminiscent of the Lindahl mechanism in the context of public-goods provision.

The finding that a new-technology firm incurs more cost than an old-technology firm implies that *the cost-sharing effect* generated in a cooperative investment regime differs between firms when their production technologies are different. In particular, an old-technology firm can enjoy more benefits from cost sharing than a new-technology firm, whereas the cost-sharing effect may damage a new-technology firm. Furthermore, we can verify that, as k becomes small, $|\Delta s^*| \equiv |s_1^* - s_2^*|$ becomes large if $s_1^* \neq s_2^*$. This finding indicates that an increase in investment incentives enhances the difference in the cost-sharing effect between different technology-adoption firms.

We should note that a Nash bargaining rule also derives the joint-profit maximizing investment, whereas the cost-sharing pattern under a Nash bargaining rule is different from a cost-sharing pattern under the unanimity sharing rule.[6] However, we can verify

[6] Indeed, the cost-sharing formula under a Nash bargaining rule is more complicated than that under the unanimity sharing rule.

that the qualitative result that a new-technology firm incurs more burden than an old-technology firm also holds in a Nash bargaining rule.

Profits and investments under cooperative investment Using the unanimity sharing rule under cooperative investment, the equilibrium profits and the investment levels – taking firms' downstream technologies as given – are derived as follows:

$$
\begin{aligned}
\pi_i^{*cc} &= \frac{1}{9}\left(v+\Delta c+\theta^{*cc}\right)^2 - f - \frac{1}{2}\left(\frac{1}{2}k\left(\theta^{*cc}\right)^2+\widetilde{F}\right),\ \theta^{*cc} = \frac{4\left(v+\Delta c\right)}{9k-4}, \\
\pi_i^{*oo} &= \frac{1}{9}\left(v+\theta^{*oo}\right)^2 - \frac{1}{2}\left(\frac{1}{2}k\left(\theta^{*oo}\right)^2+\widetilde{F}\right),\ \theta^{*oo} = \frac{4v}{9k-4}, \\
\pi_i^{*oc} &= \frac{1}{9}\left(v-\Delta c+\theta^{*oc}\right)^2 - s_i^{*oc}\left(\frac{1}{2}k\left(\theta^{*oc}\right)^2+\widetilde{F}\right),\ \theta^{*oc} = \frac{2\left(2v+\Delta c\right)}{9k-4}, \\
\pi_i^{co} &= \frac{1}{9}\left(v+2\Delta c+\theta^{*co}\right)^2 - f - s_i^{*co}\left(\frac{1}{2}k\left(\theta^{*co}\right)^2+\widetilde{F}\right),\ \theta^{*co} = \frac{2\left(2v+\Delta c\right)}{9k-4}\left(=\theta^{*oc}\right), \\
\text{where } s_i^{*oc} &= \frac{3kv-\left(3k-2\right)\Delta c}{3k\left(2v+\Delta c\right)} \text{ and } s_i^{*co} = \frac{3kv+2\left(3k-1\right)\Delta c}{3k\left(2v+\Delta c\right)}.
\end{aligned}
$$

4.1.3 Comparison of investment regimes

Now, we can characterize the equilibria in the second stage by comparing the profits in the two investment regimes, given the two firms' technology choices. Each firm's incentive to agree regarding the cooperation for investment is given in the following four cases.

Case (c,c)*:* When two firms choose a new technology,

$$\pi_i^{*cc} \gtrless \pi_i^{*ncc} \text{ iff } \widetilde{F} \gtrless \frac{4k\left(v+\Delta c\right)^2}{\left(9k-4\right)^2} \equiv \widetilde{F}^{cc}.$$

Case (o,o)*:* When two firms choose an old technology,

$$\pi_i^{*oo} \gtrless \pi_i^{*noo} \text{ iff } \widetilde{F} \gtrless \frac{4kv^2}{\left(9k-4\right)^2} \equiv \widetilde{F}^{oo}.$$

Case (o,c)*:* When firm i chooses an old technology, and the rival firm chooses a new technology,

$$\pi_i^{*oc} \gtrless \pi_i^{*noc} \text{ iff } \widetilde{F} \gtrless \frac{2\left(3kv - (3k-2)\Delta c\right)(2v+\Delta c)}{3(9k-4)^2} \equiv \widetilde{F}^{oc}.$$

Case (c, o)*:* When firm i chooses a new technology, and the rival firm chooses an old technology,

$$\pi_i^{*co} \gtrless \pi_i^{*nco} \text{ iff } \widetilde{F} \gtrless \frac{2\left(3kv + 2(3k-1)\Delta c\right)(2v+\Delta c)}{3(9k-4)^2} \equiv \widetilde{F}^{co}.$$

We then obtain the following lemma.

Lemma 2 *$\widetilde{F}^{oc} < \widetilde{F}^{oo} < \widetilde{F}^{cc} < \widetilde{F}^{co}$.*

Proof. The result is easily obtained by a direct comparison between any two of the four thresholds. ■ ■

According to Lemma 2, a firm's incentive to cooperate for investment depends not only on its technology choice but also on the choice of the other firm. Suppose that two firms choose the same technology. In that case, a new technology produces a weaker incentive for cooperative investment than an old technology for two reasons. First, investment based on the profit motive is greater for a new-technology firm than for an old-technology firm because of the larger profits in a new-technology firm. Second, the investment cost a firm incurs in a non-cooperative investment regime is small due to full spillovers. Therefore, when both firms adopt a new technology, they want to invest in an upstream facility non-cooperatively (i.e., they have no incentive to cooperate for investment). However, as the fixed cost $\widetilde{F}$ becomes larger, the cost-sharing effect in a cooperative investment regime dominates these factors, which means that both firms agree to cooperate for investment.

Next, suppose that one firm uses an old technology, while the other adopts a new technology. In that case, the old-technology firm has the strongest incentive to cooperate for investment in all four states, because an old-technology firm has a weak investment incentive (due to its small profits) if it invests in an upstream facility non-cooperatively. In addition, the firm can obtain substantial benefit from the cost-sharing effect, if it is in a cooperative investment regime. Hence, an old-technology firm has a strong incentive to cooperate for investment.

By contrast, a firm that adopts a new technology (while the other uses an old technology) has the weakest incentive to cooperate for investment of all four states, because a new-technology firm has a strong investment incentive due to its large profits, if it invests in an upstream facility non-cooperatively. Conversely, the cost-sharing effect works negatively in a cooperative investment regime, because it incurs a larger proportion of the investment cost than an old-technology firm. Hence, a new-technology firm has the weakest incentive to cooperate for investment.

4.2 Equilibria in technology-choice games

Using the results of firms' incentives to cooperate for investment in the second stage, we ensure that the following five cases appear based on the interval of $\widetilde{F}$.

