Cost analysis in the manufacturing industry by a learning model of outsourcing

Hirotoshi Kambara

Graduate School of Business Science,
University of Tsukuba,
3-29-1 Otsuka, Bunkyo-ku, Tokyo, 112-0012, Japan
Email: s1545004@u.tsukuba.ac.jp

Abstract: Most empirical studies provide evidence that the relationship between the degree of outsourcing and firm performance is an inverted U-shape. Those studies implemented regression analysis to provide evidence of the inverted U-shaped relationship statistically. Cost reduction is used to represent firm performance in this study. Therefore, the purpose of this study is to examine how the relationship between the degree of outsourcing and the total cost of a firm becomes a U-shape instead of an inverted U-shape in the manufacturing industry. Cost analysis is implemented by simulations using a learning model of outsourcing to provide a more structural explanation than a statistical method. As a result, I suggest that the internal coordination cost and external coordination cost affect the relationship between the total cost of a firm and the outsourcing rate.

Keywords: outsourcing; firm performance; learning model; learning rate; capability; production cost; internal coordination cost; external coordination cost; U-shape; inverted U-shape.

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Biographical notes: Hirotoshi Kambara received his MBA from the Hosei University, Japan. He is a doctoral candidate at The University of Tsukuba. His main research interests include firm boundary and strategy.

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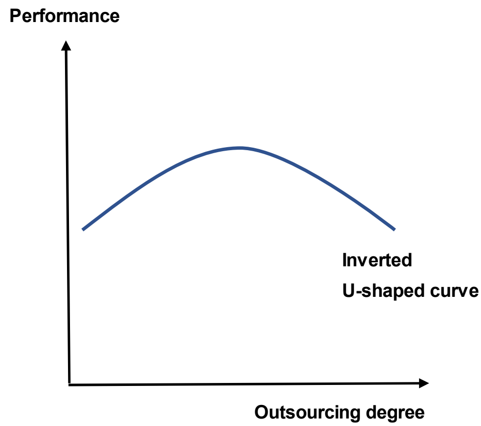
1 Introduction

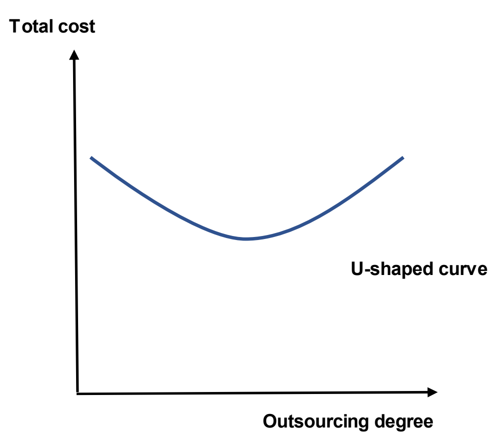
The relationship between outsourcing and firm performance has been discussed in numerous previous studies. Most of them provide empirical evidence of an inverted U-shaped relationship between them, as shown in Figure 1, when the degree of outsourcing is plotted on the x-axis and firm performance is plotted on the y-axis (Grimpe and Kaiser, 2010; Kotabe and Mol, 2009; Kotabe et al., 2012; Leachman et al., 2005; Rothaermel et al., 2006; Weigelt and Sarkar, 2012). These studies suggest that firms should balance integration and outsourcing to improve their performance.

Figure 1 Inverted U-shaped relationship between outsourcing and firm performance (see online version for colours)



In this study, cost reduction is used for firm performance instead of profitability (Kambara, 2013, 2016; Kotabe and Mol, 2009), revenue (Rothaermel et al., 2006), or sales share (Grimpe and Kaiser, 2010; Kotabe et al., 2012). The inverted U-shaped relationship between outsourcing and firm performance (profitability) implies that a firm's total cost increases when the outsourcing rate approaches full integration and full outsourcing. Therefore, the purpose of this study is to examine how we can obtain a U-shaped relationship between the total cost of a firm and outsourcing in the manufacturing industry, as shown in Figure 2.

Figure 2 U-shaped relationship between outsourcing and total cost (see online version for colours)



Kambara (2016) empirically shows that the relationship between outsourcing and firm performance is U-shaped under the production organisation. The activities of the production organisation are under the production operations of the firm's value chain, while those of the company-wide organisation are under its overall value chain, such as R&D, production, sales and marketing, and general management (HRM, accounting, legal affairs, etc.).

Kambara (2016) developed a hypothesis by introducing the concept of product architecture. From the perspective of product architecture, transaction costs can be reduced by outsourcing if a firm engages in modular product design, and is also reduced by integration if a firm engages in interdependent product design (Baldwin, 2007; Baldwin and Clark, 2000; Christensen et al., 2002).

A similar explanation is produced by capability theory. Capability theory tells us that if the cost of internally developing ancillary capabilities is higher (lower) than that of buying them from other companies in the market, then outsourcing (integration) strategy should be adopted (Barney, 1999; Christensen et al., 2002; Jacobides and Winter, 2005; Langlois and Robertson, 1995). Therefore, transaction costs can be reduced by outsourcing if the market has production capability, and they can also be reduced by integration if the firm has production capability. A partial outsourcing strategy would bring cost inefficiency, because a firm must pay attention to economising costs both internally and externally. Therefore, I assume that the relationship between the production cost of a firm and the outsourcing rate is an inverted U-shape under the production organisation.

