

# Research on Supplier Development Strategy Considering Spillover Effect in Competitive Environment

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**Abstract:** Aiming at the optimal investment strategy of the manufacturer to the supplier, considering the film stars brought by the spillover effect in the investment process, the profit, investment level and the impact on the supply chain members of the manufacturer under the three investment strategies are studied. It is found that: (1) As long as the manufacturer invests, the profit obtained under the three investment strategies is always higher than that without investment and investment is always beneficial to suppliers; (2) In the case of one manufacturer's investment, the equilibrium solution of the manufacturer under three investment strategies is analyzed, and it is found that the investment manufacturer is more willing to invest in the supplier's portfolio; (3) When the manufacturer's investment ability is high, the profit of non-investors may be higher due to the spillover effect, and the investment manufacturer will gradually reduce its investment level.

**Keywords:** Supplier development, Cost reduction, Spillover, Investment strategy.

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## 1. Introduction

With the prevalence of outsourcing, manufacturers often rely on suppliers of raw materials and parts to produce the final product. Purchasing magazine estimates that the 100 largest U.S. manufacturers spend 48 cents on each dollar of sales to buy raw materials and components. Therefore, the success of a manufacturer depends largely on the performance of its suppliers in the current fierce market competition. This urges manufacturers to establish close cooperation with their suppliers, especially key suppliers. Supplier development is a strategy widely used by manufacturers to cultivate close supplier relationships to improve supply chain efficiency. In practice, through supplier development, Honda has increased its supplier production efficiency by 50 % and product quality by 30 %, achieving a significant reduction in its own costs. Automakers such as Toyota, Porsche and Nissan also have their own professional supplier development teams. The 16th North American automobile supplier working relationship index annual study points out that competition makes vehicle manufacturers invest more funds in supplier development [1]. When Hyundai Kia lags behind Toyota in supplier management, in the pursuit of similar interests, Hyundai Kia copied Toyota's supplier development experience [2].

Manufacturers consider investing in their suppliers to help reduce production costs, which is one of the common types of supplier development in the industry. Manufacturers' investment in suppliers is usually divided into two types: special investment and general investment. Special investment refers to the investment made to meet the special requirements of the manufacturer. For example, the manufacturer purchases a computer numerical control machine tool, installs it in the supplier's production workshop, produces parts specifically for the manufacturer, and trains the supplier on how to use the machine tool; In 2017, Apple invested USD 200 million in Corning to improve the process and equipment of Gorilla Glass, and the glass produced by this process was specially used by Apple. The general

investment includes the manufacturer's investment in a part of the supplier's production line, which also serves other manufacturers, or investment in the supplier's lean manufacturing plan [3]. For example, Samsung invested \$ 111 million in Sharp to improve the quality of the LCD panel, but the investment in the development of the LCD panel is also available to Apple; Xiaomi has invested heavily in Sharp and Toshiba to improve the quality of mobile phone screens, but the improved mobile phone screens are also used in Apple's phones. Samsung and Xiaomi's supplier development practice shows that competitors benefit from the spillover effect of supplier development-supplier development implemented by manufacturers on common suppliers.

The spillover effect aggravates market competition and damages the interests of manufacturers as investors. Especially when the spillover effect triggers the "free-riding behavior" of competitors, manufacturers as investors may not tolerate it. For example, John Deere, a tractor manufacturer, invested heavily in suppliers to build a Superior Supplier Base, but the company's inability to tolerate free-riding by competitors led it to reconsider its supplier development plan - specifically investing in suppliers in areas such as castings or information systems, and the resulting cost reduction only benefited John Deere [4]. Moreover, some manufacturers attach importance to the confidentiality of the supplier's development process, so as to help the supplier physically separate the production business and prevent competitors from understanding these processes in depth. It is worth noting that some manufacturers are willing to accept the 'free-riding behavior' caused by spillover effects. For example, Honda's manager is willing to disclose the information flow of supplier development to rival Ford from the perspective of "rising ship" [5]; Toyota is well aware of the spillover effects of supplier development on competitors, and is willing to accept these spillover effects [6]. Toyota embeds supplier development activities that generate spillover effects into a portfolio of supplier development types, because its supplier development plan is not only for the general production

