A System Dynamics Approach to Decision Making on Outsourcing from Suppliers with Different Innovation Capabilities

Bowon Kim
KAIST Graduate School of Management
207-43 Cheongryangri Dongdaemoon-Ku, Seoul, 130-012 KOREA
T. +82 2 958 3610, F. +82 2 958 3604; bwkim@cais.kaist.ac.kr

In this paper, we develop an economic insight into a dynamic outsourcing decision when a firm can use multiple suppliers with different innovation capabilities. Many firms focus primarily on current cost structures when they choose their suppliers or make a plant location decision. The research result in this paper implies that focusing only on the present cost structure might lead to a short-term solution with possible long-term sub-optimality. In order to achieve long-term effectiveness, the firm must take into account the dynamic evolution of cost structure, which is often carried out by the suppliers' innovating activities. The setting can be handily extended to a global market, where an individual supplier can be analogized with a pool of suppliers in a particular country. To support our propositions, we employ an optimal control theory modeling and its numerical examples derived from system dynamics simulation.

Subjects: Supply Chain Management, Supplier Innovation
Methodology: System Dynamics Simulation, Optimal Control Theory Modeling

1. Introduction

Supply chain management has become an important issue for operations improvement. In essence, it is concerned with how to effectively manage the relationship between manufacturers (customers) and suppliers. The reason the supplier relationship is much emphasized is that suppliers are one of the most important sources of innovation for manufacturing firms (von Hippel 1988): one of the critical questions raised by operations managers could be "How to encourage and reap benefits from our suppliers' innovation?" But, this might be a little biased point of view from the supplier's perspective: it may not be always profitable to innovate for the manufacturer unless there should be some form of reward for that innovation either directly from the manufacturer or from its own improvement due to the innovation.

Therefore, managing the supplier's innovation and benefiting from it require systemic approaches encompassing the two possibly conflicting perspectives, i.e., manufacturer's and supplier's. The primary research question raised in this paper is 'Under what circumstances could it be mutually beneficial for the manufacturer to subsidize the supplier's innovation and, in turn, for the supplier to offer its customer (manufacturer) with innovated supplies?' We can further break down the research question into two more specific ones as follows:

i) How much subsidy should the manufacturer provide to its supplier with varying degree of innovation capability? That is, what is the relationship between the supplier's innovation capability and manufacturer's support level?

ii) How would the manufacturer's subsidy amount be affected by the market demand uncertainty? Should the optimal subsidy be increased or decreased as the uncertainty embedded in market demand increases?

In order to answer the questions, we set up and solve an analytical model using system dynamics simulation. However, as in most cases involving system dynamics simulation models, our model is also based on specific assumptions about the dynamic behaviors of decision variables. We will talk about some of the research limitations due to possible idiosyncrasy of the assumptions. In the next section, we describe our research models, single-supplier and two-supplier, and relevant assumptions. Section 3 depicts and summarizes the simulation outcomes. In the final section, we suggest managerial implications of the simulation analysis.

2. Model Formulation

For our research, a supply network is defined to consist of manufacturers, suppliers, and product markets (Hammond 1992). In this paper, we intend to examine the interplay among those constituents of the supply network, and try to find out, rather than simply replicate, 'optimal dynamics' of the key decision variables. Thus, we formulate the problem as an optimization one, and utilize the optimizer in the simulation software.

Although the primary perspective in our model is the manufacturer's, we espouse the reasoning that for a solution optimal to both of the participants in the supply network, they need to have a network perspective, i.e., the supplier and the manufacturer need to share at least a comparable goal for the network operations. Thus, the objective in our model is to optimize the decision variables/parameters for maximum network profit as well as the manufacturer's.

We first consider a simple supply network in which there is only one supplier transacting with the manufacturer. A more complicated model involving two suppliers will be derived from the analysis result for the single supplier case.