The key question in this study is under what conditions can we turn the inverted U-shaped relationship between the production cost of a firm and the outsourcing rate under the production organisation into the U-shaped relationship between the total cost of a firm and the outsourcing rate under the company-wide organisation? In order for the inverted U-shaped curve to be transformed to the U-shaped one, there incur rapidly increasing additional costs when outsourcing and integration rates become high. It is estimated that the shape can be transformed if additional costs are larger than the cost reduction realised by the efficiency of complete outsourcing and integration.

In this study, I assume that additional costs are generated when the 'to be integrated' activities for which a firm can utilise its learning capability are outsourced or when the 'to be outsourced' activities for which it can utilise its learning capability are integrated. Under this assumption, mathematical learning models of outsourcing are constructed.

In Section 2, prior studies regarding learning models are reviewed. In Section 3, learning models for outsourcing are constructed. Simulation is implemented in Section 4, and implications and concluding remarks are presented in Section 5.

2 Literature review

The learning curve, which shows that unit cost decreases at a constant rate each time the number of units manufactured doubles, was observed by Wright (1936). Wright's research on aircraft production was the first documentation of an organisational learning curve (Argote and Epple, 1990). Conley (1970) of the Boston Consulting Group introduced the experience curve. According to Conley (1970), the learning-curve effect is applied not only to direct labour but also to most of the activities performed by a corporation. Conlay also noted that the composite learning curve (or the experience curve), which is composed of the total cost of a product, declines at a fixed percentage as the cumulative quantity of units manufactured doubles. Hall and Howell (1985) pointed out that these terms, the learning curve and the experience curve, are often used interchangeably, but the former is usually applied to labour costs and the latter is applied to the total cost of a product.

Indirect costs should be considered as well as direct costs in studying the learning-curve effect. Abernathy and Wayne (1974, p.110) noted that "product design, marketing, purchasing, engineering, and manufacturing must be carefully coordinated and managed". In reply to this point, we find several preceding studies. In the analysis of the relationship between the total production cost of a firm and the outsourcing rate, Anderson and Parker (2002) introduced the integration cost, and Cha et al. (2008) introduced the coordination cost in their learning models.

The integration cost concept of Anderson and Parker (2002, p.314) includes "learning from component design and production about how best to integrate the component into the overall product design", and the cost increases as the outsourcing rate increases because only the firm producing the component can learn component integration. The coordination cost concept of Cha et al. (2008) is the cost of monitoring, controlling, and managing the work, and it is incurred in-house, depending on the outsourcing rate; therefore, it increases in proportion to the outsourcing rate.

Cha et al. (2009) utilised the learning models and the simulation data of Cha et al. (2008), and implemented further simulations based on four cases to determine the optimal outsourcing rate of information technology. Their results imply that the relationship between the total cost of a firm and the outsourcing rate is a U-shaped curve if the production knowledge transfer rate from a vendor to a firm is high, and it is an inverted U-shaped curve if the rate is low. In addition to the production knowledge transfer rate, the authors used the coordination knowledge depreciation rate to offer optimal outsourcing strategies.

However, most of the preceding studies regarding make or buy decisions (Grimpe and Kaiser, 2010; Kambara, 2013, 2016; Kotabe and Mol, 2009; Kotabe et al., 2012; Leachman et al., 2005; Rothaermel et al., 2006; Weigelt and Sarkar, 2012) do not provide a structured explanation of how the relationship between outsourcing and firm performance becomes an inverted U-shaped curve or a U-shaped curve. These studies developed hypotheses qualitatively and applied statistical methods to test them.

This study attempts to show how we can obtain a U-shaped relationship between the total cost of a firm and the outsourcing rate in the manufacturing industry by changing the learning rates of key factors such as production and coordination. I employ two coordination costs in the learning model of outsourcing: the internal coordination cost and the external coordination cost. Anderson and Parker (2002) and Cha et al. (2008, 2009) do not consider the external coordination cost, which increases in proportion to the integration rate.

There are a significant number of preceding studies that employed a learning model. However, few studies have investigated the relationship between the total cost of a firm and the outsourcing rate. In this respect, this study significantly contributes to the further development of the learning model.

3 Model construction

In this section, first, a basic learning model of knowledge and cost is introduced. Then, learning models for outsourcing are constructed.

3.1 Knowledge and cost learning model

Let the initial unit production cost = C_0 and the unit production cost at $t = C(t)$, the initial production knowledge level = k_0, the accumulated production knowledge at $t = k(t)$, and the exponent = b, then the standard learning model can be written as in equation (1) (Cha et al., 2008; Wei et al., 2017).

$$\frac{C(t)}{C_0} = \left(\frac{k(t)}{k_0}\right)^{-b}, \qquad (b > 0) \tag{1}$$

b is the parameter that shows the effects of the accumulated knowledge on production cost. In this study, b is called the learning rate (Anderson and Parker, 2002). $C(t)/C_0$ is the ratio of the unit production cost at t to the initial unit production cost. When the ratio is 80%, 20% of the unit production cost is reduced every time the accumulated production knowledge doubles. When the accumulated production knowledge doubles, $k(t)/k_0 = 2$. Let $C(t)/C_0 = y$, then equation (1) can be written as $y = 2^{-b}$. y is the proficiency rate (Yukita and Osada, 2010). The $b = -\log_2 y$ relationship between the proficiency rate and the learning rate is shown in Table 1.