capacity of suppliers, but also for production processes dedicated to Toyota (such as customized computer-aided design systems and shared inventory systems) [7]. Toyota's supplier development practice shows that when manufacturers implement supplier development, they may make portfolio investment in suppliers - special investment and general investment at the same time. The above practice shows that in a competitive environment, the existence of spillover effects makes it necessary for manufacturers to carefully consider their investment strategies when implementing supplier development.

At present, some scholars have studied the development of suppliers. Modi and Mabert [8] found that the buyer's on-site visits and training programs to suppliers have a positive impact on on-time delivery and product design. Yawar et al [9] found that enterprises can improve supply chain performance by implementing supplier development (such as technology investment, logistics integration or financial assistance). Saghiri et al [10] used the least squares method to explore the impact of supplier development on supplier-buyer cooperation and resource allocation. Literatures [8-10] explore the impact of supplier development on supply chain indicators based on empirical analysis. Different from the above literature, some scholars use theoretical modeling methods to study supplier development, such as Iyer et al [11], Li [12] and Lee and Li [13]. Literatures [11-13] only consider the manufacturer's supplier development decision in the case of monopoly, and have not yet involved the manufacturer's supplier development decision in a competitive environment. For this reason, Jin et al [14] considered two competing supply chains, each of which contains a manufacturer and a supplier, and studied how the manufacturer's supplier integration decision promotes the development of suppliers that reduce costs. Feng et al [15] further expanded the research of literature [14]. In two competing electric vehicle supply chains, considering the electric vehicle manufacturer recycling retired batteries, in the case of the coexistence of positive channels and reverse channels, the impact of the electric vehicle manufacturer's integration decision on the development of cost-reducing suppliers is analyzed. Literatures [14-15] have not considered the impact of spillover effects on supplier development in a competitive environment.

In recent years, some scholars have focused on the impact of spillover effects on supplier development. Gupta [16] studied the impact of spillover effects on channel structure and effort investment incentives in the process of manufacturer investment, and found that in industries with large spillover effects, decentralized manufacturers invest more in process innovation than fully coordinated manufacturers. Ge [17] found that the spillover effect is more beneficial to enterprises that are not involved in R & D cooperation. Agrawal [18] explored how the interaction between spillover effects, competition, and shared supplier investment returns affects investment thresholds and investment time. The above literature only considers the case where the spillover effect is exogenous, and has not yet addressed the supplier development of the manufacturer when the spillover effect is endogenous. To this effect, Qi et al [19] considered the case where two competing manufacturers invested in one supplier, explored the spillover effects caused by exclusive investment and capacity investment and the conditions for the spillover effects, and found that if competitors were reluctant to invest, the manufacturer

investing in the supplier allowed capacity to overflow to the competitor under certain conditions. Qi et al [20] further extended the literature [19] to the case of uncertain demand, and found that manufacturers are more likely to consider exclusive investment when the demand correlation is reduced. Veldman [21] considered the case where the spillover effect is beneficial to both competitive manufacturers, and explored the investment strategy of the two competitive manufacturers when the manufacturer's implementation of supplier development can reduce the supplier's production cost. Literatures [19-20] explore the manufacturer's investment strategy selection problem when the spillover effect is only beneficial to the manufacturer with less supplier development ability.