2.1. Single-Supplier Model

To properly answer the research questions, we start with a simple model involving only one supplier. Figure 1 describes the dynamics in an influence diagram. In the dynamics, we can see that the manufacturer has an option to support its supplier's innovation that can lead to lower supply cost and eventually cheaper price of the final product. It is reasonably assumed that the market demand is affected by the final product price: the cheaper the price, the more the average demand for that product. Increased market demand can translate into improved manufacturer's profitability. However, it might not be yet clear whether the increased profit encourages the manufacturer's subsidy for the supplier innovation. Another factor we need to consider is the uncertainty embedded in the market demand. We need results from system dynamics simulation to determine whether the market demand uncertainty would increase the average market demand and whether the uncertainty affects the manufacturer's subsidy decision. In Figure 1, there are 2 types of interaction, one between supplier and manufacturer and the other between market and manufacturer. As the key decision making entity, the manufacturer must effectively manage the two interactions for an optimal solution.

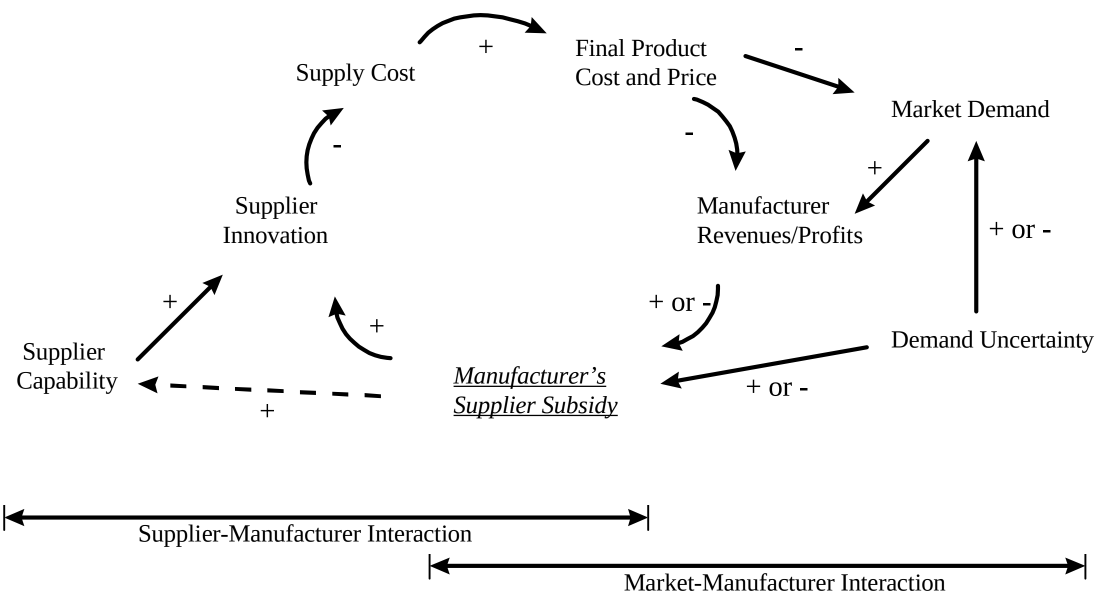
More detailed and specific model equations and parameters are presented in Appendix 1. The primary objective of the system dynamics simulation is to determine the optimal amount of manufacturer's support for supplier innovation as

i) supplier's innovation capability varies, and/or

ii) magnitude of the market demand uncertainty changes.

The simulation will also show how the optimized performance measures such as manufacturer's profit and network profit are affected by these changes over time. It is in order that we define the network profit more formally: network profit is the sum of manufacturer's profit and supplier's. If we consider a situation in which the manufacturer regards its supplier as partner and also vice versa, it is logical to assume the network profit to be a proper performance measure for the network (consisting of manufacturer and supplier) as a whole.