Table 1 Proficiency and learning rates

Proficiency rate (y)	*Learning rate (b)*	*Unit production cost reduction rate*
95%	0.074	5%
90%	0.152	10%
80%	0.322	20%
70%	0.515	30%
60%	0.737	40%
50%	1.000	50%

Multiplying both sides of equation (1) by C_0 brings equation (2), as shown below:

$$C(t) = C_0\left(\frac{k(t)}{k_0}\right)^{-b}, \qquad (b > 0) \tag{2}$$

Dutton and Thomas (1984) showed that learning rates vary across industries. A mature industry has small room for proficiency. The industry I surveyed in this study is the Japanese electronic device industry, which is more mature than the IT industry as a whole. As we may assume that the proficiency rate of firms belonging to this industry is relatively high, I use the low production learning rate for the simulations implemented in Section 4. On the other hand, high learning rates are used for the IT industry (Cha et al., 2008).

Li and Rajagopalan (1998) introduced the formulation of knowledge depreciation. According to Li and Rajagopalan (1998, p.144), "the knowledge gained from learning by doing may depreciate over time due to a number of factors, for example, employee turnover or technical changes". The key assumptions of the models developed in this study are that the costs decrease as knowledge level increases and that the marginal change in knowledge level is a function of the output quantity and the knowledge depreciation rate (Cha et al., 2008). Let q = output quantity and ε = knowledge depreciation rate. The dynamics of the knowledge level at t can be written as in equation (3) (Cha et al., 2008; Li and Rajagopalan, 1998).

$$\frac{dk(t)}{dt} = q - \varepsilon k(t) \tag{3}$$

The change in knowledge can be affected by two factors: the stock of knowledge increases with production volume, and knowledge depreciates over time (Li and Rajagopalan, 1998).

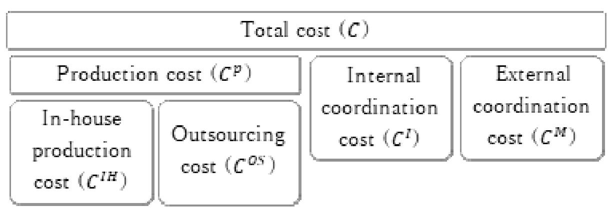
Solving equation (3) yields equation (4) (Cha et al., 2008).

$$k(t) = \frac{q}{\varepsilon} + \left(k_0 - \frac{q}{\varepsilon}\right)e^{-\varepsilon t} \tag{4}$$

3.2 Learning model of outsourcing

Figure 3 shows the cost structure used in the mathematical models in this study. I assume that the total cost consists of the production cost, internal coordination cost, and external coordination cost. The in-house production cost and the outsourcing cost together make the production cost.

Figure 3 Cost structure



Let the outsourcing rate = x ($0 < x < 1$). The total cost, production cost, internal coordination cost, and external coordination cost at t can be written as $C_t(x, t)$, $C_t^P(x, t)$, $C_t^I(x, t)$ and $C_t^M(x, t)$, respectively. The total cost is formulated as in equation (5).

$$C_t(x, t) = C_t^P(x, t) + C_t^I(x, t) + C_t^M(x, t) \tag{5}$$

I assume the total cost is that of the company-wide organisation, and the production cost is that of the production organisation. The learning model used in this study covers the cost range of the experience curve, which includes indirect costs such as sales and general administration costs, in addition to the direct costs. Thus, the composite learning curve (Conley, 1970) is used in this study.

Assuming that the in-house production cost at $t = C_t^{IH}(x, t)$ and the outsourcing cost at $t = C_t^{OS}(x, t)$, the production cost at t, $C_t^P(x, t)$, can be written as in equation (6).

$$C_t^P(x, t) = (1 - x)C_t^{IH}(x, t) + xC_t^{OS}(x, t) \tag{6}$$

From equation (2), $C_t^{IH}(x, t)$ can be written as in equation (7).

$$C_t^{IH}(x,t) = C_0^{IH}\left(\frac{k_t^{IH}(x,t)}{k_0^{IH}}\right)^{-\alpha} \qquad (\alpha > 0) \tag{7}$$

C_0^{IH} initial in-house production cost

k_0^{IH} initial in-house production knowledge

$k_t^{IH}(x,t)$ accumulated in-house production knowledge at t

α in-house production learning rate.