The buyer clearly recognizes that there may be spillover effects in supplier development. However, the above examples show that the buyer has a different approach. This paper designs a game theory framework to explicitly capture these opposite choices. An important feature of the model is to regard investment spillovers as an endogenous phenomenon, which is in line with reality, because buyers have different investment choices. To do this, the model accounts for the key difference between the knowledge investment exclusive relationship and those suppliers whose development investment spills over to rival buyers. That is to say, this paper divides supplier development investment into shared supplier's specific production technology and general production technology. An example of "vendor-specific development" (also known as "specific investment") is when a buyer purchases a computer numerical control (CNC) machine that manufactures parts specifically for that buyer, installs it on the supplier's site, and trains the supplier to use the machine. Examples of "general supplier development" (or "general investment") include the buyer investing in a part of the supplier's production line, which also serves other buyers, or investing in the supplier's enterprise lean manufacturing plan. Another new feature of the model in this paper, consistent with the Toyota example given above, is that buyers have the opportunity to invest in a portfolio of supplier development types. This enables us to study the interaction between generic and specific supplier development decisions, whether buyers and shared suppliers benefit from portfolio investment types or prefer to focus on specific supplier development types.

In the framework of this paper, the buyer invests in general or specific supplier development, and then shares the supplier to determine best wholesale price. When setting the price, the supplier can treat the buyer differently and decide for each buyer how much the cost reduction brought by supplier development can be returned to the buyer when the wholesale price is reduced. In studying the buyer's investment decisions, we consider two important model elements that drive the results of the file. First, we allow the buyer to invest in general supplier development capabilities different from specific investment capabilities, which means that investing in one type of supplier development may be more costly than investing in another type of supplier development. This is quite natural, for example, the buyer may be good at manufacturing engineering, so it is easy to clearly identify supplier improvements, the buyer can benefit directly from them. However, at the same time, buyers may implement an expensive supplier development training program, and competitors may also benefit from it. These differences in

capabilities affect the buyer's preference for a type of investment. We also study what happens when the buyer's general investment ability is different. Secondly, this paper studies the role of competition intensity in the product market and models it as product substitutability. If buyers are competitors in their respective markets, then the spillover effects of supplier development are unlikely to attract attention, because they will not damage the company's competitiveness. Higher levels of competition increase the relative importance of supplier-specific development, as buyers use specific investments to differentiate themselves from competitors (through lower wholesale prices).

Based on this, this paper considers that the manufacturer's general investment or portfolio investment in the supplier will produce spillover effects, and the spillover effect is endogenous. It studies the manufacturer's investment strategy choice, and discusses the following questions: (1) When the manufacturer adopts the supplier development strategy, what is the manufacturer's optimal investment strategy? (2) What is the impact of market competition intensity and supplier development capability on the manufacturer's equilibrium strategy? (3) If the spillover effect produces free-riding behavior, what are the conditions for free-riding behavior? (4) When the manufacturer participates in general investment or portfolio investment to produce spillover effects, how the spillover effects affect the manufacturer's investment strategy choice.

## 2. Problem Description and Model Assumptions

Considering a supply chain consisting of a supplier ( $S$ ) and two competing manufacturers 1 and 2, the supplier produces parts and components at unit production cost  $c$ , and supplies parts and components to manufacturer  $i$  at the wholesale price  $w_i$  ( $i=1, 2$ ), manufacturer  $i$  sells products to consumers at the retail price  $p_i$ ; manufacturers 1 and 2 produce alternative products and compete on price. According to Literatures [22], [23] and [24], the demand function of manufacturer  $i$  is:

$$q_i = a - p_i + \theta(p_j - p_i), \quad i=1,2 \quad j=3-i \quad (1)$$

Among them,  $a$  is the potential market demand of the manufacturer, and  $\theta > 0$  is the substitutable level of the two manufacturers' products, reflecting the intensity of competition between the two manufacturers, which indicates that the demand is sensitive to the price difference between the two manufacturers, rather than to the sales price. The greater the  $\theta$  means the more intense the competition between manufacturers 1 and 2, when consumers are more inclined to choose products with lower sales prices.