Figure 1. Supply Network Dynamics of Single Supplier Model



The optimization problem can be described concisely as follows:

Maximize *{Manufacturer's Profit + Network Profit}*
Subject to *{Dynamic Constraints}*
By changing *{Manufacturer's Supplier Subsidy}*
As varying *{Demand Uncertainty, Supplier Innovation Capability}.*

There must be an agreeable mechanism to allocate the network profit between manufacturer and supplier in case either one of them realizes less profit than that achieved when the supplier subsidy was not considered. This is an issue of fair distribution of the profit from coordination (Kim and Mauborgne 1991).

2.2. Two (Multiple) Supplier Model

As an alternative to a multiple-supplier case, a two-supplier model was developed where there are two suppliers transacting with a manufacturer (customer) as the name insinuates. Although considering only 2 suppliers is mainly for analytical simplicity, we believe the analysis outcomes based on the two-supplier model can be applicable to the multiple-supplier situation reasonably well: for instance, Dyer and Ouchi (1993) suggested that utilizing two suppliers is usually enough to give the firm competitive benefits which could be derived from having more than two suppliers (Lau and Lau 1994).

Most of the parameters, variables, and dynamic relations used in this two-supplier model are similar with those in the single-supplier case. The most important difference, however, is that the manufacturer now has an option to procure its resources from more than one supplier.

There are a few changes and additions in the two-supplier model due to this difference. That is, the two-supplier model needs to take into account the following issues in addition to those for the single-supplier model:

i) The manufacturer has to decide on how to divide the demand for the final product into two for the two suppliers. For example, suppose the market demand for the final product is 100 units. Then, the manufacturer must decide how many units out of 100 should be procured from supplier 1 and how many from supplier 2. This issue essentially relates to defining rules or criteria with which the manufacturer determines the demand split between two suppliers.

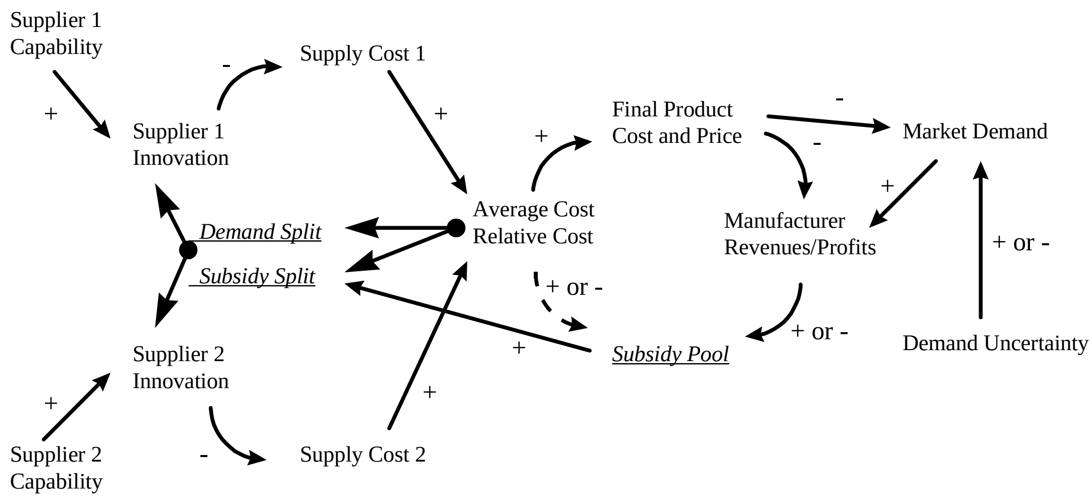
ii) As in the single-supplier model, the manufacturer needs to determine the optimal amount of supplier subsidy. But, in the two-supplier model, the manufacturer must take a further step to decide how to split the subsidy pool between the two suppliers.