Let the total output quantity of the firm, which includes both in-house and outsourcing production quantities, = q and the in-house production knowledge depreciation rate = ε^P. The dynamics of the in-house production knowledge can be written as in equation (8).

$$\frac{dk_t^{IH}}{dt} = (1-x)q - \varepsilon^P k_t^{IH}(x,t) \tag{8}$$

In equation (8), $(1 - x)q$ shows the effects on the in-house production knowledge accumulation of the firm and $\varepsilon^P k_t^{IH}(x,t)$ shows the depletion of in-house production knowledge due to technology obsolescence, employee turnover, and other factors.

As written in equation (7), $C_t^{OS}(x,t)$ can be written as in equation (9). μ is the markup by the vendor (Anderson and Parker, 2002), which assumes that the firm pays $(1 + \mu)$ times the vendor's production cost of the outsourced quantity.

$$C_t^{OS}(x,t) = (1+\mu)C_0^{OS}\left(\frac{k_t^{OS}(x,t)}{k_0^{OS}}\right)^{-\beta} \qquad (\beta > 0) \tag{9}$$

C_0^{OS} initial outsourcing cost

k_0^{OS} initial vendor production knowledge

$k_t^{OS}(x,t)$ accumulated vendor production knowledge at t

β vendor production learning rate

μ markup by vendor.

Let the vendor production knowledge depreciation rate = ε^O and the dynamics of the vendor production knowledge can be written as in equation (10).

$$\frac{dk_t^{OS}}{dt} = x(q+Q) - \varepsilon^O k_t^{OS}(x,t) \tag{10}$$

In equation (10), xq, which is the first component of $x(q + Q) = xq + xQ$, shows the effects on vendor production knowledge accumulation. I assume that Q is the additional production quantity transferable from the vendor to the customer firm. Because the vendor also owns its production knowledge with the quantity offered to the other firms, xQ, which is the second component of $x(q + Q)$, shows the effects on vendor production knowledge accumulation transferable from the vendor to the customer firm. Therefore,

$x(q + Q)$ shows the total effects on vendor production knowledge accumulation. $\varepsilon^O k_t^{OS}(x, t)$ shows the depletion of vendor production knowledge due to technology obsolescence, employee turnover, and other factors.

Next, I formulate the internal coordination cost and external coordination cost. The integration cost of Anderson and Parker (2002) and the coordination cost of Cha et al. (2008, 2009) are the costs that increase as the outsourcing rate increases. These studies do not consider the costs that increase as the integration rate increases. Because coordination should be considered for both cases, this study includes two coordination costs in the learning models.

The internal coordination cost $C_t^I(x, t)$ can be written as in equation (11). The internal coordination cost is the cost of coordinating, managing, and integrating the 'to be integrated' activities for which the firm can utilise its coordination learning capability. If such activities are outsourced, the loss becomes larger and additional costs are incurred. When the outsourcing rate increases, the cost of coordinating, managing, and integrating such outsourced activities incur rapidly increasing additional costs because the coordination knowledge accumulated by coordinating internal activities cannot be utilised. The internal coordination cost includes such additional increasing costs. This model is equivalent to the integration cost model of Anderson and Parker (2002).

$$C_t^I(x, t) = C_0^I \left(\frac{k_t^I(x, t)}{k_0^I} \right)^{-\gamma} \qquad (\gamma > 0) \tag{11}$$

C_0^I initial internal coordination cost

k_0^I initial internal coordination knowledge

$k_t^I(x, t)$ accumulated internal coordination knowledge at t

γ internal coordination learning rate.

Let the internal coordination knowledge depreciation rate = ε^I and the dynamics of the internal coordination knowledge can be written as in equation (12).

$$\frac{dk_t^I}{dt} = (1-x)q - \varepsilon^I k_t^I(x, t) \tag{12}$$

In equation (12), $(1 - x)q$ shows the effects on the internal coordination knowledge accumulation of the firm with integration and $\varepsilon^I k_t^I(x, t)$ shows the depletion of internal coordination knowledge due to technology obsolescence, employee turnover, and other factors.

The external coordination cost $C_t^M(x, t)$ can be written as in equation (13). The external coordination cost is the cost of coordinating, managing, and integrating the 'to be outsourced' activities for which the firm can utilise its coordination learning capability. If such activities are integrated, the loss becomes larger and additional costs are incurred. When the integration rate increases, the cost of coordinating, managing, and integrating such integrated activities incurs rapidly increasing additional costs because the coordination knowledge accumulated by coordinating external activities cannot be utilised. The external coordination cost includes such additional increasing costs. Anderson and Parker (2002) did not consider this type of coordination cost.

$$C_t^M(x,t) = C_0^M \left(\frac{k_t^M(x,t)}{k_0^M} \right)^{-\delta} \qquad (\delta > 0) \tag{13}$$

C_0^M	initial external coordination cost
k_0^M	initial external coordination knowledge
$k_t^M(x,t)$	accumulated external coordination knowledge at t
δ	external coordination learning rate.

Let the external coordination knowledge depreciation rate = ε^M and the dynamics of the external coordination knowledge can be written as in equation (14).

$$\frac{dk_t^M}{dt} = xq - \varepsilon^M k_t^M(x,t) \tag{14}$$

In equation (14), xq shows the effects on the external coordination knowledge accumulation of the firm with outsourcing and $\varepsilon^M k_t^M(x,t)$ shows the depletion of external coordination knowledge due to technology obsolescence, employee turnover, and other factors.

