Holdup Problems in Early Supplier Involvement and the Manufacturer's Optimal Strategy

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Abstract

While early supplier involvement has been adopted in many industries to facilitate product innovation, its impact on new product development performance is mixed. This study examines the dynamic relationship between the manufacturer and supplier using cooperative investment framework, and argues that, due to the nature of the investment, post-contractual holdups can reduce the benefits from the collaboration suggested by the resource-based view, leading to a longer development lead time and a lower probability of a radical innovation. These problems are different from the classical agency problems in that they are not based on asymmetric information between the principle and the agent and/or their different attitudes towards risk, and thus cannot be solved by monitoring or standard contracts. The study offers insights for manufacturers in deciding whether to strategically commit to their suppliers. While the commitment strategy increases the suppliers' incentive to collaborate, the non-commitment strategy reduces holdup problems. The manufacturer's optimal strategy is derived considering two contingent factors. The findings enrich the understanding of supply chain partner collaboration in new product development from a new perspective.

***Keywords*:** Early Supplier Involvement, New Product Development, Holdup, Cooperative Investment

1. Introduction

With rapid changes in technologies and market structure, proactive new product development (NPD) has become an important source of dynamic competitive advantage (Brown and Eisenhardt 1995, Clark and Fujimoto 1991). Firms that develop new products quickly catch the attention of customers and capture larger market share in many industries. Yet, original equipment manufacturers face a great challenge in NPD due to the loss of hierarchical control over their suppliers and the lack of relevant knowledge and expertise in critical parts from outsourcing. Under such circumstances, inter-firm collaboration has been suggested to provide an efficient mechanism to leverage suppliers' knowledge and capabilities in NPD (Grant 1996). Early supplier involvement (ESI) is a form of inter-firm collaboration in which manufacturers involve suppliers at an early stage of the product development/innovation process, generally at the level of concept and design (Bidault et al. 1998, LaBahn and Krapfel 2000). Japanese manufacturers adopting ESI were able to bring new automobiles to market faster, with more innovative features but less effort in terms of development hours and number of engineers (Wynstra et al. 2001).

The benefits of ESI can be explained from the resource-based view (RBV) of the firm, which argues that resource bundles determine firms' performance (Barney 1991, Wernerfelt 1984). While the manufacturer's resource bundle changes with suppliers' complementary resources, joint capabilities can be developed and exploited (Wagner and Hoegl 2006). Consequently, ESI could generate a positive influence on process efficiency and product effectiveness such as cost deduction, quality improvement, shorter development cycle time, and high customer satisfaction. While many researchers (Birou and Fawcett 1994, Droge et al. 1999, Ragatz et al. 1997, Wynstra et al. 2001) have documented these benefits, there are also a number of studies that showed no significant benefits or found negative effects of supplier involvement on NPD performance (Eisenhardt and Tabrizi 1994, Von Corswant and Tunalv 2002, Zirger and Hartley 1996).

This study, drawn on cooperative investment framework (Che and Chung 1999, Che and Hausch 1999), reconciles the above findings by examining the potential holdup problems in ESI. Holdups may occur when a supplier can make an investment that will increase the profit for the manufacturer, but refrains from doing so due to the concern that after the investment, the manufacturer will use the bargaining power to reduce the its profit. Due to the occurrence of holdups, ESI may not always lead to better performance measures (*ex post*), even though it offers many potential benefits to manufacturers (*ex ante*). This study also shows how the manufacturer could use different levels of commitment to its suppliers as a strategy to reduce holdups. The manufacturer's optimal strategy is examined considering the degree of competitions among the suppliers and the probability of achieving a radical innovation.

The rest of the paper is structured as follows. Section 2 provides a literature review of research related to ESI and introduces cooperative investment framework. Section 3 describes the collaboration process and basic assumptions of the model. Section 4 derives outcomes under two strategies – commitment and non-commitment by the manufacturer. The implications are discussed in Section 5 and conclusions appear in the last section.

2. Literature Review and Theoretical Framework

2.1. Empirical Findings of ESI

According to the RBV, a manufacturing firm's performance largely depends on its resource bundle. ESI brings in more valuable and useful resources from a supplier, providing the manufacturer with an opportunity to enhance its performance. While many endeavors have been devoted to assess the impact of ESI on NPD performance, the results seem to be inconclusive. In particular, collaboration between manufacturers and suppliers in the NPD process could be costlier and slower in the information and communication technology sector, because suppliers tend to make projects more complex (Littler et al. 1998). ESI was also found to have no significant impact on product development time in electronics industry (Zirger and Hartley 1996). Eisenhardt & Tabrizi (1994) uncovered that the supplier involvement has no impact on high uncertainty industries. Further, only 20% of the respondents in a survey agreed that they were currently satisfied with the results of supplier integration efforts while over 45% disagreed (Handfield et al. 1999).

Two different approaches have been suggested to resolve these inconsistencies (Monczka et al. 2000, Primo and Amundson 2002, Wynstra et al. 2001). The first approach is based upon the contingency theory, that is, ESI is not an optimal practice or strategy in every circumstance. The decision to use ESI may be contingent upon the product type, the complexity of the products supplied, the supplier's technological capability, and the extent and timing of the supplier involvement (Kamath and Liker 1994, Laseter and Ramdas 2002, Monczka et al. 2000).