Depending on which criteria to use, the demand split issue can become extremely trivial. For instance, if the criteria are solely based on cost differential (absolute-cost rule), the manufacturer might want to procure 100% of the demand from the supplier that can have a cost advantage, however small it would be, over the other supplier. This decision rule can distort the true comparative advantage between the suppliers. Suppose there are two different situations, (1) supplier 1's unit cost is $10 and supplier 2's $15, and (2) supplier 1's cost is $10 and supplier 2's $11. According to the simple 'absolute-cost criteria,' supplier 1 will get 100% demand order from the manufacturer. The 'relative difference' is not reflected at all.

Another fallacy is concerned with implementation in a real business setting. Suppose that in the current period, supplier 1's cost is $10 and supplier 2's $11, but in the next period, supplier 1's $10 and supplier 2' $9.99. Should the manufacturer strictly apply the cost-only-criteria, he has to procure 100% from supplier 1 in the current period, but solely from supplier 2 in the next. The rule forces the manufacturer to change its primary source of supplies constantly as well as instantly. Should there be no transaction cost, this kind of instant change might be possible. But, in reality, such constant and instant changes would cost enormous transaction expenses: it is practically impossible for a manufacturer to determine the supplier selection exclusively based on the absolute-cost difference. In our simulation model, we used a demand split rule that takes into account the relative cost advantage (relative-cost rule) rather than the absolute cost difference: therefore, gradual adjustment of demand split becomes possible. For instance, if supplier 1's cost is $10 and supplier 2's $11, then supplier 1 would get about 52.4% ($\approx \frac{11}{10+11}$) of the demand and supplier 2 gets the rest of it, i.e., 47.6%. Likewise, if supplier 1's cost is $10 and supplier 2's $9.99, then supplier 1 would get about 49.97% ($\approx \frac{9.99}{10+9.99}$) of the demand, which is quite different from 0%, the demand split for supplier 1 under the 'absolute-cost rule.'

The relative-cost rule seems more realistic than the absolute-cost in two respects. First, as already mentioned, the relative-cost rule allows the manufacturer to adjust his demand split structure gradually rather than instantly. Second, when the relative cost varies frequently, it can become risky to rely completely on a single supplier because the balance of relative cost could shift to the other supplier again. In addition, the manufacturer must consider the importance of maintaining longer-term relationships with multiple suppliers as a way to secure stable and continuous procurements in an uncertain business environment (Davis 1993, Arntzen, et al. 1995).

Figure 2. Supply Network Dynamics of Two Supplier Model

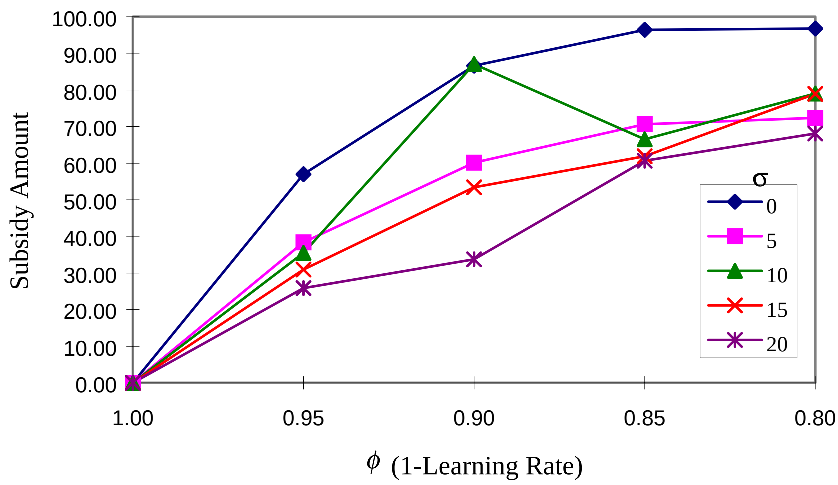


The split of supplier subsidy pool is built into the simulation model so that it becomes part of an optimal solution.