(i) $\widetilde{F} \in \left(0,\ \widetilde{F}^{oc}\right]$, (ii) $\widetilde{F} \in \left(\widetilde{F}^{oc},\ \widetilde{F}^{oo}\right]$, (iii) $\widetilde{F} \in \left(\widetilde{F}^{oo},\ \widetilde{F}^{cc}\right]$, (iv) $\widetilde{F} \in \left(\widetilde{F}^{cc},\ \widetilde{F}^{co}\right]$, (v) $\widetilde{F} \in \left(\widetilde{F}^{co},\ \widetilde{F}^{\max}\right]$ [7]

Then, in each of the five cases (i) to (v), we have a technology-choice game in the first stage by applying the appropriate profits determined in the second stage. For example, for (i), the profits in a non-cooperative investment regime are applied to all four states in a technology-choice game in the first stage. We then characterize the equilibrium in a technology-choice game for a given level of $\left(f,\ \widetilde{F}\right)$. The procedure to derive the equilibria for all levels of $\left(f,\ \widetilde{F}\right)$ is in Appendix C. The equilibria are shown in Figure 2.

(Insert Figure 2 around here.)

[7] $\widetilde{F}^{\max}$ is defined as the level of $\widetilde{F}$ such that $\pi^{*oo}\left(\widetilde{F}^{\max}\right) = 0$.

We compare the equilibrium with the strategic technology choice and with the two separate cases in Section 3 (refer to Figures 1 and 2). We obtain several findings from the comparison.

First, a firm's incentive to adopt a new technology in a non-cooperative investment regime is greater than in the second benchmark in which firms have no opportunity to invest in an upstream facility. On the contrary, its incentive in a cooperative investment regime is weaker than in the second benchmark. Interestingly, this is the case, regardless of the fact that the investment levels for an upstream facility are the same between the two investment regimes. In fact, the region in which $l^* = 0$ in a cooperative investment regime is larger than that of a non-cooperative investment regime is shown in Figure 2. This is due to a cost-sharing effect of cooperation for investment. In particular, the share of investment cost increases if a firm adopts a new technology while the other continues to use an old technology. Suppose that f is large, such that two firms use an old technology. If one firm deviates to a new technology, that firm must owe a larger proportion of the investment cost under cooperative investment. In other words, the cost-sharing effect under cooperative investment works negatively for a new technology firm. Hence, the firm has less incentive to adopt a new technology in a cooperative investment regime than it does in a non-cooperative investment regime.

Second, we ensure that the region in which non-cooperative investment occurs is enlarged for the strategic technology choice compared with the first benchmark in which firms have no opportunity to upgrade their production technologies. In particular, for $\widetilde{F} \in \left(\widetilde{F}^{oo}, \ \widetilde{F}^{cc}\right]$, the region of a cooperative investment regime is curtailed for $f \leq f^{\overline{N}}$, which originates from a firm's opportunity to adopt a new technology. For example, when $f \in \left[f^{\underline{N}}, \ f^{\overline{N}}\right]$, only one firm adopts the new technology in a non-cooperative investment regime, whereas no firm has an incentive to adopt the new technology in a cooperative investment regime because of the negative cost-sharing effect in the latter regime, as explained above. Conversely, if a firm invests in an upstream facility non-cooperatively, it can enjoy larger profits due to a new technology because the other firm uses an old technology. Therefore, a non-cooperative investment regime emerges as f becomes small. Moreover, when $f \leq \underline{f^N}$, both firms have an incentive to adopt a new technology in a non-cooperative investment regime. Then, the two firms have the benefit of a large demand-enhancing effect generated from large investments with full spillovers, which dominates the disadvantage of fierce retail competition. Therefore, a non-cooperative investment regime prevails in the range of f.

Third, for $\widetilde{F} \in \left(\widetilde{F}^{cc},\ \widetilde{F}^{co}\right]$, firm heterogeneity does not appear in a cooperative investment regime, which is understandable due to the difference in the proportion of investment cost with firm heterogeneity and which makes it difficult for firms to agree on investment cooperation (refer to the difference between $\widetilde{F}^{oc}$ and $\widetilde{F}^{co}$ in Figure 2). Fourth, we observe that the boundaries of firm heterogeneity depend not only on the fixed cost of a new technology, f, but also on the fixed cost of upstream investment, $\widetilde{F}$, in a cooperative investment regime, which is also due to a change in the cost burden of the upstream investment that is related to a firm's decision regarding technology choice.

We summarize three of these findings as a proposition.

Proposition 1 *For the strategic technology choice, we have the following:*

(i) Cooperative investment deters firms from adopting a new technology.

(ii) A cooperative investment regime is less likely to occur than the case in which firms have no opportunity to upgrade its production technology.

(iii) Firm heterogeneity may not occur under cooperative investment.

5 Strategic Cooperation

Next, we examine the second scenario, i.e., when firms decide whether to cooperate for investment in anticipation of each firm's choice of production technology. This scenario is for strategic cooperation. As stated in Section 2 above, each firm's proportional cost and the level of upstream investment are determined based on the firm's production technology, which is chosen in the second stage. Anticipating its rival firm's technology choice and its own technology, a firm decides whether it agrees to cooperate for investment in the first stage.

Given the investment regime determined in the first stage, each firm chooses its production technology in the second stage. We then compare the profits between a cooperative investment regime and a non-cooperative investment regime in the first stage. The procedures to derive the equilibria are in Appendix D. As Figure 3 shows, the characterization of the equilibria depends on the range of $\left(f,\ \widetilde{F}\right)$.

(Insert Figure 3 around here.)

Figure 3 shows that the region of a cooperative investment regime changes dramatically based on the fixed cost for a new technology f. In particular, when f is in the range of $f \in \left[f^{\underline{N}},\ f^{\overline{N}}\right]$, cooperative investment prevalently occurs with the adoption of an old technology by both firms because of the difference in a firm's incentive to adopt a new technology between the two investment regimes. In particular, for $f \in \left[f^{\underline{N}},\ f^{\overline{N}}\right]$, only one firm adopts a new technology in a non-cooperative investment regime, whereas in a cooperative investment regime, no firm has an incentive to adopt the new technology. If one firm adopts a new technology in a cooperative investment regime, the threshold level of $\widetilde{F}$ for the agreement regarding the cooperation for investment is $(1/2)\left(\widetilde{F}^{oc} + \widetilde{F}^{co}\right)$ because it reflects the inequality of $(1/2)\left(\pi_i^{*oc} + \pi_i^{*co}\right) \gtreqless (1/2)\left(\pi_i^{*noc} + \pi_i^{*nco}\right)$. However, because $(1/2)\left[\pi_i^{*oc} + \pi_i^{*co}\right] < \pi_i^{*oo}$ for $f \in \left[f^{\underline{N}},\ f^{\overline{N}}\right]$, the threshold that reflects $(1/2)\left(\pi_i^{*noc} + \pi_i^{*nco}\right) \gtreqless \pi_i^{*oo}$ moves leftward to $(1/2)\left(\widetilde{F}^{oc} + \widetilde{F}^{co}\right)$, which indicates that a cooperative investment regime prevalently dominates a non-cooperative investment regime in this range of f. We note that the difference in the number of firms that adopt a new technology is one (i.e., $l^* = 1$ in a non-cooperative investment regime, while $l^* = 0$ in a cooperative investment regime).