The second approach concerns the quality of collaboration (Hoegl and Wagner 2005), for instance, to what extent the supplier's R&D capabilities is utilized. Integrating suppliers aims not only to access more resources but also to utilize those resources efficiently. While the resource bundle increases with supplier involvement, the quality of collaboration, which is the result of interaction between the manufacturer and supplier, may not (Wu and Ragatz 2010).

This study combines the two lines of research by showing how the manufacturer's strategies in ESI affect NPD performance and how its optimal strategy may be influenced by a specific set of contingencies. To understand this requires us to discuss the special features of the inter-firm relationship.

2.2. Cooperative Investment and Holdups

Two aspects of ESI distinguish it from other forms of inter-firm relationship. First, the supplier often has to pay investment costs that do not immediately improve its own profit, but generates direct benefits to the manufacturer by reducing operations cost, improving quality or features, or shortening the time to bring the new product to market. This type of investment has been referred to as cooperative investment (Che and Hausch 1999). For instance, some Japanese automakers pay for consultants to work with suppliers to improve production methods (Dyer and Ouchi 1993). Suppliers make specific investments to customize parts for the manufacturer (Asanuma 1989) or relocate their facilities adjacent to major manufacturers to reduce shipping costs and improve supply reliability. Second, the outcome of NPD is difficult to predict; hence it is difficult to write a complete contract at the start of the project. Any contract employed in NPD is likely to be vague and may be renegotiated between the two parties after the supplier's investment has been made.

These two features combined may result in the occurrence of holdups because the supplier may be reluctant to make full investment for the NPD project. To explore the extent to which holdup problems may affect NPD, two critical dimensions of NPD performance are studied in this paper: the NPD lead time and the level of innovation.

The NPD lead time is a measure of time taken by the project team to develop the product (Olson et al. 1995, Sarin and McDermott 2003). Time is a critical competitive dimension (Stalk 1988) and faster development is usually associated with better initial market performance (Ali et al. 1995).

The level of innovation (i.e., product innovativeness) is defined as the degree of newness of the product under development (Ancona and Caldwell 1990, 1992, Olson et al. 1995, Sarin and Mahajan 2001). Other researchers (Andrews and Smith 1996, Moorman and Miner 1997) used new product creativity to reflect the novelty of a new product that has the potential to change thinking and practices. Product innovation is critical for organizational growth in order to survive in the changing markets, technologies, regulations, and competitors (Hage 1980, Morone 1993). The levels of innovation can be classified as radical or incremental. Compared to an incremental innovation, a radical innovation tends to be more difficult and costly to achieve, but usually generates larger profit.

Confronted with holdups, the manufacturer could use a level of commitment it makes to its supplier as a strategy to mitigate them. A commitment can be viewed as a mechanism that makes it costly for the manufacturer to switch to other suppliers, for instance, lock-in with a strategic supplier or penalty clause for terminating the project without consulting the supplier. In contrast, a non-commitment strategy allows the manufacturer to engage in relationship with multiple suppliers and retain a high degree of flexibility to change the suppliers. This study helps the manufacturer identify its optimal commitment strategy considering 1) the degree of competitions among the suppliers, and 2) the probability of achieving a radical innovation.

3. MODEL

The model featured in this study attempts to capture the interactions between the manufacturer and the supplier in an NPD project. The manufacturer, in its selection process, is able to identify a supplier with appropriate R&D capabilities to design and deliver a core part for the new product. The project is risky: it may result in a radically or marginally innovative product, or it may fail and yield nothing. A radically innovative product requires an equally innovative part from the supplier. Such a product will generate a stream of future profit with a present value P. An incrementally innovative product, which requires a part that is only incrementally innovative, will bring in a lower present value of profit cP, where $0<c<1$. Also, we assume that c is sufficiently large such that there is a significant difference between the profits in both types of innovation. Due to the uncertainty of the project outcome, no renegotiation-proof contract is possible for this task, and the expected profit from the sales of the new product are negotiated only after the new part is fully developed. Both parties are risk-neutral, and there is no asymmetric information.

Demand for the new product changes over time, and thus affects P. To capture this, we assume that time is continuous and the evolution of P follows geometric Brownian motion:

$$\frac{dP}{P} = \alpha dt + \sigma dZ, \qquad (1)$$

where α is the percentage change of P; σ is a constant volatility rate of the rate of change of P; and dZ is the increment of a standard Brownian motion. A constant risk-free interest rate r exists and $r > \alpha$. Both parties share all information and observe P at all time.

To capture the manufacturer-supplier relationship in the simplest fashion, the involvement process is divided into three stages – design, development, and negotiation (Figure 1).

<Insert Figure 1 about here>

The design stage requires the supplier to collaborate with the manufacturer to generate a blueprint for a part that fits the profile of the new product. The manufacturer can choose whether to commit to the selected strategic supplier. A commitment means that the manufacturer cannot later switch to other suppliers. The outcome of this collaboration is uncertain: there is a probability τ that this collaboration is successful, in which case it yields a blueprint acceptable to both parties. In order to achieve the probability of a success τ, the supplier has to put in a collaboration effort. The effort function, denoted by $F(\tau)$, has the following standard properties: $F'(\tau) > 0$, $F''(\tau) > 0$, and $F(0) = 0$. In case that the collaboration fails, which occurs with a probability $1-\tau$, the project is abandoned and both parties get nothing in return.