The optimization problem can be described concisely as follows:

Maximize *{Manufacturer's Profit + Network Profit}*
Subject to *{Dynamic Constraints}*
By changing *{Manufacturer's Supplier Subsidy,*
Subsidy Split, Demand Split between Two Suppliers}
As varying *{Demand Uncertainty, Supplier Innovation Capability}.*

Figure 3. Manufacturer's Support for Supplier's Innovation: Single-Supplier Model



3. System Dynamics Simulation

We present the simulation result in Figure 3 and 4 for the single-supplier model and Figure 5 to 7 for the two-supplier model. Specific parameter values are shown in Appendix 1. Here we state basic characteristics of the dynamics and defer in-depth interpretation and implications of the outcomes to the final section of this paper.

Figure 4. Optimal Network Profit: Single-Supplier Model

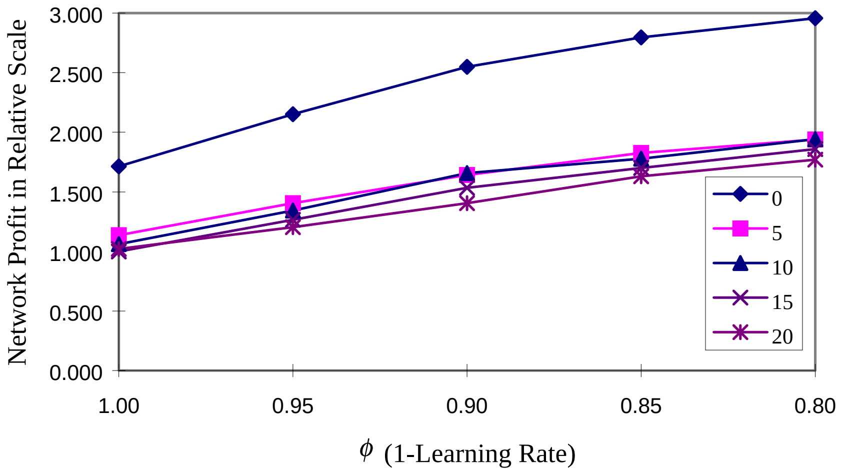


Figure 5. Manufacturer's Support for Supplier's Innovation: Two-Supplier Model

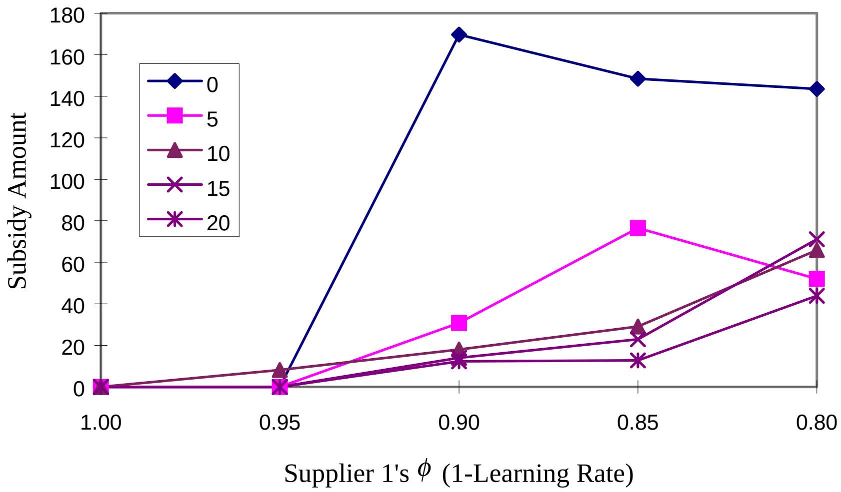


Figure 3 outlines the optimal amount of supplier subsidy the manufacturer invests for supplier innovation as the market demand uncertainty (σ) and the supplier's innovation/learning capability (ϕ) vary. As described in Appendix 1, the demand uncertainty is represented by its standard deviation: the higher the uncertainty, the larger the standard deviation (σ). Supplier's learning capability is captured by the progress rate, ϕ (i.e., 1 - learning rate): the lower the progress rate, the higher the supplier's innovation capability (Yelle 1979).