By contrast, a non-cooperative investment regime with two new-technology firms prevails as f becomes slightly small to be in the range of $f \in \left[\overline{J}\left(\widetilde{F}\right),\ f^{\underline{N}}\right]$. In this range of f, two firms adopt the new technology in a non-cooperative investment regime, whereas no firm adopts it in a cooperative investment regime, indicating that the difference in the number of new-technology firms is two. Because $\pi_i^{*cc} > \pi_i^{*oo}$ and $\pi_i^{*ncc} \gtreqless \pi_i^{*cc}$ if and only if $\widetilde{F} \lesseqgtr \widetilde{F}^{cc}$, a non-cooperative investment regime appears beyond $\widetilde{F}^{cc}$. The reason for this is that the two firms have the benefit of a large demand-enhancing effect generated from large investments with full spillovers in a non-cooperative investment regime, which dominates the benefit of the cost-sharing effect in a cooperative investment regime. As f decreases to be in the range of $f \in \left[\underline{J}\left(\widetilde{F}\right),\ \overline{J}\left(\widetilde{F}\right)\right]$, a cooperative investment regime reappears prevalently, because $(1/2)\left[\pi_i^{*oc} + \pi_i^{*co}\right] > \pi_i^{*cc}$ in this range of f, such that the threshold that reflects $(1/2)\left(\pi_i^{*oc} + \pi_i^{*co}\right) \gtreqless \pi_i^{*ncc}$ moves more leftward to $\widetilde{F}^{cc}$, which reflects $\pi_i^{*cc} \gtreqless \pi_i^{*ncc}$. Notably, the difference in the number of new-technology firms again shrinks to one.

In sum, investment cooperation prevails when the difference in the number of new-technology firms is only one between the two investment regime, due to the following explanation. Suppose, for example, that only one firm adopts a new technology in a non-cooperative investment regime, while no firm adopts a new technology in a cooperative investment regime. Then, the total investment level in a non-cooperative investment regime is larger than that in a cooperative investment regime. However, due to the cost-sharing effect under joint ownership, a firm's profit, which includes a variable portion of the investment cost, can be larger in a cooperative investment regime than in a non-cooperative investment regime: this dominates the benefit of a larger demand-enhancing effect of investment with spillovers in a non-cooperative investment regime. Therefore, investment cooperation prevails for a wide range of fixed costs for investments in that situation. By contrast, when the difference in the number of new-technology firms becomes two, the benefit of the cost-sharing effect under joint ownership is overcome by the benefit of a larger demand-enhancing effect in a non-cooperative investment regime.

This finding suggests that investment cooperation might be used strategically by taking advantage of a firm's non-cooperative technology choice. In other words, the likelihood of cooperation does not depend on the magnitude of the fixed cost for investment when firms can upgrade their production technologies.

The other two findings are the same as for the strategic technology choice. A firm's incentive to adopt a new technology in a cooperative investment regime is weaker than that in a non-cooperative investment regime, regardless of the fact that the investment levels for an upstream facility are the same between the two investment regimes. In addition, the boundaries of firm heterogeneity depend not only on the fixed cost for a new technology but also on the fixed cost of the upstream investment in a cooperative investment regime, which is due to a change in the cost burden of the upstream investment that is related to a firm's decision regarding technology choice.

We summarize two of the findings above as a proposition.

Proposition 2 *For strategic cooperation, we have the following:*

(i) Cooperative investment deters firms from adopting a new technology.

(ii) The likelihood of cooperation does not depend on the magnitude of the fixed cost for investment. In particular, investment cooperation prevails when the difference in the number of new-technology firms is only one between the two investment regimes.

6 Discussion

In this paper, we have examined the relationship between the likelihood of cooperative upstream investment and each firm's non-cooperative decision regarding technology choice by building a specific model. In the model, upstream investment is assumed to have a demand-enhancing effect, whereas a firm's technology choice has a cost-reducing effect. The main results obtained from the analysis are as follows. When there is an opportunity to cooperate for investment, a firm's incentive to adopt an efficient technology becomes weak. When the adoption of an efficient technology is used as a strategic device, investment cooperation is less likely to occur than without the opportunity of the adoption. In addition, the size of the fixed cost for investment may not matter for investment cooperation when a firm has the opportunity to upgrade its technology. In particular, a firm has an incentive to cooperate for investment even if the fixed cost is small, as long as the difference in the number of firms that adopt a new technology is only one between the two investment regimes. In this section, we check the robustness of these results by discussing the specifications of the model.

First, the assumption of a demand-enhancing effect by an upstream investment is not critical to our analysis. In fact, if we assume a cost-reducing effect instead of a demand-enhancing effect generated by an upstream investment, the qualitative results do not change as long as it benefits both firms (i.e., full spillovers).

Second, we have assumed a homogeneous-goods market in our model. Product differentiation affects a firm's incentive to make an upstream investment, which also depends on the choice of investment regimes. In particular, as products become differentiated, the investment level increases in a non-cooperative investment regime, which, in turn, increases the difference in the investment level between the two investment regimes. This effect must be included in our analysis.

Third, we have used the unanimity sharing rule to determine the proportional cost and the investment level in a cooperative investment regime. Although we thus use a Nash bargaining in place of the unanimity sharing rule, the qualitative feature that an efficient firm must incur a higher share of investment than an inefficient firm does not change. Hence, our results also hold under the Nash bargaining rule.

Fourth, the number of firms and the degree of spillover affect the difference in the level of upstream investment between a non-cooperative investment regime and a cooperative regime. For example, as the degree of spillovers decreases in a non-cooperative investment regime, each firm's production and profits decrease. Thus, a cooperative investment regime is more likely to occur than it is in the case of full spillovers. However, the qualitative results continue to hold regarding the comparison between the two investment regimes and the relationship between the likelihood of cooperation and a firm's non-cooperative decision regarding the technology choice, because the finding that a firm's proportional cost depends on the firm's production technology in a cooperative investment regime is unaffected by the degree of spillovers.

7 Concluding Remarks

In this paper, we have examined the welfare implications of the relationship between the cooperative investment decision and each firm's non-cooperative choice regarding production technology by focusing on the timing of two decisions.

Thus, we have considered two scenarios. The first occurs when a firm chooses its production technology in anticipation of the opportunity to cooperate for investment (the strategic technology choice). The other occurs when firms decide whether to cooperate for investment in anticipation of each firm's choice of production technology (strategic cooperation).

We have shown that cooperation for investment deters firms' adoption of an efficient technology in each of two scenarios. This finding is explained by a cost-sharing effect in a cooperative investment regime. Since an efficient firm must incur a larger proportion of the investment cost under cooperation than an inefficient firm, a firm has only weak incentives to adopt an efficient technology.

Then, we have shown that cooperative investment is less likely to occur for the strategic technology choice than when a firm has no opportunity to upgrade its production technology. Moreover, firm heterogeneity is less likely to occur under investment cooperation. By contrast, the likelihood of investment cooperation does not depend on the magnitude of the fixed investment cost for strategic cooperation. These results indicate that one of two decisions actually relates to the other and is used as a strategic device for the other decision.