If the collaboration is successful, the supplier can deliver at least an incrementally innovative blueprint to the manufacturer. This type of blueprint requires no additional investment from the supplier in the development stage. However, during the course of the collaboration, the supplier may find out that an alternative blueprint for radically innovative part can also be achieved. Whenever this opportunity occurs, the supplier has to decide which type of blueprint it will pursue and deliver to the manufacturer. If it delivers a radically innovative blueprint, the supplier will have to pay an investment cost I in the development stage. The investment I reflects the capability of the selected supplier to develop the blueprint relative to the other suppliers. We assume that the other suppliers have lower capability and could develop a radically innovative part at a higher cost mI , where $m > 1$.

Although at the end of the design stage, the supplier knows with certainty whether a radical innovation is possible, this possibility is uncertain at the beginning of the design stage. At this point, the supplier and the manufacturer have to assess the possibility of achieving a blueprint for a radically innovative part, considering factors outside their controls such as technology limitation, material affordability, and resources availability. Denote π as the conditional probability that a radical innovation is possible if the collaboration is successful. A radical innovation will occur with probability $\tau\pi$, given that the full investment in the development stage is paid; an incremental innovation will occur with probability $\tau(1-\pi)$; and the project may fail with probability $1-\tau$.

In the negotiation stage, the manufacturer and the supplier negotiate the expected profit from the sales of the new product. Negotiations occur after the development stage is completed. The developed part cannot be used directly in other products and thus has no value elsewhere. The supplier's bargaining power is reflected in the negotiated share of the profit denoted by ρ , where $0 \le \rho \le 1$. The commitment by the manufacturer gives the supplier a bargaining power in the negotiation stage and guarantees a fraction of the profit (ρ) for the supplier regardless of the type of innovation. Without the commitment, the supplier may still have a bargaining power if it delivers a blueprint for a radically innovative part because the other suppliers with higher investment cost will find it not optimal to compete. In this case, the supplier will be able to demand a profit share of ρ in the negotiation stage. However, the supplier will have no bargaining power by delivering a blueprint for an incrementally innovative part because other suppliers can also provide the same part.

4. Manufacturer's Optimal Strategy in ESI

To obtain the optimal the manufacturer's commitment strategy, the manufacturer's expected profit under the commitment and non-commitment strategies are derived using backward induction, starting from the negotiation stage, then to the development stage, and finally to the design stage. At each stage, each party rationally maximizes its own expected profit.

A real options framework (Dixit and Pindyck 1994) is used to capture the impact of ESI on the NPD lead time. However, the model departs from other standard real option models which allow the manufacturer to decide its own investment timing. In the model described below, the supplier is able to choose the timing of investment and use this flexibility to its own advantage.

4.1. Commitment Strategy

Consider the situation in which the manufacturer is committed to the selected supplier. At the beginning of the development stage, the supplier has no competition, thus it has flexibility to choose when to start the development. In the case of a radically innovative part, for the supplier to pay the investment cost I, its share of profit must be high enough to cover the cost, that is, $\rho P - I$ must be non-negative. If the supplier invests and starts the development at $P = \frac{I}{\rho}$, it will only break even. Now, consider a strategy of waiting until P reaches a pre-specified threshold that is greater than $\frac{I}{\rho}$. At this level of P the supplier will make a profit. However, the waiting strategy is risky because P may never go up to the threshold level or it may take too long. The supplier trades off these costs and benefits of waiting and chooses the investment threshold that maximizes its own share of profit.

We follow a standard procedure in real option literature of solving an ordinary differential equation to derive the value function of the supplier's share of profit. To formalize this, let P_C denote the threshold level of P at which the supplier makes the investment and start the development of a radically innovative part, and let S_C denote the supplier's share of profit after the design stage is completed *(ex post)*. We obtain $S_C = (\rho P_C - I)\left(\frac{P}{P_C}\right)^{\gamma}$, where the term $(\rho P_C - I)$ is the supplier's share of the profit minus the investment cost, and the term $\left(\frac{P}{P_C}\right)^{\gamma}$ is a stochastic discount factor that incorporates both a discount rate and the risk-neutral probability that P reaches P_C. The uncertainty of P reaching P_C is governed by the parameter $\gamma = \left(\left(r - \delta - \frac{\sigma^2}{2}\right) + \sqrt{\left(r - \delta - \frac{\sigma^2}{2}\right)^2 + 2\sigma^2 r}\right) / \sigma^2 > 1.$

For an incrementally innovative part, there is no investment, so it is optimal for the supplier to start the development right away, and $S_C = \rho c P$. To summarize:

$$S_C = \begin{cases} (\rho P_C - I)\left(\frac{P}{P_C}\right)^{\gamma} & \text{for a radical innovation,} \\ \rho c P & \text{for an incremental innovation,} \end{cases} \qquad (2)$$

The level of P_C that maximizes the supplier's profit is given by:

$$P_C = \frac{\gamma}{\gamma - 1}\frac{I}{\rho}. \qquad (3)$$

For the proofs of the results, see Appendix.

At the break-even threshold for the supplier, $P_C = \frac{I}{\rho}$, the lead time is the shortest. The higher P_C is, the longer the development lead time becomes. Equation (3) shows that, because $\frac{\gamma}{\gamma - 1} > 1$, the supplier will invest at $P_C > \frac{I}{\rho}$, so it will wait beyond its break-even point, prolonging the development.