When manufacturer  $i$  implements supplier development, it invests in suppliers to reduce the unit production cost of suppliers. Manufacturer  $i$  invests in supplier development in three ways: investment in general supplier development activities (general investment, recorded as  $G$ ), investment in special supplier development activities (special investment, recorded as  $S$ ), and simultaneous investment in general supplier development activities and special supplier development activities (portfolio investment, recorded as  $P$ ). Let  $x_i$  be the unit production cost reduction level of the supplier when the manufacturer  $i$  makes general investment; the supplier's unit production cost reduction level is reduced when  $s_i$  makes a special investment for manufacturer  $i$ . For

the convenience of analysis,  $x_i$  is called the general investment level of manufacturer  $i$ , and  $s_i$  is called the special investment level of manufacturer  $i$ . When the manufacturer  $i$  makes a general investment and the investment level is  $x_i$ , the cost paid by the manufacturer  $i$  is  $\gamma x_i^2/2$ , where  $\gamma$  indicates the investment ability of the manufacturer  $i$  to make a general investment (i.e. general investment ability). The smaller  $\gamma$  means the greater the general investment capacity of manufacturer  $i$  [3-4]. When manufacturer  $i$  makes a special investment and the investment level is  $s_i$ , the cost paid by manufacturer  $i$  is  $\sigma s_i^2/2$ , where  $\sigma$  represents the investment ability of manufacturer  $i$  to make a special investment (i.e., special investment ability). It is noted that the smaller  $\sigma$  means the greater special investment ability of manufacturer  $i$ , because for the same  $s_i$ , the smaller  $\sigma$  makes the capital invested by manufacturer  $i$  lower. If manufacturer  $i$  makes both special investment and general investment, when the special investment level is  $s_i$  and the general investment level is  $x_i$ , in view of the fact that the basic cost reduction projects are usually completely different, referring to the literature [24], considering that the cost paid by manufacturer  $i$  for general investment and special investment in the process of supplier development does not affect each other, the cost of manufacturer  $i$  is  $(\gamma x_i^2 + \sigma s_i^2)/2$ . Note: If both manufacturers invest in the supplier development process, the investment costs of both parties do not affect each other, which is consistent with the manufacturer's interpretation of supplier development in different projects, and their respective costs are only related to the invested project [25-27].

Single manufacturer investment situation: Manufacturer  $i$  invests in suppliers and manufacturer  $j$  does not invest. When manufacturer  $i$  only participates in special investment, the cost of parts required by supplier to produce manufacturer  $i$  is  $c - s_i$ , and the cost of parts required by manufacturer  $j$  is  $c$ . When manufacturer  $i$  only participates in general investment, the cost of parts required by supplier to produce manufacturer  $i$  is  $c - s_i$ , and the cost of parts required by supplier to produce manufacturer  $j$  is  $c - s_i$  due to the spillover effect. When manufacturer  $i$  participates in portfolio investment (that is, general investment and special investment at the same time), the cost of parts required by supplier to produce manufacturer  $i$  is  $c - s_i - x_i$ , and the cost of parts required by manufacturer  $j$  is  $c - s_i$ .

$n$  manufacturers invest in suppliers, where  $n \in \{1, 2\}$ .  $G_n$  denotes the general investment of  $n$  manufacturers to suppliers;  $S_n$  denotes the special

investment of  $n$  manufacturers to suppliers;  $P_n$  denotes the portfolio investment of  $n$  manufacturers to suppliers. The relevant parameters are shown in Table 1.

**Table 1.** Parameter symbols

symbols	Meaning
p	The manufacturer's unit product sales price
w	Supplier's unit product wholesale price
C	Supplier's unit production cost
c	The supplier's fixed production cost
s	The investment level of manufacturers participating in special investment
x	The investment level of manufacturers participating in general investment
I	Total investment cost of the manufacturer
$\sigma$	Manufacturer's ability to invest in special investment
$\gamma$	Manufacturer's ability to invest in general investments
$\theta$	Level of substitutability of the product
a	The basic needs of manufacturers
q	The needs of manufacturers
$\pi_i$	Profit of manufacturers
$\pi_s$	Profit of suppliers