4 Simulation analysis

In this section, simulation is implemented with the learning models of outsourcing developed in Section 3. First, I develop the numerical values to be used in the simulations. Next, I provide the results. I assume that the industry surveyed in this study is the Japanese electronic device industry.

4.1 Numerical value setting

Table 2 shows the numerical values used in the simulations. These values are set for three scenarios.

There are four key parameters: in-house production learning rate (α), vendor production learning rate (β), internal coordination learning rate (γ), and external coordination learning rate (δ). Simulations are implemented by changing these four parameters. The relationship between total cost and the outsourcing rate is investigated by changing γ and δ, with α and β fixed in each scenario.

Three scenarios are employed to show how the above four key parameters affect the shape of the total cost curve. Scenario 1 shows how the inverted U-shaped curve of the production cost is transformed into the U-shaped curve of the total cost, step by step. Scenario 2 shows the case where all total cost curves remain an inverted U-shape. On the other hand, Scenario 3 shows the case where all total cost curves become U-shaped. As a result, Scenarios 2 and 3 support Scenario 1.

Table 2 Parameters for simulation

Notation	*Description*	*Scenario 1*	*Scenario 2*	*Scenario 3*
q	Total output quantity	15,000	same as left	same as left
Q	Additional production quantity transferable from vendor	7,500	same as left	same as left
C_0^{IH}	Initial in-house production cost	10	same as left	same as left
C_0^{OS}	Initial outsourcing cost	10	same as left	same as left
k_0^{IH}	Initial in-house production knowledge	112,500	same as left	same as left
k_0^{OS}	Initial vendor production knowledge	112,500	same as left	same as left
α	In-house production learning rate	0.074	0.515	0.074
β	Vendor production learning rate	0.074	0.515	0.074
ε^P	In-house production knowledge depreciation rate	0.1	same as left	same as left
ε^O	Vendor production knowledge depreciation rate	0.1	same as left	same as left
C_0^I	Initial internal coordination cost	1	same as left	same as left
C_0^M	Initial external coordination cost	1	same as left	same as left
k_0^I	Initial internal coordination knowledge	22,500	same as left	same as left
k_0^M	Initial external coordination knowledge	22,500	same as left	same as left
γ	Internal coordination learning rate	① 0.074	same as left	① 0.515
		② 0.515		② 0.737
		③ 0.074		③ 0.515
		④ 0.515		④ 0.737
δ	External coordination learning rate	① 0.074	same as left	① 0.515
		② 0.074		② 0.515
		③ 0.515		③ 0.737
		④ 0.515		④ 0.737
ε^I	Internal coordination knowledge depreciation rate	0.1	same as left	same as left
ε^M	External coordination knowledge depreciation rate	0.1	same as left	same as left
μ	Markup rate by vendor	0.05	same as left	same as left
t	Point of time	5	same as left	same as left

First, the four key parameters in each scenario are shown. Assuming a high proficiency rate (95%) for a mature manufacturing industry, such as the Japanese electronic device industry, a low learning rate (0.074) is assigned to α and β for Scenarios 1 and 3. As for γ and δ, four combinations are used in Scenarios 1 and 2: $\gamma = \delta = 0.074$, $\gamma = 0.515/\delta =$

0.074, $\gamma = 0.074/\delta = 0.515$, and $\gamma = \delta = 0.515$. In Scenario 2, $\alpha = \beta = 0.515$ (proficiency rate 70%) is used.

Finally, in Scenario 3, assuming that the room for coordination proficiency is larger than that of production proficiency, four combinations with high coordination learning rates are used: $\gamma = \delta = 0.515$, $\gamma = 0.737$; $\delta = 0.515$, $\gamma = 0.515$; $\delta = 0.737$, and $\gamma = \delta = 0.737$. These learning rates are relatively high because the coordination proficiency is assumed to be lower than that of production in the Japanese electronic device industry. Even much higher learning rates, such as 1.2~2.5, are used for the innovation parameters of production and coordination in the IT industry (Cha et al., 2008).

Next, the other numeric values, which are fixed for all scenarios, are set.

Assuming the average annual total cost and average total unit cost of Japanese electronic device manufacturers are JPY180,000 (in millions) and JPY12 (in thousands), respectively, the total output quantity (q) is 15,000 (in thousands), because this figure is calculated by dividing the total cost by the total unit cost. In this study, quantities and costs are expressed in thousands, and I omit the currency symbol for simplification. I assume that the additional production quantity from vendor (Q) is 50% of q (that is, 7,500).

As for the production costs, I assume that there is no difference between the initial in-house production cost and the initial outsourcing cost, and $C_0^{IH} = C_0^{OS} = 10$. I assume that the initial in-house production knowledge and initial vendor production knowledge is the same, and they are given by multiplying q by 7.5 (Cha et al., 2008), which makes $k_0^{IH} = k_0^{OS} = 112,500$. I assume that the in-house production knowledge depreciation rate and vendor production knowledge depreciation rate are equal and $\varepsilon^P = \varepsilon^O = 0.1$ (Cha et al., 2008).