When both types of blueprint are possible, if the investment cost for a radical innovation is high, the supplier may choose not to pursue such a blueprint, and delivers an incrementally innovative one instead. Let $\bar{I}$ denote a cutoff point above which the supplier finds it not optimal to invest for a radically innovative part. To obtain this point, set the supplier's profits in both types of innovation equal and solve for *I*:

$$\bar{I} = \gamma^{\frac{1}{1-\gamma}} c^{\frac{1}{1-\gamma}} \rho \frac{\gamma - 1}{\gamma} P, \qquad (4)$$

Recall that at the beginning of the design stage, the probability of achieving a radical innovation is π >0. However, the supplier strictly prefers to develop an incrementally innovative part if $I > \bar{I}$, so for this range of *I*, the probability of achieving a radical innovation becomes zero. In this case, the commitment strategy hinders a radical innovation, even though it may be technically and financially feasible. The results are summarized in Proposition 1:

Proposition 1: For $I \le \overline{I}$, the commitment strategy lengthens the product development lead time for a radical innovation; and for $I > \overline{I}$, it inhibits a radical innovation.

The intuition behind this result is that the commitment strategy gives the supplier the flexibility to time the investment and to influence the type of innovation. The supplier then uses the flexibility to maximize its own benefits, which may not be in the best interest of the manufacturer. In other words, the manufacturer's commitment strategy creates two holdup problems – a lower probability of a radical innovation and a longer development lead time.

Turning to the manufacturer, its share profit at the end of the design stage (*ex post*), denoted by B_C, can be derived in a similar fashion to that of the supplier:

$$B_C = \begin{cases} (1-\rho)P_C\left(\dfrac{P}{P_C}\right)^{\gamma} & \text{for a radical innovation,} \\ (1-\rho)cP & \text{for an incremantal innovation,} \end{cases} \tag{5}$$

Going back one step to the beginning of the design stage, the supplier has to decide how much collaboration effort it will put in. The supplier's expected profit at this point is the product of probability of the collaboration success and its share of profit, subtract the effort it puts in. Denote τ_C as the probability of the success of the collaboration, and $E[S_C]$ as the supplier's expected profit at the outset of design stage (*ex ante*). From Proposition 1, we know that if $I \ge \overline{I}$, the supplier will never develop a radically innovative part, so the product will be incrementally innovative with certainty, and the share of profit for the supplier will be ρcP. If $I < \overline{I}$, and the supplier will deliver a radically innovative part whenever possible, so the share of profit for the supplier is $\left(\pi(\rho P_C - I)\left(\dfrac{P}{P_C}\right)^{\gamma} + (1-\pi)\rho cP\right)$.

To summarize:

$$E[S_C] = \begin{cases} \tau_C \rho c P - F(\tau_C) & \text{if } I \geq \bar{I}, \\ \tau_C \left(\pi(\rho P_C - I)\left(\dfrac{P}{P_C}\right)^{\gamma} + (1-\pi)\rho c P \right) - F(\tau_C) & \text{if } I < \bar{I}. \end{cases} \tag{6}$$

Now, we derive the supplier's choice of effort in the design stage. Denote τ_c^* as the level of τ_c that maximize the supplier's profit: τ_c^* solves the following first-order conditions:

$$\begin{cases} \pi(\rho P_C - I)\left(\dfrac{P}{P_C}\right)^{\gamma} + (1-\pi)\rho c P = \dfrac{\partial F(\tau)}{\partial \tau} & \text{if } I < \bar{I}, \\ \rho c P = \dfrac{\partial F(\tau)}{\partial \tau} & \text{if } I \geq \bar{I}. \end{cases} \tag{7}$$

The solution exists and is unique because of the assumption that $F'(\tau) > 0$, and $F''(\tau) > 0$.

For the manufacturer, its expected profit at the outset of design stage (*ex ante*), denoted by $E[B_C]$, is derived in a similar fashion to that of the supplier:

$$E[B_C] = \begin{cases} \tau_C^*(1-\rho)cP & \text{if } I \geq \bar{I}\ , \\ \tau_C^* \left(\pi(1-\rho)P_C\left(\dfrac{P}{P_C}\right)^{\gamma} + (1-\pi)(1-\rho)cP \right) & \text{if } I < \bar{I}\ . \end{cases} \tag{8}$$

4.2. Non-Commitment Strategy

Now consider a situation in which the manufacturer does not make any commitment to the selected supplier. If the supplier delivers a radically innovative blueprint, it may not freely choose the timing of investment any longer because if it waits too long the manufacturer may turn to other suppliers to develop the part. Let P_N denote the threshold level of P at which the supplier makes the investment and S_N denote the supplier's share of profit after the design stage (*ex post*). In case of a radical innovation, because the selected supplier has comparative advantage over the other suppliers, it has a bargaining power in the negotiation stage and gets a share of profit ρ. The functional form of S_N is similar to that of S_C, because it obeys the same differential equation: $S_N = (\rho P_N - I)\left(\frac{P}{P_N}\right)^{\gamma}$, but with a different investment threshold P_N as discussed below. For an incremental innovation, the supplier has no comparative advantage, so it has no bargaining power in the negotiation stage and the share of profit is zero. That is:

$$S_N = \begin{cases} (\rho P_N - I)\left(\frac{P}{P_N}\right)^{\gamma} & \text{for a radical innovation,} \\ 0 & \text{for an incremental innovation,} \end{cases} \tag{9}$$

From the above equations, because $(\rho P_N - I)\left(\frac{P}{P_N}\right)^{\gamma} > 0$, the supplier will deliver a radically innovative part whenever possible. So irrespective of the development cost *I*, the *(ex ante)* probability of a radical innovation is always π.