### 3. Model Construction and Solution

#### 3.1. Construction of Non-Investment Game Model

Firstly, a game model is constructed for the case where two manufacturers do not make any investment, and the equilibrium decision is compared with the equilibrium decision of single manufacturer investment and two manufacturers investment to explore the impact of different investment strategies of manufacturers on performance. In the case of no investment, the supplier produces parts at the production cost  $c$ , sells them to the manufacturer  $i$  at the wholesale price  $w_i$ , and the manufacturer  $i$  sells products to consumers at the retail price  $p_i$ . At this time, the profit function of manufacturer  $i$  is:

$$\pi_i^N = (p_i^N - w_i^N)(a - p_i^N + \theta(p_j^N - p_i^N)) \quad (2)$$

Supplier's profit is:

$$\begin{aligned} \pi_s^N &= (w_1^N - c)(a - p_1^N + \theta(p_2^N - p_1^N)) + \\ & (w_2^N - c)(a - p_2^N + \theta(p_1^N - p_2^N)) \end{aligned} \quad (3)$$

A Stackelberg game dominated by the manufacturer is constructed, and the inverse method is used to solve the problem. The retail price of  $p_i^N$  manufacturer  $i$  and the wholesale price of  $w_i^N$  the supplier is respectively:

$$p_i^N = \frac{a\theta + \theta c + 3a + c}{2(\theta + 2)} \quad (4)$$

$$w_i^N = \frac{a + c}{2} \quad (5)$$

The profits of the manufacturer  $i$  and the supplier are:

$$\pi_i^N = \frac{(\theta + 1)(a - c)^2}{4(\theta + 2)^2} \quad (6)$$

$$\pi_s^N = \frac{(a - c)^2(\theta + 1)}{2(\theta + 2)} \quad (7)$$

#### 3.2. Construction of Single Manufacturer Investments

Considering that only manufacturer  $i$  ( $i = 3 - j, j = 1, 2$ )

implements supplier development and invests in suppliers, manufacturer  $i$  considers three strategies when investing in suppliers: general investment, special investment and portfolio investment. Under each investment strategy, the manufacturer's problem is to determine the optimal retail price to maximize its own revenue; the purpose of manufacturer  $i$  investing in suppliers is to gain cost advantages, but the existence of spillover effect reduces the cost of manufacturer  $j$ , thus weakening the competitive advantage of manufacturer  $i$ . Therefore, manufacturer  $i$  not only needs to consider the decision-making of pricing and investment level, but also needs to consider the impact of investment spillover effect on itself, that is, when manufacturer  $j$  does not invest in suppliers, under the spillover effect, manufacturer  $i$  adopts which investment strategy is more beneficial to itself.

##### 3.2.1. Manufacturer $i$ Makes General Investments

When manufacturer  $i$  makes a general investment in the supplier, let  $x$  be the general investment level of manufacturer  $i$ , then the cost that manufacturer  $i$  needs to pay is  $\gamma x^2/2$ . Due to the spillover effect of general investment, the unit production cost of the supplier is  $c - x$ . The profit function of manufacturer  $i$  is:

$$\pi_i^{G_i} = (p_i^{G_i} - w_i^{G_i})(a - p_i^{G_i} + \theta(p_j^{G_i} - p_i^{G_i})) - \frac{\gamma x^2}{2} \quad (8)$$

The profit function of manufacturer  $j$  is:

$$\pi_j^{G_i} = (p_j^{G_i} - w_j^{G_i})(a - p_j^{G_i} + \theta(p_i^{G_i} - p_j^{G_i})) \quad (9)$$

The supplier's profit function is:

$$\begin{aligned} \pi_s^{G_i} &= (w_i^{G_i} - (c - x))(a - p_i^{G_i} + \theta(p_j^{G_i} - p_i^{G_i})) + \\ & (w_j^{G_i} - (c - x))(a - p_j^{G_i} + \theta(p_i^{G_i} - p_j^{G_i})) \end{aligned} \quad (10)$$