Now, I set the numerical values of the coordination costs. I assume that the ratio of the average total cost minus the average cost of goods sold to the average cost of goods sold of the Japanese electronic device manufacturing companies is 20%, and the initial internal coordination cost and initial external coordination cost are the same. Since $C_0^{IH} = C_0^{OS} = 10$, we can obtain $C_0^I = C_0^M = 1$ because $C_0^I + C_0^M = 2$ is 20% of 10. I also apply the same ratio (20%) to find the initial internal coordination knowledge and initial external coordination knowledge, which brings us $(k_0^{IH} = k_0^{OS} = 112{,}500) \times 20\% = k_0^I = k_0^M = 22{,}500$. I assume that the internal coordination knowledge depreciation rate and the external coordination knowledge depreciation rate are also equal and $\varepsilon^I = \varepsilon^M = 0.1$.

Finally, I assume that the markup by the vendor is 5% (Anderson and Parker, 2002) and the point of time (t) is 5.

4.2 Simulation results

Table 3 shows the summary of the equations used in the simulations. Investigations of the effects on coordination and production costs by outsourcing are conducted before three simulation analyses.

Table 3 Equations used for simulation

Description	*Equation for cost and accumulated knowledge at t*
Total cost at *t*	$C_t(x,t) = C_t^P(x,t) + C_t^I(x,t) + C_t^M(x,t)$
Production cost at *t*	$C_t^P(x,t) = (1-x)C_t^{IH}(x,t) + xC_t^{OS}(x,t)$
In-house production cost at *t*	$C_t^{IH}(x,t) = C_0^{IH}\left(\frac{k_t^{IH}(x,t)}{k_0^{IH}}\right)^{-\alpha} \quad (\alpha > 0)$
Accumulated in-house production knowledge at *t*	$k_t^{IH}(x,t) = \frac{(1-x)q}{\varepsilon^P} + \left(k_0^{IH} - \frac{(1-x)q}{\varepsilon^P}\right)e^{-\varepsilon^P t}$
Outsourcing cost at *t*	$C_t^{OS}(x,t) = (1+\mu)C_0^{OS}\left(\frac{k_t^{OS}(x,t)}{k_0^{OS}}\right)^{-\beta} \quad (\beta > 0)$
Accumulated vendor production knowledge at *t*	$k_t^{OS}(x,t) = \frac{x(q+Q)}{\varepsilon^O} + \left(k_0^{OS} - \frac{x(q+Q)}{\varepsilon^O}\right)e^{-\varepsilon^O t}$
Internal coordination cost at *t*	$C_t^I(x,t) = C_0^I\left(\frac{k_t^I(x,t)}{k_0^I}\right)^{-\gamma} \quad (\gamma > 0)$
Accumulated internal coordination knowledge at *t*	$k_t^I(x,t) = \frac{(1-x)q}{\varepsilon^I} + \left(k_0^I - \frac{(1-x)q}{\varepsilon^I}\right)e^{-\varepsilon^I t}$
External coordination cost at *t*	$C_t^M(x,t) = C_0^M\left(\frac{k_t^M(x,t)}{k_0^M}\right)^{-\delta} \quad (\delta > 0)$
Accumulated external coordination knowledge at *t*	$k_t^M(x,t) = \frac{xq}{\varepsilon^M} + \left(k_0^M - \frac{xq}{\varepsilon^M}\right)e^{-\varepsilon^M t}$

4.2.1 Effect on coordination costs by outsourcing

Figure 4 describes the relationship between the internal coordination cost and outsourcing rate for the internal coordination learning rate (γ) of 0.074, 0.152, 0.515, and 0.737.

As the integration rate increases, the internal coordination knowledge is accumulated, which reduces the internal coordination cost. In addition, the higher internal coordination learning rate reduces the cost more than the lower one. The $\gamma = 0.737$ cost curve has the steepest soaring slope among the four curves.

Figure 5 describes the relationship between the external coordination cost and outsourcing rate for the external coordination learning rate (δ) of 0.074, 0.152, 0.515, and 0.737.

As the outsourcing rate increases, external coordination knowledge is accumulated, which reduces the external coordination cost. In addition, the higher external coordination learning rate reduces the cost more than the lower one. The $\delta = 0.737$ cost curve has the steepest declining slope among the four curves.

Figure 4 Internal coordination cost vs. outsourcing rate (see online version for colours)