Because of the competitions, the investment threshold in this case is different from that in the commitment case. To derive P_N, we use the fact that the competitions will lower the supplier's profit to the point where no other suppliers can compete. Consider the break-even point of the other suppliers. Because their investment costs are mI, the other suppliers will break even at $P = m\frac{I}{\rho}$. At this point, if *m* is strictly greater than 1, which we assume to be the case, the selected supplier still makes a profit. It has no incentives to reduce the threshold further than this, so it will choose $P_N = m\frac{I}{\rho}$. Next, compare this threshold to P_C. Because P_C is the threshold that maximizes the supplier's profit, P_N will not be higher than P_C. This means that whenever m is equal or greater than $\frac{\gamma}{\gamma-1}$, the supplier will choose $P_N = P_C$. Therefore, the investment threshold is given by:

$$P_N = \begin{cases} m\frac{I}{\rho} & \text{if } m < \frac{\gamma}{\gamma-1}, \\ P_C & \text{if } m \geq \frac{\gamma}{\gamma-1}, \end{cases} \tag{10}$$

and the effects of non-commitment strategy are summarized in Proposition 2.

Proposition 2: The non-commitment strategy can shorten the development lead time, and makes a radical innovation possible with probability π, regardless of the investment cost.

The intuition behind this proposition is that the non-commitment strategy allows the manufacturer to maintain a credible threat of changing the supplier, which can help reduce holdup problems. This result does not mean that the non-commitment strategy will make the manufacturer change the supplier, but it suggests that such a strategy makes the threat of changing credible. In equilibrium, the manufacturer will continue to work with the selected supplier; however, such a threat can have an impact on the actions of the supplier.

Next, we derive the manufacturer's profit after the design stage (*ex post*), denoted by B_N:

$$B_N = \begin{cases} (1-\rho)P_N\left(\frac{P}{P_N}\right)^{\gamma} & \text{for radical innovation,} \\ cP & \text{for incremental innovation,} \end{cases} \tag{11}$$

The results are similar to those in the commitment case, except in the case of a radical innovation, the investment threshold is now P_N instead of P_C, and in the case of an incremental innovation, the manufacturer keeps all the profit.

Now, moving to the start of the design stage (*ex ante*), the supplier's expected share of profit, denoted by $E[S_N]$ is derived:

$$E[S_N] = \tau_N \pi(\rho P_N - I)\left(\frac{P}{P_N}\right)^{\gamma} - F(\tau_N), \tag{12}$$

where τ_N is the probability of the design success when the manufacturer does not make any commitment. Next, define τ_N^* as the level of τ_N that maximizes the supplier's expected profit, then τ_N^* can be derived by solving the following first-order condition:

$$\pi(\rho P_N - I)\left(\frac{P}{P_N}\right)^{\gamma} = \frac{\partial F(\tau)}{\partial \tau} \tag{13}$$

The optimal τ_N^* declines with the degree of competitions among the suppliers (m), but increases with the probability of a radical innovation (π). Put alternatively, under non-commitment strategy, intense competitions among the suppliers increase the chance of design failure and discourage suppliers to put in effort.

Next, the manufacturer's expected profit at the start of the design stage (*ex ante*), denoted by $E[B_N]$, is given by:

$$E[B_N] = \tau_N^*\left(\pi(1-\rho)P_N\left(\frac{P}{P_N}\right)^{\gamma} + (1-\pi)cP\right) \tag{14}$$

4.3. Equilibrium Outcomes

In this subsection, we derive the manufacturer's optimal commitment strategy by comparing the expected profit under the commitment strategy, $E[B_C]$ to that under a non-commitment strategy, $E[B_N]$. The discussion of commitment strategy and non-commitment strategy in the prior subsections indicates a potential trade-off between holdups and incentive/effort. In the following analysis, we consider only the case in which $I \geq \bar{I}$. As stated in Proposition 1, if the manufacturer commits to the supplier, the collaboration will always result in an incremental innovation. Proposition 3 describe the equilibrium outcomes under different levels of competition among the suppliers.

Proposition 3: When the competitions among the suppliers are high, the commitment strategy is optimal for the manufacturer; otherwise, the non-commitment strategy is optimal.

Proof: See Appendix.

To understand this conclusion, first, consider the trade-off between the costs and benefits of the commitment strategy. The costs of the commitment are (*ex post*) holdups, and its benefits are (*ex ante*) increases in the collaboration effort in the design stage.

If the competitions are intense (low m), the supplier expects low profit, so it will puts in low effort to collaborate with the manufacturer in the design stage *(ex ante)*. Without the supplier's effort, the project has high risk of failure. Under this situation, the commitment strategy is optimal because it increases the incentive of the supplier to exert more effort. In contrast, when the supplier has greater expected profit because of low competitions (high m), the benefits of the commitment are low *(ex ante)* and the costs can be high because it may create holdup problems *(ex post)*. So the optimal strategy is non-commitment.

From the RBV, it may be argued that if there are many suppliers with high capability, the manufacturer may want to capture the resources of these suppliers by involving multiple suppliers in a project, and it may seem that a non-commitment strategy should be employed.

However, Proposition 3 cautions against such a strategy because it may undermine the collaboration effort and increase the risk of the project failure.

Next, Proposition 4 links the equilibrium outcomes with the probability of a radical innovation.

Proposition 4: When the probability of a radical innovation is high, the non-commitment strategy is optimal for the manufacturer; otherwise, the commitment strategy is optimal.

Proof: See Appendix.