Appendix

Appendix A: The derivation of the second-best optimum

To derive the second-best optimum, we use a two-step procedure. In the first step, given the number of firms that adopt the new technology, which is denoted by l, we derive the optimum upstream investment θ^{**l} and the associated social welfare SW^{**l}. Then, in the second step, we compare SW^{**l} between the cases of $l = 0, 1,$ and 2 to obtain the second-best optimum.

In the first step, given l, we obtain the optimal investment and the associated social welfare as follows.

$$\begin{aligned}
\text{For } l &= 0,\ \theta^{**0} = \frac{8v}{9k-8} \text{ and } SW^{**0} = \frac{4kv^2}{9k-8} - \widetilde{F}. \\
\text{For } l &= 1,\ \theta^{**1} = \frac{4(2v+\Delta c)}{9k-8} \text{ and } SW^{**1} = SW^{**0} + \frac{\Delta c\,(8kv + (11k-8)\,\Delta c)}{2(9k-8)} - f - \widetilde{F}. \\
\text{For } l &= 2,\ \theta^{**2} = \frac{8(v+\Delta c)}{9k-8} \text{ and } SW^{**2} = \frac{4k(v+\Delta c)^2}{9k-8} - 2f - \widetilde{F}.
\end{aligned}$$

In the second step, the comparison of social welfare among the cases of $l = 0, 1,$ and 2 provides the characterization of the second-best optimum as follows. The second-best optimum with $l^{**} = 1$ occurs if and only if

$$f^{\underline{H}} < f < f^{\overline{H}}, \text{ where } f^{\underline{H}} \equiv \frac{\Delta c\,(8kv - (3k-8)\,\Delta c)}{2(9k-8)} \text{ and } f^{\overline{H}} \equiv \frac{\Delta c\,(8kv + (11k-8)\,\Delta c)}{2(9k-8)}. \tag{5}$$

Similarly, when $f \leq f^{\underline{H}}$, we obtain the second-best optimum with $l^{**} = 2$. Finally, when $f \geq f^{\overline{H}}$, we obtain the second-best optimum with $l^{**} = 0$.

Appendix B: proof of Lemma 1

We prove two findings stated in Lemma 1: the first is the characterization of the unanimity sharing rule with the associated investment, and the second is to show that the unanimity sharing rule achieves the investment that maximizes the joint profit of all firms. In fact, the latter finding holds regardless of the specifications of demand and the cost functions with any given number of downstream firms.[8] Hence, we show the proof in a general formulation of firm profit.

Let us denote the retail profit of a firm by $\widetilde{\pi}_i^*(\theta_i)$ excluding the shared cost for upstream investment. Under the unanimity sharing rule, given s_i, firm i finds its investment θ_i that maximizes its profits. In fact, the problem of firm i is represented by

$$\underset{\theta_i}{Max}\ \pi_i = \widetilde{\pi}_i^*(\theta_i) - s_i F(\theta_i)\,, \ \ i = 1, ...n.$$

Then, we obtain the first-order condition as follows.

$$\frac{d\widetilde{\pi}_i^*(\theta_i)}{d\theta_i} = s_i F'(\theta_i)\,, \ \ i = 1, ...n, \tag{6}$$

where $\sum_{i=1}^{n} s_i = 1$. Then, under the unanimity sharing rule, all firms must agree on the level of their investments, i.e., $\theta_1^* = \theta_2^* = ... = \theta_n^* \equiv \theta^*$, assuming s_i $(i = 1, ..., n)$. Since $F(\theta) = \widetilde{F} + f(\theta)$ with $f'(\theta) > 0$ and $f"(\theta) > 0$, the necessary and sufficient condition for $\theta_1^* = \theta_2^* = ... = \theta_n^* \equiv \theta^*$ is

$$\frac{1}{s_1}\frac{d\widetilde{\pi}_1^*}{d\theta_1} = \frac{1}{s_2}\frac{d\widetilde{\pi}_2^*}{d\theta_2} = ... = \frac{1}{s_n}\frac{d\widetilde{\pi}_n^*}{d\theta_n} \equiv Z. \tag{7}$$

[8] Furthermore, this finding holds for any type of retail competition regardless of the interdependency of markets and demand substitutability.

Summing (7) with respect to i, we obtain

$$\sum_{i=1}^{n} \frac{d\widetilde{\pi}_i^*}{d\theta_i} = Z. \tag{8}$$

Substituting (8) into (7), we obtain

$$s_i^* = \frac{\frac{d\widetilde{\pi}_i^*}{d\theta_i}}{\sum_{j=1}^{n} \frac{d\widetilde{\pi}_j^*}{d\theta_j}}, \quad i = 1, ...n. \tag{9}$$

Applying (9) to the specification of our model with $n = 2$, we obtain s_i^*, which is stated in the proposition. Moreover, substituting s_i^* into (6) with $F(\theta) = \widetilde{F} + \left(k\theta^2/2\right)$, we also have θ^*, which is also stated in the proposition.

It is also easily shown that the unanimity sharing rule achieves the investment that maximizes the joint profit of all downstream firms. In fact, substituting (9) into (6) directly yields

$$\sum_{i=1}^{n} \frac{d\widetilde{\pi}_i^*}{d\theta_i} = F'(\theta_i),$$

which is exactly the first-order condition for the joint-profit maximizing investment between all downstream firms. ■

Appendix C: The derivation of the equilibria for the strategic technology choice

As stated in the text, we have five cases (i) to (v) based on the level of $\widetilde{F}$. In each case, a technology-choice game is derived by applying the appropriate profits determined in the second stage. Table 1 describes the technology-choice games for cases (i) to (v). We examine the equilibrium in each case. Refer to Table 1 and Figure 2 to follow the procedure below.

(Insert Table 1.)

Case (i): $0 < \widetilde{F} \leq \widetilde{F}^{oc}$

In this case, each firm chooses its production technology in a non-cooperative investment regime for all states. Hence, the argument in the second benchmark applies to this case. In particular, we have a region with the thresholds $f^{\overline{N}}$ and $f^{\underline{N}}$ in which firm heterogeneity appears (i.e., only one firm adopts a new technology, $l^* = 1$). Here, $f^{\overline{N}}$ and $f^{\underline{N}}$ are given by

$$\begin{aligned} f^{\overline{N}} &\equiv \frac{4(9k-2)(3k-1)\Delta c(3kv+\Delta c)}{9k(9k-4)^2} \\ \text{and } f^{\underline{N}} &\equiv \frac{4(9k-2)(3k-1)\Delta c(3kv+(3k-1)\Delta c)}{9k(9k-4)^2}. \end{aligned}$$

Above $f^{\overline{N}}$, no firm adopts a new technology. Below $f^{\underline{N}}$, two firms adopt a new technology.