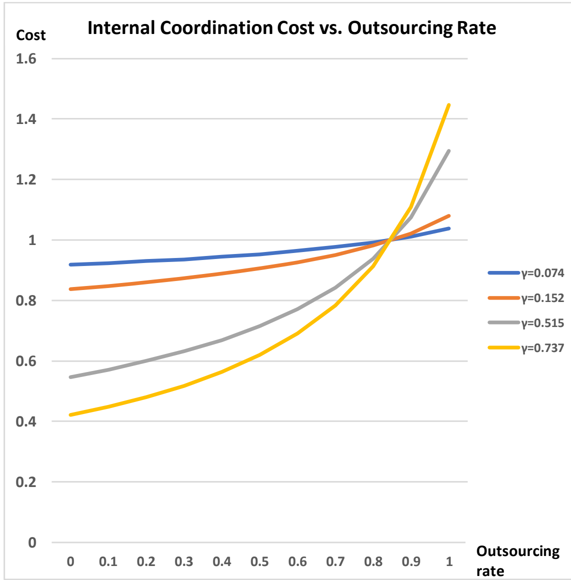
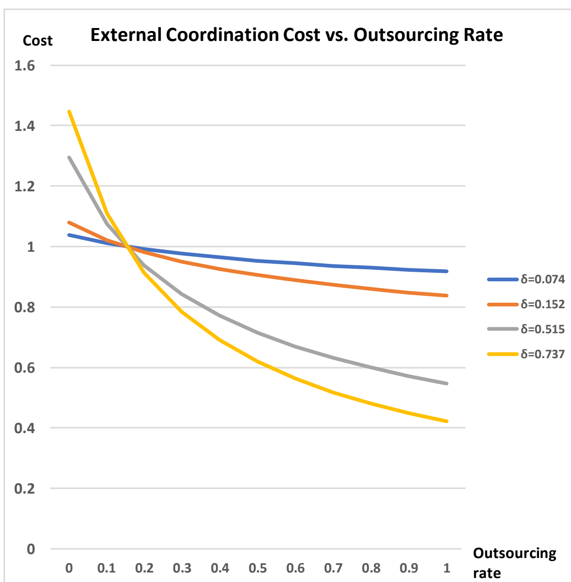


Figure 5 External coordination cost vs. outsourcing rate (see online version for colours)

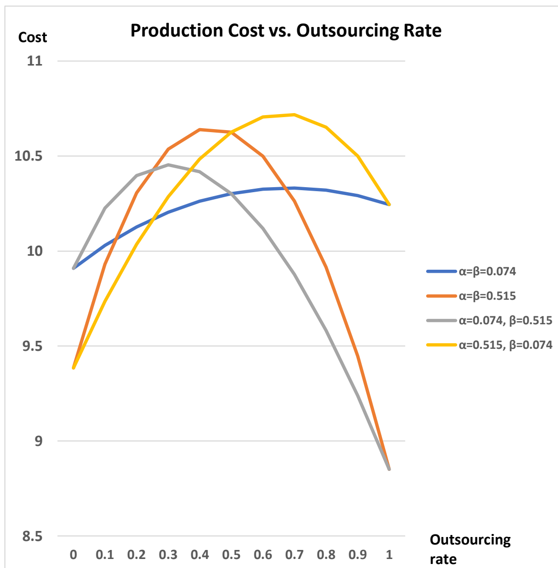


4.2.2 Effect on production cost by outsourcing

Figure 6 describes the relationship between the production cost and outsourcing rate for the combinations $\alpha = \beta = 0.074$, $\alpha = \beta = 0.515$, $\alpha = 0.074$; $\beta = 0.515$, and $\alpha = 0.515$; $\beta = 0.074$. Each of the four curves has an inverted U-shape, which means either complete outsourcing or complete in-house production strategy has the lowest production cost.

Comparing the $\alpha = \beta = 0.074$ curve with the $\alpha = \beta = 0.515$ curve, the latter has much steeper slopes on both sides of its inverted U-shaped curve. As the integration rate increases, the in-house production knowledge is accumulated, which reduces the in-house production cost. In addition, the higher in-house production learning rate reduces the cost more than the lower one. On the other hand, as the outsourcing rate increases, vendor production knowledge is accumulated, which reduces the vendor production cost. In addition, the higher vendor production learning rate reduces the cost more than the lower one. These two effects on cost reduction explain the difference in shapes between the two inverted U-shaped curves.

Figure 6 Production cost vs. outsourcing rate (see online version for colours)



Next, comparing the $\alpha = 0.074$; $\beta = 0.515$ curve with the $\alpha = 0.515$; $\beta = 0.074$ curve, it is observed that the former minimises the production cost with complete outsourcing and the latter minimises the cost with complete integration. When the vendor production learning rate is higher than that of in-house production, the effect on cost reduction is larger in outsourcing than in integration because the firm can utilise accumulated vendor production knowledge more. On the other hand, when the in-house production learning rate is higher than that of vendor production, the effect on cost reduction is larger in integration than in outsourcing, because the firm can utilise accumulated in-house production knowledge more.

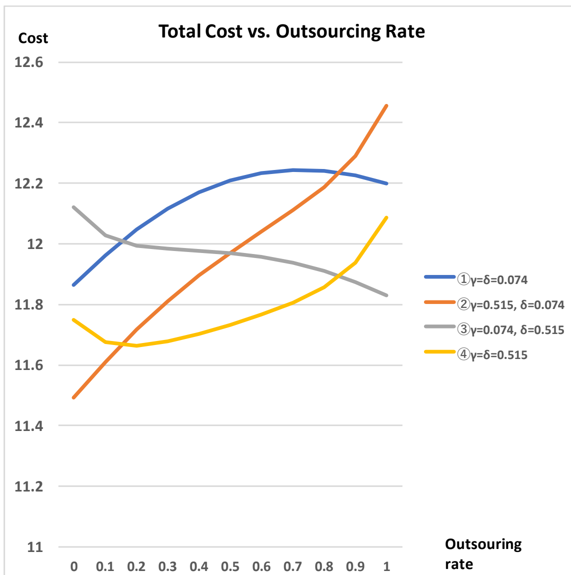
4.2.3 Scenario 1

Figure 7 describes the relationships between the total cost and the outsourcing rate in Scenario 1. As the in-house production learning rate (α) and the vendor production learning rate (β) are assumed to be low in this scenario, $\alpha = \beta = 0.074$ is used for simulation. Therefore, the proficiency rate of this scenario is 95%, which reflects the mature Japanese electronic device industry in production.