Consider the situation in which a radical innovation is unlikely to happen (low π). The supplier could lose incentive to collaborate with the manufacturer, which leads to the failure of the project. The commitment strategy is optimal because it helps increase the supplier's incentive to put in more effort *(ex ante).* In addition, the cost of the commitment is low *(ex post).* On the other hand, if the chance of making a radical innovation is high (high π), the commitment strategy may significantly reduce the probability of such innovation *(ex post).* Furthermore, a prospect of a radical innovation already gives the supplier a motivation to collaborate with the manufacturer, so there is little additional benefit from the commitment *(ex ante).*

Although it may seem that when a radical innovation is highly anticipated, the manufacturer and the supplier should pull resources bundles together as much as possible, and the commitment strategy may seem to be optimal. However, when the supplier has to make a large investment for such innovation, Proposition 4 warns that such a strategy may not be optimal because the costs of holdups may outweigh the benefits of a higher collaboration effort.

5. Discussions and Numerical Examples

Our model demonstrates that the holdups are a distinct force that could unfavorably affect NPD performance. These holdup problems reduce the benefits of the resource expansion suggested by the RBV. While holdups can be viewed as another type of agency costs, they are different from the classical agency problems in that they are not based on asymmetric information between the principle and the agent and/or their different attitudes towards risk. We showed that even under the assumption of information symmetry and risk-neutrality, the inherent nature of cooperative investment and the supplier's self-interest to maximize its own profit still bring about holdup problems, and because these is no asymmetric information, monitoring the supplier's behavior and facilitating communication will not necessarily reduce these problems.

Our analysis also shows that the effect of ESI on NPD performance depends on both the effort made by the supplier in the design stage and the holdup problems in the development stage. Specifically, manufacturers that commit to the selected supplier are likely to have a higher probability of a successful new product (*ex ante*). However, due to holdup problems, new products tend to have a longer lead time or lower level of innovation (*ex post*). In contrast, manufacturers that do not commit to suppliers may bring new products to market faster with a higher expected level of innovation (*ex post*), but they face a higher risk of NPD failure (*ex ante*).

Our model further suggests that the manufacturer's optimal strategy in ESI depends on two key contingencies: the expected probability of a radical innovation (π) and the degree of competitions among the suppliers (m). Here we present a numerical example of the manufacturer's optimal commitment strategies to facilitate the understanding of the conclusion.

Table 1 summarizes the parameters. The effort cost function is assumed to be quadratic, i.e.,

$$F(\tau) = \frac{a}{2}\tau^2 . \tag{15}$$

<Insert Table 1 about here>

With this cost function, the model can be solved analytically and has closed form solutions:

$$\begin{cases} \tau_C^* = \dfrac{\rho c P}{a} \\ \tau_N^* = \dfrac{\pi \rho^\gamma P^\gamma I^{1-\gamma}(m-1)m^{-\gamma}}{a} \end{cases} \tag{16}$$

<Insert Figure 2 about here>

Figure 2 shows how the manufacturer's optimal strategy is influenced by both m and π. The red area is where the effect of m dominates: when the competitions are sufficiently high, the chance of radical innovation does not matter and the manufacturer should always use the commitment strategy. In the blue area, π dominates m: for projects with very low probability of a radical innovation, competitions among the suppliers do not matter and the manufacturer should always use the commitment strategy.

The yellow area is where both m and π affect the manufacturer's strategy. When the degree of competitions among the supplier is not intense and there is a sufficient probability of achieving a radical innovation, then the optimal strategy is to use the non-commitment strategy, as indicated by the yellow area above the curve; otherwise the commitment strategy is optimal as indicated by the yellow area under the curve.

The model shows that there are situations under which manufacturers may optimally make the commitment to the supplier and accept holdups as a mean to motivate the supplier to put in collaboration effort. In such a case, committed manufacturers with holdup problems may have higher expected profits than the non-committal ones with no holdups. Multi-stage interactions in our model make it possible for the manufacturer to trade off the costs and benefits across stages. This is impossible in a standard one-stage holdup model in which manufacturers always try to avoid holdups that reduce the expected profit.