Case (ii): $\widetilde{F}^{oc} < \widetilde{F} \leq \widetilde{F}^{oo}$

In this case, a firm has an incentive to cooperate for investment when it adopts an old technology and a rival adopts a new technology. However, because the rival has no incentive to cooperate for investment, the investment cooperation does not occur, including for the state of $(c^o,\ c)$. Therefore, the characterization of the equilibria is the same as in case (i).

Case (iii): $\widetilde{F}^{oo} < \widetilde{F} \leq \widetilde{F}^{cc}$

There is a possibility to cooperate for investment when both firms adopt an old technology. Then, the equilibria with firm heterogeneity (i.e., $(c^o,\ c)$ or $(c,\ c^o)$) occur if and only if $\pi_i^{*noc} > \pi_i^{*ncc}$ and $\pi_i^{*nco} > \pi_i^{*oo}$. The inequality of $\pi_i^{*noc} > \pi_i^{*ncc}$ is rewritten as $f > f^{\underline{N}}$. Similarly, the equality of $\pi_i^{*nco} > \pi_i^{*oo}$ is rewritten as $f < \overline{R}\left(\widetilde{F}\right)$, where

$$\overline{R}\left(\widetilde{F}\right) \equiv \left(\frac{(9k-2)(3kv+2(3k-1)\Delta c)^2}{9k(9k-4)^2} - \frac{kv^2}{9k-4}\right) - \frac{1}{2}\widetilde{F}.$$

Then, we ensure that there are four regions in this case. First, when $\pi_i^{*ncc} > \pi_i^{*noc}$ and $\pi_i^{*nco} > \pi_i^{*oo}$ (i.e., when $f < f^{\underline{N}}$ and $f < \overline{R}\left(\widetilde{F}\right)$), we obtain the equilibrium with $(c,\ c)$ under a non-cooperative investment regime. Second, when $\pi_i^{*ncc} < \pi_i^{*noc}$ and $\pi_i^{*nco} < \pi_i^{*oo}$ (i.e., when $f > f^{\underline{N}}$ and $f > \overline{R}\left(\widetilde{F}\right)$), we obtain the equilibrium with $(c^o,\ c^o)$ under a cooperative investment regime. Third, when $\pi_i^{*ncc} < \pi_i^{*noc}$ and $\pi_i^{*nco} > \pi_i^{*oo}$ (i.e., when $f > f^{\underline{N}}$ and $f < \overline{R}\left(\widetilde{F}\right)$), we obtain the equilibrium with $(c,\ c^o)$ or $(c^o,\ c)$ under a non-cooperative investment regime. Fourth, when $\pi_i^{*ncc} > \pi_i^{*noc}$ and $\pi_i^{*nco} < \pi_i^{*oo}$ (i.e., when $f < f^{\underline{N}}$ and $f > \overline{R}\left(\widetilde{F}\right)$), there are multiple equilibria[9]: the equilibrium with $(c,\ c)$ under a non-cooperative investment regime and the equilibrium with $(c^o,\ c^o)$ under a cooperative investment regime.

Case (iv): $\widetilde{F}^{cc} < \widetilde{F} \leq \widetilde{F}^{co}$

There are two states in which cooperation for investment occurs: the first is the state in which two firms adopt a new technology, while the second is the state in which two firms adopt an old technology. Then, the equilibria with firm heterogeneity (i.e., $(c^o,\ c)$ or $(c,\ c^o)$) occur if and only if $\pi_i^{*nco} > \pi_i^{*oo}$ and $\pi_i^{*noc} > \pi_i^{*cc}$. The equality of $\pi_i^{*nco} > \pi_i^{*oo}$ is rewritten as $f < \overline{R}\left(\widetilde{F}\right)$, while the inequality of $\pi_i^{*noc} > \pi_i^{*cc}$ is rewritten as $f > \underline{R}\left(\widetilde{F}\right)$, where

$$\underline{R}\left(\widetilde{F}\right) \equiv \left(\frac{k\left(v+\Delta c\right)^2}{9k-4} - \frac{\left(9k-2\right)\left(3kv-\left(3k-2\right)\Delta c\right)^2}{9k\left(9k-4\right)^2} -\right) + \frac{1}{2}\widetilde{F}.$$

Here, we note that $f = \underline{R}\left(\widetilde{F}\right)$ is the straight line that includes two points of $\left(\underline{J}\left(\widetilde{F}^{oc}\right),\ \widetilde{F}^{oc}\right)$ and $\left(f^{\underline{N}},\ \widetilde{F}^{cc}\right)$ in Figure 2, where

$$\underline{J}\left(\widetilde{F}\right) \equiv \frac{\Delta c\left(4kv+\Delta c\right)}{9k-4} - \left(\frac{\Delta c\left(v+\Delta c\right)}{3\left(9k-4\right)} + \frac{\Delta c\left(9k-4\right)}{6k\left(2v+\Delta c\right)}\widetilde{F}\right).$$

In other words, $\underline{J}\left(\widetilde{F}\right)$ is defined as the level of f such that $\pi_i^{*cc} = \pi_i^{*oc}$. Then, we ensure that there is no region in which $f < \overline{R}\left(\widetilde{F}\right)$ and $f > \underline{R}\left(\widetilde{F}\right)$, which means that there are

[9] We restrict our focus to pure-strategy equilibria.

no equilibria with firm heterogeneity. Then, we obtain three kinds of equilibria, depending on the level of $\left(f,\ \widetilde{F}\right)$. When $\pi_i^{*noc} > \pi_i^{*cc}$ and $\pi_i^{*nco} < \pi_i^{*oo}$ (i.e., when $f > \underline{R}\left(\widetilde{F}\right)$ and $f > \overline{R}\left(\widetilde{F}\right)$), we obtain the equilibrium with $(c^o,\ c^o)$ under a cooperative investment regime. When $\pi_i^{*noc} < \pi_i^{*cc}$ and $\pi_i^{*nco} < \pi_i^{*oo}$ (i.e., when $f < \underline{R}\left(\widetilde{F}\right)$ and $f > \overline{R}\left(\widetilde{F}\right)$), we obtain the equilibrium with $(c^o,\ c^o)$ or $(c,\ c)$ under a cooperative investment regime. When $\pi_i^{*noc} < \pi_i^{*cc}$ and $\pi_i^{*nco} > \pi_i^{*oo}$ (i.e., when $f < \underline{R}\left(\widetilde{F}\right)$ and $f < \overline{R}\left(\widetilde{F}\right)$), we obtain the equilibrium with $(c,\ c)$ under a cooperative investment regime.