The decision order is as follows: First, manufacturer  $i$  implements supplier development and makes general investment in suppliers to ensure long-term cooperation between manufacturers and suppliers. Therefore, the manufacturer's general investment decision is a long-term decision and cannot be changed at will. Secondly, the supplier determines the wholesale price. The supplier decides the wholesale price after evaluating the cost reduction brought by the manufacturer's implementation of supplier development. The rationality of this assumption is that the manufacturer wants the supplier to improve the process in its production process and consider the reduction level of its production cost when setting the wholesale price. Finally, the two manufacturers determine the retail price. In many industries, contract types and contract terms are known in the market, indicating that manufacturer  $i$  can observe  $w_j$  [14, 24].

##### 3.2.2. Manufacturer $i$ Makes Special Investments

When manufacturer  $i$  makes a special investment in the supplier, let  $s$  be the special investment level of manufacturer  $i$ , and the cost that manufacturer  $i$  needs to pay is  $\sigma s^2/2$ . Since there is no spillover effect in the special investment, the unit production cost of suppliers supplying parts to manufacturer  $i$  is  $c - s$ , and the unit production cost of suppliers supplying parts to manufacturer  $j$  is unchanged. The profit function of manufacturer  $i$  is:

$$\pi_i^{S_i} = (p_i^{S_i} - w_i^{S_i})(a - p_i^{S_i} + \theta(p_j^{S_i} - p_i^{S_i})) - \frac{\sigma s^2}{2} \quad (11)$$

The profit function of manufacturer  $j$  is:

$$\pi_j^{S_i} = (p_j^{S_i} - w_j^{S_i})(a - p_j^{S_i} + \theta(p_i^{S_i} - p_j^{S_i})) \quad (12)$$

The supplier's profit function is:

$$\begin{aligned} \pi_s^{S_i} = & (w_i^{S_i} - c + s)(a - p_i^{S_i} + \theta(p_j^{S_i} - p_i^{S_i})) + \\ & (w_j^{S_i} - c)(a - p_j^{S_i} + \theta(p_i^{S_i} - p_j^{S_i})) \end{aligned} \quad (13)$$

The decision order is similar to that of manufacturer  $i$  for general investment: first, manufacturer  $i$  determines the special investment level; then, the supplier determines the wholesale price; finally, the two manufacturers determine the retail price.

### 3.2.3. Manufacturer $i$ Makes Portfolio Investment

When manufacturer  $i$  invests in suppliers, let  $x$  and  $s$  be the general investment level and special investment level of manufacturer  $i$  respectively, and the investment cost of manufacturer  $i$  is  $\gamma x^2/2 + \sigma s^2/2$ . The unit production cost of suppliers supplying parts to manufacturer  $i$  is  $c - s - x$ ; considering that the special investment does not have spillover effect, the unit production cost of suppliers supplying parts to manufacturer  $j$  is  $c - x$ . The profit function of manufacturer  $i$  is:

$$\pi_i^R = (p_i^R - w_i^R)(a - p_i^R + \theta(p_j^R - p_i^R)) - \left( \frac{\gamma x^2}{2} + \frac{\sigma s^2}{2} \right) \quad (14)$$

The profit function of manufacturer  $j$  is:

$$\pi_j^R = (p_j^R - w_j^R)(a - p_j^R + \theta(p_i^R - p_j^R)) \quad (15)$$

The supplier's profit function is:

$$\begin{aligned} \pi_s^R = & (w_i^R - (c - s - x))(a - p_i^R + \theta(p_j^R - p_i^R)) \\ & + (w_j^R - (c - x))(a - p_j^R + \theta(p_i^R - p_j^R)) \end{aligned} \quad (16)$$

By using the inverse method, the optimal profit of the manufacturer and supplier under the investment model can be obtained, and the optimal profit and equilibrium solution are analyzed to obtain Proposition 1, as follows.