6. Concluding Remarks

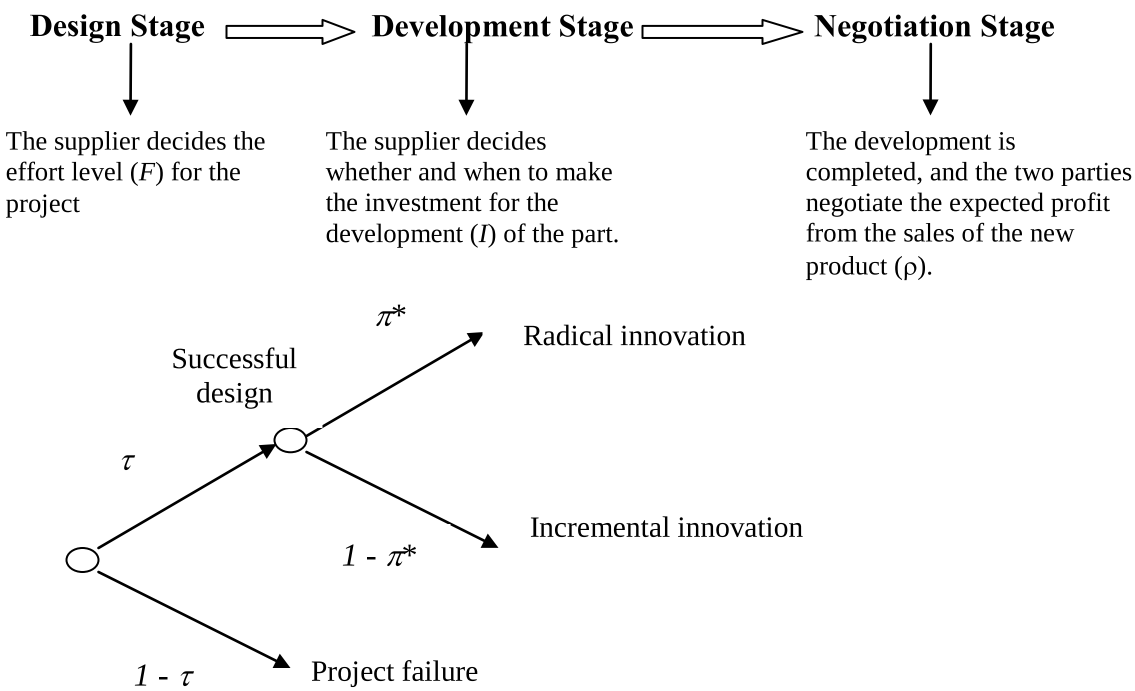
While the RBV predicts that resource expansion and integration from ESI should have a positive impact on NPD, our study suggests that the potential holdup problems derived from the nature of cooperative investment of ESI could have a negative impact on NPD. This problem is distinct from the agency cost suggested by the agency theory which also has negative impact on NPD, but assumes asymmetric information between the principle and the agent and/or their different attitudes towards risk. In contrast, holdups occur because of the lack of a complete contract and the fact that negotiation of profit distribution occurs after the investment is already made.

The analytical model demonstrates how holdup problems can generate negative impact on the NPD lead time and inhibit a radical innovation. It also shows that holdup problems can be alleviated with competitions among the suppliers, yet this may reduce the supplier's effort to collaborate in the design stage, leading to a higher probability of project failure. Given this tradeoff, this study suggests two important contingent variables that could influence the manufacturer's decision to commit to its selected supplier – the expected level of innovation and the degree of competitions among suppliers. These variables, among other factors, are critical in deciding what kind of strategy is to be used to facilitate a successful NPD.

Beyond the theoretical and managerial contributions, the analytical results provide a platform to conduct empirical research to validate them. All the variables are measurable. The overall impact of using ESI on new product performance can be empirically assessed, considering the different impacts from holdup problems, resources expansion, and agency problems. Through this exercise, more insights on how to manage ESI to support the manufacturer's strategic goal can be obtained. In addition, the influence of the contingency variables could be empirically tested to support managers' decision making in specific business contexts.

There are certain aspects of the model that warrants extensions in future research. First, the model assumes that manufacturers and suppliers collaborate only once. In practice, a successful collaboration may lead to future collaborations to develop other new products. Multiple interactions can change the supplier's incentive and the manufacturer's optimal strategies. Next, the current model abstracts from the competitions among manufacturers. Such competitions can motivate both parties to agree to rush new products to market faster, which could also change the dynamics of the collaboration. Finally, the model assumes that investment costs are opaque and specific to the supplier (the opportunity costs or the training costs, for example). Exploring mechanisms that allow for the manufacturer to share part of the development cost with the supplier is another interesting avenue to explore how to mitigate holdups.

Figure 1: Supply Involvement Stages, Major Decisions and Probability of Success



Note: π^* represents the expected probability of a radical innovation at the start of the design stage. Once the design is completed, the nature of the innovation is known to both parties.

Figure 2 The Manufacturer's Optimal Commitment Strategies

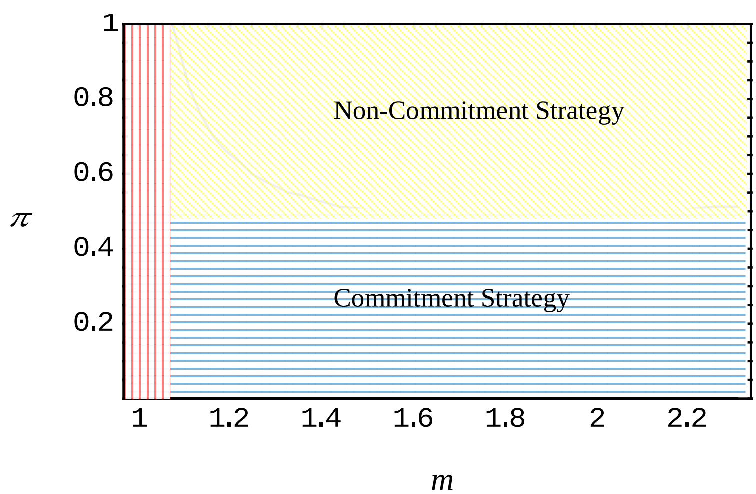


Table 1 Parameter Configuration

Parameters	*Value*
Risk-free rate, r	6%
Drift rate, α	6%
Volatility rate, σ	25%
Initial present value of the profit, P	1.0
Supplying firm's bargaining power, ρ	0.1
Development cost, I	0.1
Effort cost parameter, a	2.5