From Figure 3, we can infer that the optimal subsidy amount increases as (i) the supplier's learning capability increases, and (ii) the market demand uncertainty decreases, although with a much less regularity.

Figure 4 shows the optimal network profit (i.e., manufacturer's profit plus supplier's) for the single-supplier model: its overall dynamics resembles that in Figure 3, although the absolute difference seems much smaller among those cases with market uncertainty larger than zero.

Figure 6. Optimal Network Profit: Two Supplier Model

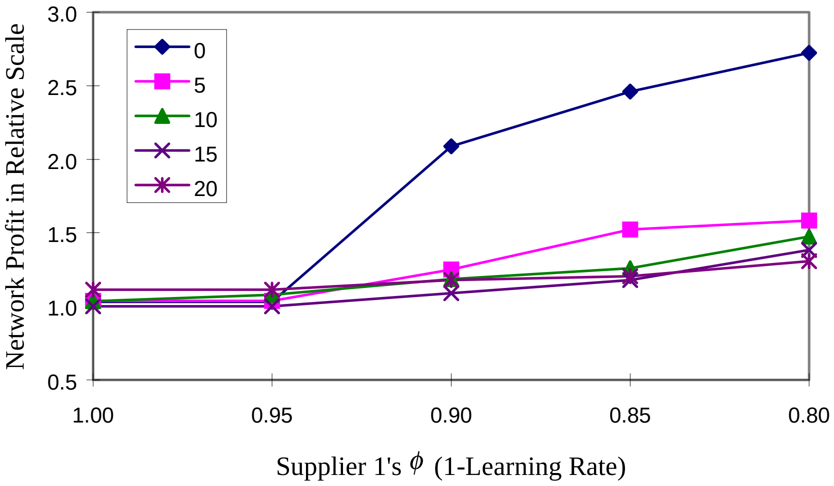
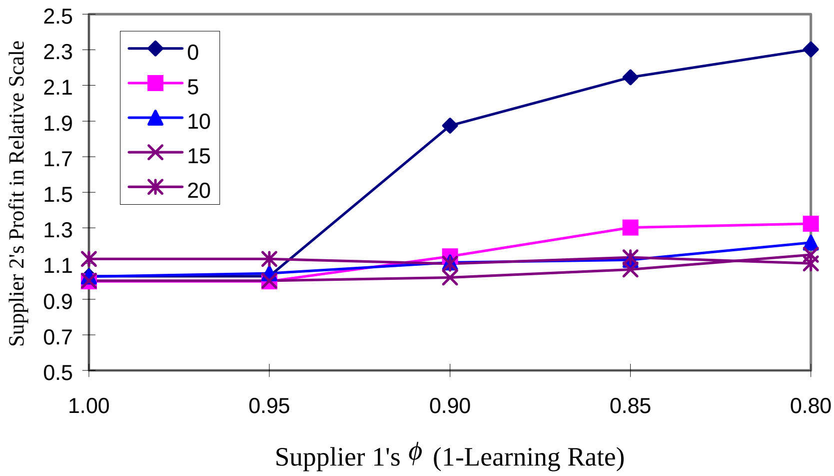


Figure 7. Less Innovative Supplier's (Supplier 2's) Profit



The simulation result for the two-supplier model is depicted in Figure 5 to 7. In this model, we need to focus on supplier 1's learning capability since the model assumes that supplier 1 is more innovative than supplier 2 without loss of generality: in fact, supplier 2 is assumed not to engage in innovating activities.