Proposition 1: (1) When manufacturer  $i$  makes portfolio investment, if  $\gamma < \gamma_1$ , then  $x^R > s^R$ ; if  $\gamma > \gamma_1$ , then  $x^R < s^R$ .

$$(2) s^R > s^{S_i}, \quad x^R > x^{G_i}.$$

Proposition 1(1) shows that when the manufacturer carries out supplier development activities, if the manufacturer carries out portfolio investment, whether the manufacturer's investment level in specific supplier development activities is higher than that in general supplier development activities depends on the relationship between the manufacturer's general investment ability and threshold  $\gamma_1$ . If the manufacturer's general investment ability is strong ( $\gamma < \gamma_1$ ), the manufacturer's general investment level is higher than the special investment level when making portfolio investment; if the manufacturer's general investment ability is poor ( $\gamma > \gamma_1$ ), the manufacturer's special investment level is higher than the general investment level when making portfolio investment. This is because in the case of the manufacturer's portfolio investment, if the manufacturer's general investment ability is strong, the positive impact of the investment on the general supplier development activities is greater than the negative impact of the competition caused by the spillover effect, and the manufacturer is more inclined to

increase the general investment in the portfolio investment; if the manufacturer's general investment ability is weak, it means that the same level of production costs are reduced, and the manufacturer needs to invest more. The negative impact of the spillover effect leading to increased competition makes the manufacturer more inclined to invest in special supplier development activities. Proposition 1(2) shows that when manufacturer  $i$  carries out supplier development activities, compared with general investment, special investment by manufacturer  $i$  investing in general supplier development activities will increase the level of general investment. It can be seen from this that the special investment of manufacturer  $i$  increases its general investment, while the general investment of manufacturers investing in special supplier development activities will increase the level of special investment.

## 4. Manufacturer's Investment Strategy Decision-Making

This section focuses on the manufacturer's profit under no investment, one-party investment and two-party investment, and discusses the manufacturer's optimal investment strategy, so as to draw proposition 3.

Proposition 2: (1)  $\pi_i^{S_i} > \pi_i^N$ ,  $\pi_i^{G_i} > \pi_i^N$ ,  $\pi_i^R > \pi_i^N$ .

$$(2) \pi_i^R > \pi_i^{G_i}, \quad \pi_s^R > \pi_s^{G_i}.$$

$$(3) \pi_i^R > \pi_i^{S_i}, \quad \pi_s^R > \pi_s^{S_i}.$$

Proposition 2(1) shows that compared with no investment, it is always the optimal strategy for manufacturer  $i$  to carry out supplier development activities and invest in suppliers. It can be seen that manufacturer  $i$  can always benefit from the investment in suppliers. On the other hand, it is easy to get  $\pi_i^R > \pi_i^{S_i} > \pi_i^{G_i}$  and  $\pi_s^R > \max\{\pi_s^{S_i}, \pi_s^{G_i}\}$ , so in the case of only manufacturer  $i$  to carry out supplier development activities, manufacturer  $i$  is more willing to portfolio investment in suppliers, and suppliers are also willing to accept the portfolio investment of manufacturer  $i$ .

Proposition 2(2) shows that when manufacturer  $i$  carries out supplier development activities, compared with general investment, special investment by manufacturer  $i$  investing in general supplier development activities will increase the level of general investment. It can be seen that the special investment of manufacturer  $i$  increases its general investment. On the other hand, it is easy to know: when the manufacturer  $i$  invests, if  $s^R = 0$ , then  $\pi_i^R = \pi_i^{G_i}$ . Therefore, for any  $x^R > 0$ , when manufacturer  $i$  sets  $s^R$  for supplier development, it needs to weigh the pros and cons between general investment and portfolio investment. Proposition 2(2) also shows that when only manufacturer  $i$  carries out supplier development activities, manufacturer  $i$  will make portfolio investment, and suppliers also tend to make portfolio investment by manufacturer  $i$ . This means that the special investment activities of manufacturer  $i$  are beneficial to both itself and suppliers. This is because the special investment of manufacturer  $i$  increases its general investment (i.e.,  $x^R > x^{G_i}$ ). Although the spillover effect reduces the procurement cost of the two manufacturers and intensifies the competition between them, the special investment of manufacturer  $i$  leads to a more obvious cost advantage of purchasing parts, which makes manufacturer  $i$  more profitable. On the other hand, it is easy to know that after the supplier sets the wholesale price