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Appendix

Derivations of S_C, B_C, and P_C when the Part is Radically Innovative

We only present the outline of the derivations; interested readers are referred to Dixit and Pindyck (1994) for details. The profit function of the supplier, S_C, obeys the ordinary differential equation (ODE):

$$\frac{1}{2}\sigma^2 P^2 S_C'' + \mu P S_C' - r S_C = 0. \quad \text{(A1)}$$

For an arbitrary value of P_C, the solution to the ODE is derived using a boundary condition:

$$S_C\big|_{P=P_C} = \rho P_C - I, \quad \text{(A2)}$$

and the solution is $S_C = (\rho P_C - I)\left(\frac{P}{P_C}\right)^{\gamma}$. The manufacturer's profit function, B_C, is derived in the same way, but ρ is replaced with $1-\rho$, and I is set to 0. We obtain $B_C = (1-\rho)P_C\left(\frac{P}{P_C}\right)^{\gamma}$. To find the optimal P_C for the supplier, the following smooth-pasting condition is used:

$$S_C'\big|_{P=P_C} = \rho. \quad \text{(A3)}$$

and the solution is $P_C = \frac{\gamma}{\gamma-1}\frac{I}{\rho}$.

Proof of Proposition 3

Formally, it will be shown that, when c is sufficiently low, there exist a unique $\overline{m} \in (1, \frac{\gamma}{\gamma-1})$, such that for $m \geq \overline{m}$, $E[B_N] - E[B_C] \geq 0$, and the manufacturer chooses the non-commitment strategy, and for $m < \overline{m}$, $E[B_N] - E[B_C] < 0$, and the manufacturer chooses the commitment strategy. First,

$$E[B_N] - E[B_C] = \tau_N^* \left(\pi(1-\rho)P_N\left(\frac{P}{P_N}\right)^{\gamma} + (1-\pi)cP \right) - \tau_C^*(1-\rho)cP \quad . \quad \text{(A4)}$$

It can be verified that if c>0, but is sufficiently small, at $m = 1$, $E[B_N] - E[B_C] < 0$, and at $m = \frac{\gamma}{\gamma-1}$, $E[B_N] - E[B_C] > 0$. By continuity of $E[B_N] - E[B_C]$, there exists $\overline{m} \in (1, \frac{\gamma}{\gamma-1})$ such that at this point $E[B_N] - E[B_C] = 0$. If $E[B_N] - E[B_C]$ is monotonically increasing in *m*, then $\overline{m}$ is unique, and the desired results obtain. But since we do not impose a particular functional form on the effort function, $E[B_N] - E[B_C]$ may not be monotonically increasing in *m*. However, because $E[B_N] - E[B_C]$ is a continuous function, and the range of *m* is compact, we argue that if *c* is sufficiently small, $\overline{m}$ is unique and the desired results obtain. In other words, the function $E[B_N] - E[B_C]$ may not be monotonic in *m*, but it crosses the zero threshold only once. To see this, note that, if $E[B_N]-E[B_C]$ is not monotonic in *m*, but does not have an interior minimum, there is only one possibility: $E[B_N]-E[B_C]$ is increasing in *m* at first, and decreasing later, but at the maximum $m, E[B_N]-E[B_C]>0$, suggesting that the function does not decrease enough to reach the zero threshold again, so $\overline{m}$ is unique. However, if $E[B_N]-E[B_C]$ has an interior minimum, but at the minimum $E[B_N]-E[B_C]>0$, then, the function $E[B_N]-E[B_C]$ crosses the zero value only once, and $\overline{m}$ is unique. For this condition to be true, *c* has to be small. To see this, denote $m_n>1$ as the value of *m* that yield the interior minimum of $E[B_N]-E[B_C]$. Now, take the limit of $E[B_N]-E[B_C]$ at the interior minimum, m_n, and let *c* goes to zero: $\operatorname*{Lim}_{c\to 0} E[B_N]-E[B_C]\big|_{m=m_n} = \tau_N^*\pi(1-\rho)P_N\left(\frac{P}{P_N}\right)^{\gamma}\Bigg|_{m=m_n} >0$, suggesting that, at the interior minimum, there exists a value of a small *c*>0 such that $E[B_N]-E[B_C]>0$, so $\overline{m}$ is unique.

Proof of Proposition 4

Formally, it will be shown that, when c is sufficiently low, there exist a unique $\overline{\pi}\in(0,1)$, such that for $\pi\geq\overline{\pi}$, $E[B_N]-E[B_C]\geq 0$, and the manufacturer chooses the non-commitment strategy, and for $\pi<\overline{\pi}$, $E[B_N]-E[B_C]<0$, and the manufacturer chooses the commitment strategy.
It can be verified that if *c*>0, but is sufficiently small, at $\pi=0$, $E[B_N]-E[B_C]<0$, and at $\pi=1$, $E[B_N]-E[B_C]>0$. By continuity of $E[B_N]-E[B_C]$, there exists $\overline{\pi}\in(0,1)$ such that at this point $E[B_N]-E[B_C]=0$. We will show that $\overline{\pi}$ is unique because $E[B_N]-E[B_C]$ is strictly increasing in π, so the desired results obtain. To see this, differentiate $E[B_N]-E[B_C]$ with respect to π: $\frac{\partial[E[B_N]-E[B_C]]}{\partial\pi}=\frac{\partial\tau_N^*}{\partial\pi}A+\tau_N^*\frac{\partial A}{\partial\pi}$. Because $\frac{\partial\tau_N^*}{\partial\pi}>0$, $\frac{\partial[E[B_N]-E[B_C]]}{\partial\pi}>0$, so $E[B_N]-E[B_C]$ is strictly increasing in π, and $\overline{\pi}$ is unique.