Figure 5 shows the optimal dynamics of supplier subsidy amount as market uncertainty and supplier 1's innovation capability vary: although somewhat more irregular than that in Figure 3, the overall dynamics can be regarded as comparable and similar interpretations can be offered. Another meaningful outcome, albeit not properly illustrated in the figure, is that the optimal solution always allocates the entire subsidy to only one supplier with higher innovation capability. We explain this phenomenon in greater detail in the last section.

Figure 6 displays the dynamics of optimal network profit (i.e., manufacturer's profit plus supplier 1's and supplier 2's) for the two-supplier model, and again with less regularity its overall behavior can be deemed comparable with that in Figure 4: that is, the network profit increases as supplier 1's innovation capability increases, and as the market demand uncertainty lessens.

It turns out that the supplier 1's optimal profit looks very similar with the dynamics of network profit, as easily anticipated. A somewhat counterintuitive outcome is related with the dynamics of less innovative supplier's optimal profit as in Figure 7. Although one can ascribe it to an idiosyncrasy of the model, it is still interesting to see that both innovative and less innovative suppliers can benefit from the supplier subsidy from a manufacturer. There seems a complementing force between suppliers even if they are competing for the same manufacturer: this can shed a new light on the supply network management, which we further elaborate on in the next section (Lau and Lau 1994).

4. Analysis and Managerial Implications

From the simulation analysis, we can infer a few managerial implications. As the market uncertainty increases, the manufacturer's overall propensity to support its supplier's innovation decreases. One possible explanation is that when the market demand is highly uncertain, it becomes also unclear whether the supplier's innovation can engender enough demand increase so that the innovation cost can be fully recovered. Since the prospect of recouping the innovation investment is limited when the market is uncertain, it seems reasonable for the manufacturer to scale down its support for the supplier's innovation as the market becomes more and more volatile.

As can be easily guessed, the higher the supplier's innovation capability, the more the manufacturer's subsidy for the supplier. It is reasonable to expect that the marginal profit (revenue) of supplier subsidy is higher when the supplier has more innovation capability.

When there are two competing suppliers, the manufacturer spends all of its supplier subsidy for only one supplier with higher innovation capability. This can be elucidated with the concept of scale economy. Since the effect of supplier innovation capability increases as the supplier's experience (thus, effort) for that innovation accumulates, it makes sense to concentrate the subsidy on one supplier's innovation effort so that the selected supplier can realize the scale economy (of innovation activity) more fully.

As a similar inference, we can conclude that the market demand split by the manufacturer to its suppliers would be done in a rather extreme way: the supplier who has the cost advantage, however small is the cost difference between the two suppliers, would get 100% demand from the manufacturer. We can see this could be the actual case if there is no transaction cost involved with the manufacturer-supplier transaction. In reality, however, there is always huge cost involved in this kind of transaction: therefore, it is almost impossible for a manufacturer to freely change its primary supplier because of a (sometimes very small) relative cost advantage that might last only for a short period of time. Considering the practical limitation, we assumed that the demand split is based on the ratio of supply cost between the two suppliers, not all-or-nothing absolute difference. In this way, the manufacturer procures its supplies from both of the suppliers even when one supplier's cost is higher than the other's. It is a premise consistent with the practical emphasis on the longer-term relationship between manufacturer and supplier.

Another very intriguing observation is that it is not only the innovative supplier, but also the less innovative supplier, who can benefit from the supplier innovation. In this research, we modeled that supplier 1 has potential to innovate over time whereas supplier 2 does not have the innovation potential although its current supply cost is cheaper than supplier 1's. Thus, all of the supplier innovation occurs by supplier 1, but still supplier 2 benefits from that innovation. The reason is that since the manufacturer retains two suppliers for longer-term consideration while varying the demand split between the two according to the relative cost difference, the cost of the manufacturer's final product is determined by the average of both suppliers' costs; the final product cost affects the product market price which influences the market demand, i.e., the lower the market price, the more the market demand. The innovative supplier's innovation enables the manufacturer to cut the product price so that the overall market demand increases for the product. Because the demand split is done according to the relative cost difference, supplier 2 can still get some order from the manufacturer that might be decreasing in a relative measure (since its cost position becomes worse than supplier 1's), but increasing in an absolute sense (since the demand increase compensates more than the loss due to the worsening relative cost position). As a result, there could be a complementary relationship between the suppliers, i.e., one supplier's innovation could increase the other's profitability as well.