Case (v): $\widetilde{F}^{co} < \widetilde{F} \leq \widetilde{F}^{\max}$

In this case, investment cooperation occurs in all states of the technology-choice game. Then, we ensure that the equilibria with firm heterogeneity (i.e., $(c^o,\ c)$ or $(c,\ c^o)$) occur if and only if $\pi_i^{*oc} > \pi_i^{*cc}$ and $\pi_i^{*co} > \pi_i^{*oo}$. The equality of $\pi_i^{*oc} > \pi_i^{*cc}$ is rewritten as $f < \underline{J}\left(\widetilde{F}\right)$, which is defined in Case (iv). In addition, the inequality of $\pi_i^{*co} > \pi_i^{*oo}$ is rewritten as $f > \overline{J}\left(\widetilde{F}\right)$, where

$$\overline{J}\left(\widetilde{F}\right) \equiv \frac{\Delta c\left(4kv + (4k-1)\,\Delta c\right)}{9k-4} - \left(\frac{\Delta c\,(v+\Delta c)}{3\,(9k-4)} + \frac{\Delta c\,(9k-4)}{6k\,(2v+\Delta c)}\widetilde{F}\right).$$

Furthermore, when $\pi_i^{*cc} > \pi_i^{*oc}$ and $\pi_i^{*co} > \pi_i^{*oo}$ (i.e., when $f < \underline{J}\left(\widetilde{F}\right)$ and $f < \overline{J}\left(\widetilde{F}\right)$), we obtain the equilibrium with $(c,\ c)$ under a cooperative investment regime. By contrast, when $\pi_i^{*cc} < \pi_i^{*oc}$ and $\pi_i^{*co} < \pi_i^{*oo}$ (i.e., when $f > \underline{J}\left(\widetilde{F}\right)$ and $f > \overline{J}\left(\widetilde{F}\right)$), we obtain the equilibrium with $(c^o,\ c^o)$ under a cooperative investment regime.

All the cases from (i) to (v) are shown in Figure 2.

Appendix D: The derivation of the equilibria for strategic cooperation

In this scenario, each firm chooses its production technology in the second stage, assuming the investment regime is provided. From the discussion in Section 3, we observe that, given a non-cooperative investment regime, the equilibria with firm heterogeneity occurs if and only if a fixed cost f is in the range of $\left[f^{\overline{N}},\ f^{\underline{N}}\right]$. However, using the argument of Case (v) in Appendix C, we obtain that, given a cooperative investment regime, the equilibria with firm heterogeneity occurs if and only if a fixed cost f is in the range of $\left[\underline{J}\left(\widetilde{F}\right),\ \overline{J}\left(\widetilde{F}\right)\right]$. Then, in the first stage, for any given pair of $\left(f,\ \widetilde{F}\right)$, we must compare the profits between the two investment regimes.

It is easy to check that at $\widetilde{F}=0$, $\underline{J}(0)<\overline{J}(0)<f^{\underline{N}}<f^{\overline{N}}$ under Assumptions (i) and (ii). Hence, the following five cases should be examined based on the level of f. Refer to Figure 3 to verify the following argument.

(i') $f\in\left(0,\ \underline{J}\left(\widetilde{F}\right)\right]$, (ii') $f\in\left(\underline{J}\left(\widetilde{F}\right),\ \overline{J}\left(\widetilde{F}\right)\right]$, (iii') $f\in\left(\overline{J}\left(\widetilde{F}\right),\ f^{\underline{N}}\right]$, (iv') $f\in\left(\ f^{\underline{N}},\ f^{\overline{N}}\right]$, (v') $f\in\left(f^{\overline{N}},\ +\infty\right]$

Case (i'): $f\in\left(0,\ \underline{J}\left(\widetilde{F}\right)\right]$

In this case, irrespective of the investment regimes, two firms choose a new technology in the second stage. Therefore, using the argument in Section 4, we obtain that cooperation for investment occurs if and only if $\widetilde{F}\leq\widetilde{F}^{cc}$.

Case (ii'): $f\in\left(\underline{J}\left(\widetilde{F}\right),\ \overline{J}\left(\widetilde{F}\right)\right]$

When a non-cooperative investment regime occurs in the first stage, two firms choose a new technology. Conversely, when a cooperative investment regime occurs, we have the equilibrium with firm heterogeneity (i.e., $(c^o,\ c)$ or $(c,\ c^o)$). Here, we assume that, in the equilibrium with firm heterogeneity, each firm obtains the average of π_i^{*co} and π_i^{*oc}. Hence, a cooperative investment occurs if and only if $\pi_i^{*ncc}\leq(1/2)\left(\pi_i^{*co}+\pi_i^{*oc}\right)$.

Case (iii'): $f\in\left(\overline{J}\left(\widetilde{F}\right),\ f^{\underline{N}}\right]$

When a non-cooperative investment regime occurs in the first stage, two firms choose a new technology. Conversely, when a cooperative investment regime occurs, two firms choose an old technology. Hence, a cooperative investment occurs if and only if $\pi_i^{*ncc}\leq\pi_i^{*oo}$.

Case (iv'): $f\in\left(\ f^{\underline{N}},\ f^{\overline{N}}\right]$

When a non-cooperative investment regime occurs in the first stage, we have the equilibrium with firm heterogeneity (i.e., $(c^o,\ c)$ or $(c,\ c^o)$). Conversely, when a cooperative investment regime occurs, two firms choose an old technology. Hence, a cooperative investment occurs if and only if $(1/2)\left(\pi_i^{*nco} + \pi_i^{*noc}\right) \leq \pi_i^{*oo}$.

Case (v'): $f \in \left(f^{\overline{N}},\ +\infty\right]$

Irrespective of investment regimes, two firms choose an old technology. Therefore, we obtain that cooperation for investment occurs if and only if $\widetilde{F} \leq \widetilde{F}^{oo}$.

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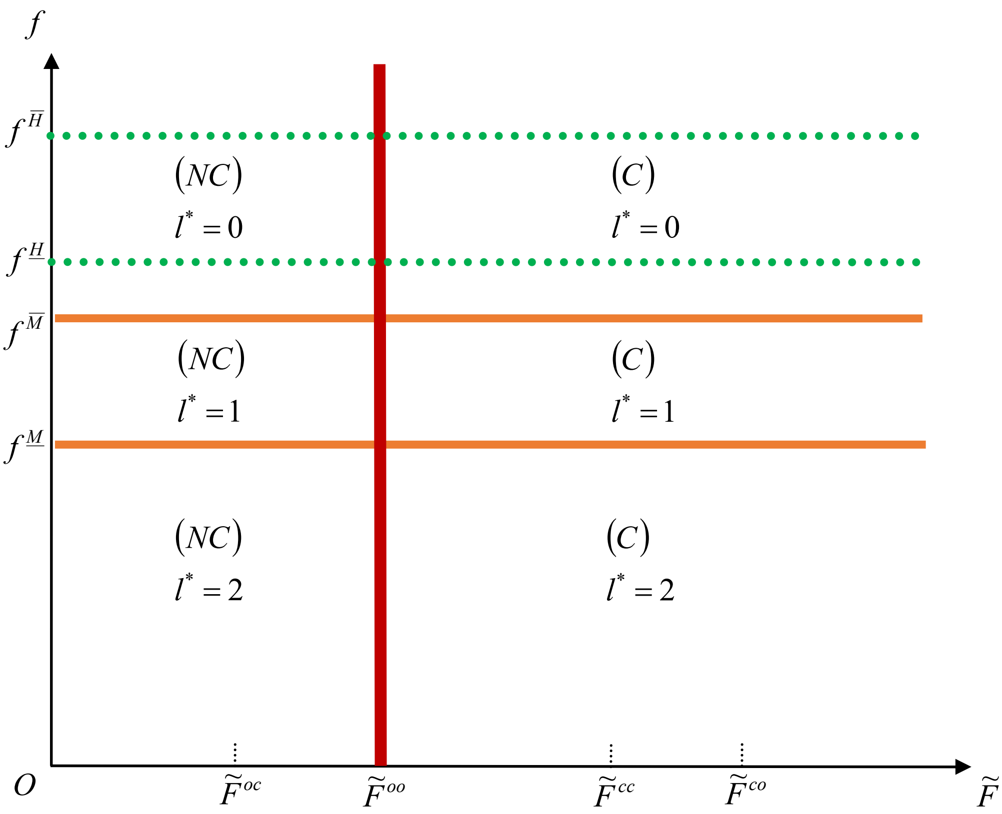