of the parts, its profit function is an increasing function of the general investment level and the special investment level, which makes the supplier accept the supplier development investment from the manufacturer  $i$ . Although the supplier benefits from the manufacturer's investment in specific supplier development activities, the specific investment of manufacturer  $i$  increases its general investment. At this time, the supplier will benefit more from the manufacturer's portfolio investment in supplier development activities.

Proposition 2(3) shows that Suppliers also want manufacturers that invest in specific supplier development activities to make general investments in their supplier development activities. After the supplier sets the wholesale price of the parts, the supplier's profit function is an increasing function of the general investment level and the special investment level, so the supplier will not refuse any investment from the manufacturer to carry out supplier development activities. Although suppliers can benefit from the manufacturer's investment ( $x_i^g > 0$  or  $x_i^s > 0$ ) behavior in general supplier development activities, due to  $s_i^g > s_i^s$  or  $s_i^g > s_i^s$ , if the manufacturer investing in special supplier development activities makes general investment, the supplier will gain more benefits. This partly explains why Tenneco, Toyota's exhaust system supplier, was both willing to implement 'joint improvement activities' and agreed to share some of the production system improvements with Toyota only. In summary, in supplier development, if the manufacturer only invests in general supplier development activities, this behavior is not only detrimental to the manufacturer itself, but also not beneficial to the supplier.

In summary, in the case of a single manufacturer to carry out supplier development, manufacturers that carry out supplier development are more willing to portfolio investment in suppliers; in the case of two manufacturers to carry out supplier development, the manufacturer is willing to make general investment, but special investment or portfolio investment may damage the interests of the manufacturer. At this time, the manufacturer may face the "prisoner's dilemma" when making special investment and portfolio investment. This "prisoner's dilemma" exists in the fiercely competitive market environment, and when the manufacturer makes portfolio investment, the existence of the "prisoner's dilemma" also depends on the manufacturer's general investment ability.

Supplier's profit under the investment of two manufacturers is higher than that of one manufacturer, and the supplier is more willing to accept the investment strategy of two manufacturers. Therefore, for suppliers, in the portfolio investment mode, the optimal investment decision is affected by the competition intensity and investment ability.

## 5. Conclusion

This paper considers a supply chain consisting of two competing manufacturers and a supplier. A game model is constructed and solved for two investment strategies: no investment and one-party manufacturer investment. Through the analysis of the equilibrium solution, the optimal investment strategy selection and its impact are explored. The research results are as follows:

(1) When the manufacturer's ability to invest in general investment is large, the cost of general investment is more, and the spillover effect is larger. At this time, the non-

investment manufacturer can 'hitchhike', and its profit is higher than that of the investor manufacturer in a certain competitive intensity area.

(2) Excluding general investment from the manufacturer's investment strategy is not the optimal strategy for manufacturers and suppliers. General investment will encourage manufacturers to increase special investment. Therefore, for suppliers, product sales and demand under portfolio investment are more, and their profits are also larger. Therefore, it is more beneficial for manufacturers to participate in portfolio investment.

(3) When the competition intensity is strong and the manufacturer's ability to invest in suppliers is strong, participating in special investment will put the manufacturer in a prisoner's dilemma. It is more advantageous for the manufacturer to promise not to invest or only to participate in general investment.

This paper studies the optimal investment strategy of manufacturers and the impact of spillover effects on investment. The research results can provide reference for management practice. However, this paper considers the manufacturer's investment ability and market competition intensity as an important driving force for supplier development. In future research, the supplier's efforts can be considered as a driving factor for supplier development.

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