The models can be easily extended to encompass decision making on outsourcing in a global market, where an individual supplier can be regarded as a pool of suppliers in a particular national market. Global outsourcing decision involving multiple suppliers can be an important future subject in this line of research.

Keeping in mind possible limitations due to the specific assumptions made in the simulation models, managers participating in supply networks as manufacturers can use the simulation result reported in this paper as a means to rethink and reevaluate their strategies in terms of investing in suppliers' innovating activities. Suppliers in the networks, in turn, can also learn some useful lessons from this research: for instance, the existence of possible common ground, i.e., complementary relationship, among suppliers competing for the same manufacturer's demand, and therefore a possibility of productive collaboration between suppliers.

References

Arntzen, B. C., G. G. Brown, T. P. Harrison, and L. L. Trafton (1995). "Global Supply Chain Management at Digital Equipment Corporation." *Interfaces, 25,* 1, 69-93.

Davis, T. (1993). "Effective Supply Chain Management." *Sloan Management Review, Summer*, 35-46.

Dyer, J. H. and W. G. Ouchi (1993). "Japanese-Style Partnerships: Giving Companies a Competitive Edge." *Sloan Management Review, Fall*, 51-63.

Hammond, J. H. (1992). "Coordination as the basis for quick response: a case for 'virtual' integration in supply networks." *HBS Working Paper* #92-007.

Kim, W. C. and R. A. Mauborgne (1991). "Implementing global strategies: the role of procedural justice." *Strategic Management Journal, 12,* 125-143.

Lau, H.-S. and A. H.-L. Lau (1994). "Coordinating two suppliers with offsetting lead time and price performance." *Journal of Operations Management, 11*, 327-337.

von Hippel, E. (1988). *The Sources of Innovation*. Oxford University Press. New York.

Yelle, L. E. (1979). "The Learning Curve: Historical Review and Comprehensive Study." *Decision Sciences, 10,* 302-328.

Appendix 1. Simulation Assumptions

A1. Single-Supplier Model
The simulation model for the single-supplier case assumes the following.

- Time horizon: $t \in [0,\ 100]$
- Market demand distribution:
  ~ Normal distribution with mean 'AverageDemand' and standard deviation σ (a decision parameter)
  ~ AverageDemand = 330 - 10×UnitPrice
  ~ UnitPrice = Supply Cost + Internal Manufacturing Cost ($10) + Markup ($10)
- Information delay: 1 period delay between observation of market demand and ordering to the supplier by the manufacturer
- Inventory Holding Cost = Inventory × Unit Price × 0.015; about 18% finance charge on the inventory
- Unit supply cost:
  ~ Unit Cost = 5 + $5(Sc)^{\Xi}$; 5 fixed cost, 5 base variable cost
  ~ Sc = Cumulative Subsidy/100; scaled subsidy
  ~ $\Xi = \dfrac{ln\phi}{ln2}$, ϕ = 1 - Learning Rate

A2. Two-Supplier Model
In addition to the assumptions described above, the two-supplier model employs the following.

- Demand split for supplier 1:
  ~ Demand for Supplier 1 = 1-$Cost1 / (Cost1 + Cost2)$
  ~ $Cost1$ = supplier 1's unit supply cost
  ~ $Cost2$ = supplier 2' unit supply cost
- Price of the final product:
  ~ UnitPrice = Average Supply Cost + Internal Manufacturing Cost ($10) + Markup ($10)
  ~ Average Supply Cost = weighted average of supplier 1's supply cost and supplier 2's supply cost