Figure 1: Two separate cases and the second-best optimum

Notes:

(NC): non-cooperative investment equilibrium, (C): cooperative investment equilibrium

$f^{\overline{M}}$ is defined by $\hat{\pi}_i^{*nco}\left(f^{\overline{M}}\right) = \hat{\pi}_i^{*noo}\left(f^{\overline{M}}\right)$.

$f^{\underline{M}}$ is defined by $\hat{\pi}_i^{*ncc}\left(f^{\underline{M}}\right) = \hat{\pi}_i^{*noc}\left(f^{\underline{M}}\right)$.

$f^{\overline{H}}$ is defined by $SW^{**1}\left(f^{\overline{H}}\right) = SW^{**0}\left(f^{\overline{H}}\right)$.

$f^{\underline{H}}$ is defined by $SW^{**2}\left(f^{\underline{H}}\right) = SW^{**1}\left(f^{\underline{H}}\right)$.

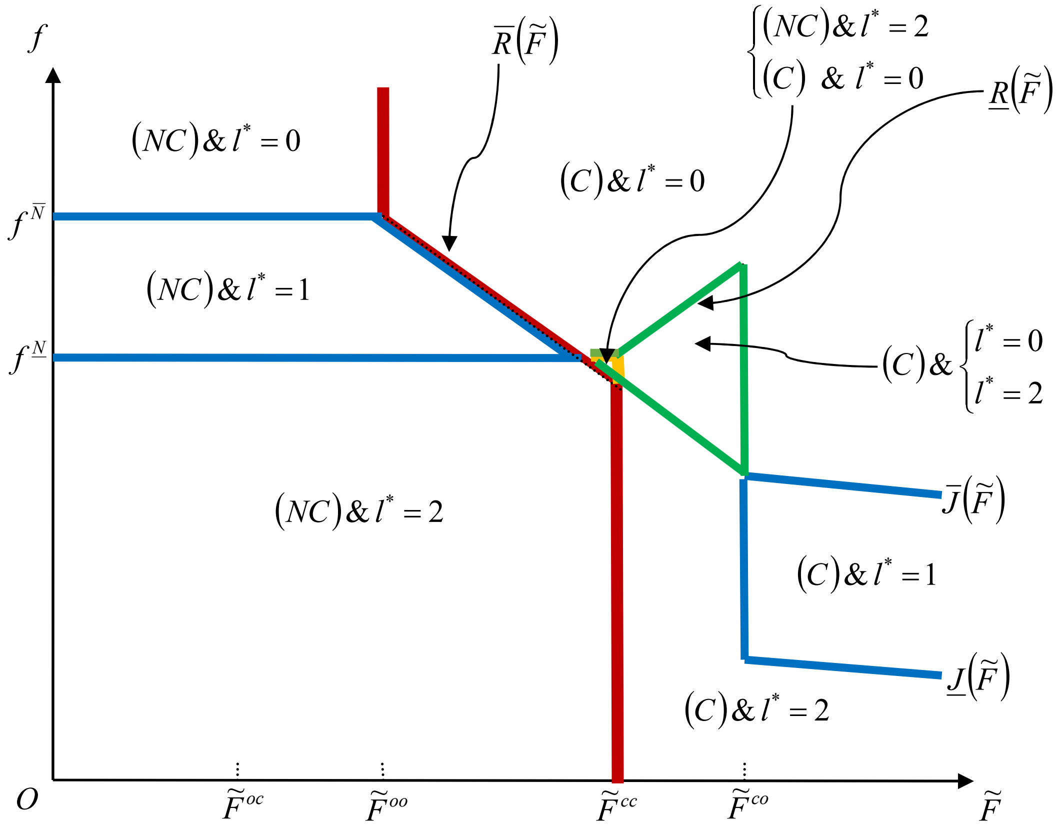

Figure 2: The Strategic Technology Choice

Notes:

(NC): non-cooperative investment equilibrium, (C): cooperative investment equilibrium

$f^{\overline{N}}$ is defined by $\pi_i^{*nco}(f^{\overline{N}},\tilde{F})=\pi_i^{*noo}(f^{\overline{N}},\tilde{F})$ for any $\tilde{F}$.

$f^{\underline{N}}$ is defined by $\pi_i^{*ncc}(f^{\underline{N}},\tilde{F})=\pi_i^{*noc}(f^{\underline{N}},\tilde{F})$ for any $\tilde{F}$.

$\overline{R}(\tilde{F})$ is defined by $\pi_i^{*nco}(\overline{R}(\tilde{F}),\tilde{F})=\pi_i^{*oo}(\overline{R}(\tilde{F}),\tilde{F})$ for $\tilde{F}\in[\tilde{F}^{oo},\tilde{F}^{co}]$.

$\underline{R}(\tilde{F})$ is defined by $\pi_i^{*noc}(\underline{R}(\tilde{F}),\tilde{F})=\pi_i^{*cc}(\underline{R}(\tilde{F}),\tilde{F})$ for any $\tilde{F}\in[\tilde{F}^{cc},\tilde{F}^{co}]$.

$\overline{J}(\tilde{F})$ is defined by $\pi_i^{*oo}(\overline{J}(\tilde{F}),\tilde{F})=\pi_i^{*co}(\overline{J}(\tilde{F}),\tilde{F})$ for any $\tilde{F}\geq\tilde{F}^{co}$.

$\underline{J}(\tilde{F})$ is defined by $\pi_i^{*cc}(\underline{J}(\tilde{F}),\tilde{F})=\pi_i^{*oc}(\underline{R}(\tilde{F}),\tilde{F})$ for any $\tilde{F}\geq\tilde{F}^{co}$.

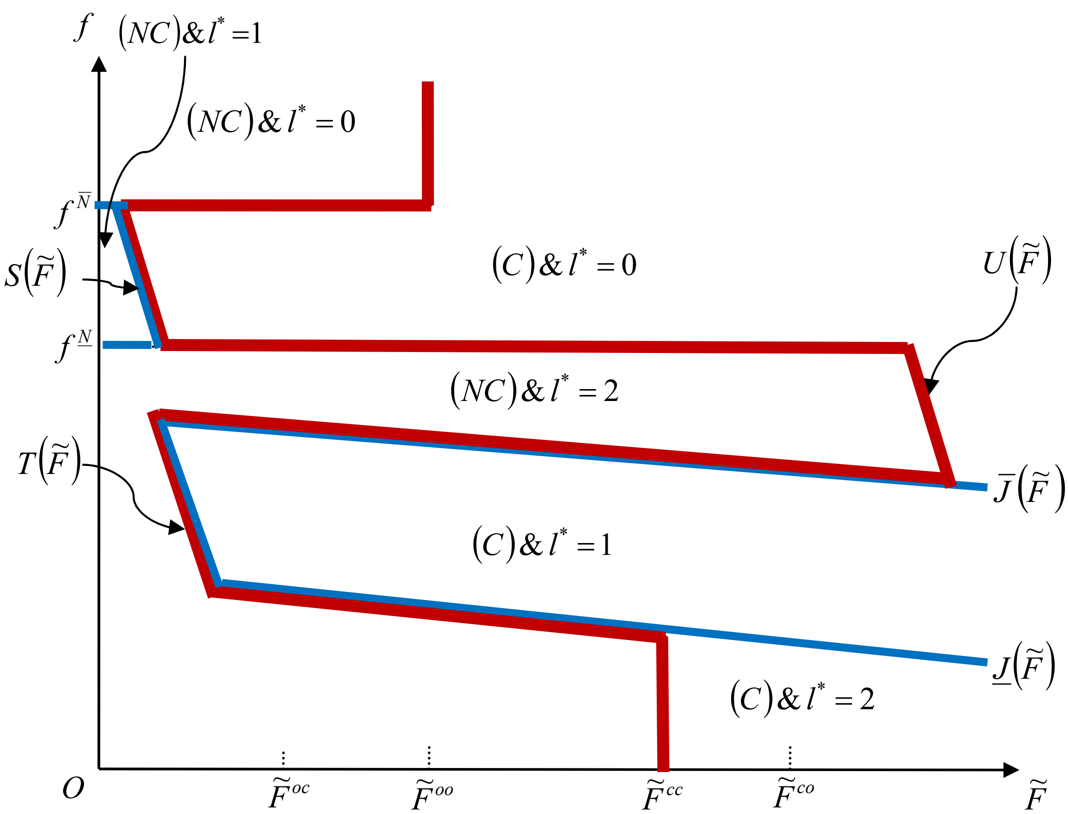

Figure 3: Strategic Cooperation

Notes:

(NC): non-cooperative investment equilibrium, (C): cooperative investment equilibrium

$f^{\bar{N}}$ is defined by $\pi_i^{*nco}\left(f^{\bar{N}},\tilde{F}\right)=\pi_i^{*noo}\left(f^{\bar{N}},\tilde{F}\right)$ for any $\tilde{F}$.

$f^{\underline{N}}$ is defined by $\pi_i^{*ncc}\left(f^{\underline{N}},\tilde{F}\right)=\pi_i^{*noc}\left(f^{\underline{N}},\tilde{F}\right)$ for any $\tilde{F}$.

$\bar{J}(\tilde{F})$ is defined by $\pi_i^{*oo}\left(\bar{J}(\tilde{F}),\tilde{F}\right)=\pi_i^{*co}\left(\bar{J}(\tilde{F}),\tilde{F}\right)$ for an appropriate range of $\tilde{F}$.

$\underline{J}(\tilde{F})$ is defined by $\pi_i^{*cc}\left(\underline{J}(\tilde{F}),\tilde{F}\right)=\pi_i^{*oc}\left(\underline{R}(\tilde{F}),\tilde{F}\right)$ for an appropriate range of $\tilde{F}$.

$S(\tilde{F})$ is defined by $\pi_i^{*oo}\left(S(\tilde{F}),\tilde{F}\right)=\frac{1}{2}\left[\pi_i^{*noc}\left(S(\tilde{F}),\tilde{F}\right)+\pi_i^{*nco}\left(S(\tilde{F}),\tilde{F}\right)\right]$ for an appropriate range of $\tilde{F}$.

$T(\tilde{F})$ is defined by $\pi_i^{*ncc}\left(T(\tilde{F}),\tilde{F}\right)=\frac{1}{2}\left[\pi_i^{*oc}\left(T(\tilde{F}),\tilde{F}\right)+\pi_i^{*co}\left(T(\tilde{F}),\tilde{F}\right)\right]$ for an appropriate range of $\tilde{F}$.

$U(\tilde{F})$ is defined by $\pi_i^{*ncc}\left(U(\tilde{F}),\tilde{F}\right)=\pi_i^{*oo}\left(U(\tilde{F}),\tilde{F}\right)$ for an appropriate range of $\tilde{F}$.

Firm 1 \ Firm 2	c	c^o
c	π_1^{ncc} , π_2^{ncc}	π_1^{nco} , π_2^{noc}
c^o	π_1^{noc} , π_2^{nco}	π_1^{noo} , π_2^{noo}

Case (i): $0 < \widetilde{F} \le \widetilde{F}^{oc}$

Firm 1 \ Firm 2	c	c^o
c	π_1^{ncc} , π_2^{ncc}	π_1^{nco} , $\pi_2^{oc}\left(\Rightarrow \pi_2^{noc}\right)$
c^o	$\pi_1^{oc}\left(\Rightarrow \pi_1^{noc}\right)$, π_2^{nco}	π_1^{noo} , π_2^{noo}

Case (ii): $\widetilde{F}^{oc} < \widetilde{F} \le \widetilde{F}^{oo}$

Firm 1 \ Firm 2	c	c^o
c	π_1^{ncc} , π_2^{ncc}	π_1^{nco} , $\pi_2^{oc}\left(\Rightarrow \pi_2^{noc}\right)$
c^o	$\pi_1^{oc}\left(\Rightarrow \pi_1^{noc}\right)$, π_2^{nco}	π_1^{oo} , π_2^{oo}

Case (iii): $\widetilde{F}^{oo} < \widetilde{F} \le \widetilde{F}^{cc}$

Firm 1 \ Firm 2	c	c^o
c	π_1^{cc} , π_2^{cc}	π_1^{nco} , $\pi_2^{oc}\left(\Rightarrow \pi_2^{noc}\right)$
c^o	$\pi_1^{oc}\left(\Rightarrow \pi_1^{noc}\right)$, π_2^{nco}	π_1^{oo} , π_2^{oo}

Case (iv): $\widetilde{F}^{cc} < \widetilde{F} \le \widetilde{F}^{co}$

Firm 1 \ Firm 2	c	c^o
c	π_1^{cc} , π_2^{cc}	π_1^{co} , π_2^{oc}
c^o	π_1^{oc} , π_2^{co}	π_1^{oo} , π_2^{oo}

Case (iv): $\widetilde{F}^{co} < \widetilde{F} \le \widetilde{F}^{\max}$

Table 1: Technology-Choice Games for the Strategic Technology Choice

Note:

(i) $\widetilde{F}^{\max}$ is the level of fixed cost at which $\pi_i^{oo} = 0$.