Four curves are described in Figure 7, with the four combinations of the internal coordination learning rate (γ) and the external coordination learning rate (δ), referring to Table 2, shown in the legend of the figure (①~④).

When the learning rates are low (e.g., ① $\gamma = \delta = 0.074$), their effects on cost reduction by integration or outsourcing are also low, as shown in Figures 4 and Figure 5. Therefore, the total cost curve ① is inverted U-shaped, reflecting the production cost curve with $\alpha = \beta = 0.074$, as shown in Figure 6.

Figure 7 Scenario 1: total cost vs. outsourcing rate ($\alpha = \beta$=0.074) (see online version for colours)



Comparing the ② ($\gamma = 0.515$, $\delta = 0.074$) curve with the ③ ($\gamma = 0.074$, $\delta = 0.515$) curve, the former describes the soaring curve while the latter describes the declining curve. Because the internal coordination learning rate is higher than the external coordination learning rate in ②, the effect on cost reduction by integration is larger than the effect by outsourcing. On the contrary, because the external coordination learning rate is higher than the internal coordination learning rate in ③, the effect on cost reduction by outsourcing is larger than that by integration.

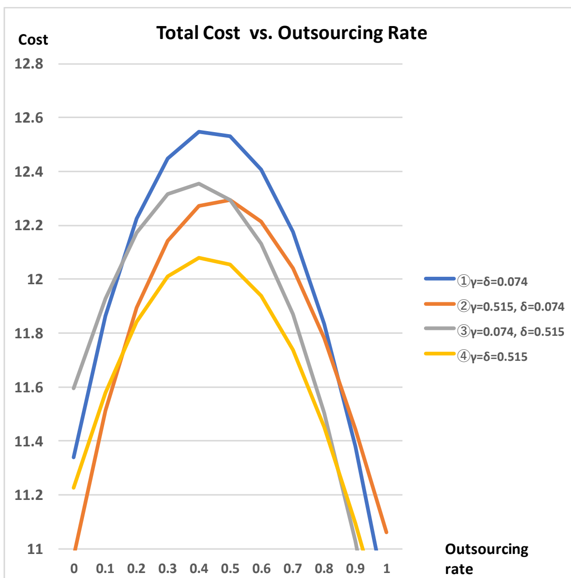
Lastly, ④ $\gamma = \delta$ =0.515 combination describes a U-shaped curve for which the internal coordination rate and the external coordination rate are the same, which is higher than the in-house production learning rate (α) and the vendor production learning rate (β). In this case, the internal coordination knowledge and external coordination knowledge are accumulated by increasing the integration rate and outsourcing rate, respectively. The effects on cost reduction by those knowledge accumulations become significantly large, which transforms the inverted U-shaped curve of the production cost into the U-shaped curve of the total cost.

In other words, when the outsourcing rate becomes higher for the internal coordination cost curve and the integration rate becomes higher for the external coordination cost curve, there are increasing additional costs. It is estimated that the inverted U-shaped curve of the production cost under the production organisation is transformed into the U-shaped curve of the total cost under the company-wide organisation when the loss incurred by complete outsourcing and complete integration is larger than the cost effectiveness realised by doing so.

4.2.4 Scenario 2

Figure 8 describes the relationship between the total cost and the outsourcing rate in Scenario 2. As the in-house production learning rate (α) and the vendor production learning rate (β) are assumed to be high in this scenario, $\alpha = \beta = 0.515$ is used for the simulation.

Figure 8 Scenario 2: total cost vs. outsourcing rate ($\alpha = \beta = 0.515$) (see online version for colours)



As in Scenario 1, four curves are described in Figure 8, with the four combinations of the internal coordination learning rate (γ) and the external coordination learning rate (δ), referring to Table 2, shown in the legend of the figure (①~④).

In this scenario, α and β are high and all four curves are inverted U-shaped, reflecting the inverted U-shaped production cost curve with $\alpha = \beta = 0.515$, which has steep slopes on both sides, as shown in Figure 6. This means that the internal coordination learning rate and the external coordination learning rate do not have enough cost reduction effects against the in-house production learning rate and the vendor production learning rate for the inverted U-shaped production cost curve to be transformed into the U-shaped total cost curve when the integration rate and the outsourcing rate increase, respectively. In other words, the cost increase generated by the internal coordination learning rate and the external coordination learning rate is too small for the shape transformation when the outsourcing rate and integration rate approach 100%, respectively.

In this study's simulation settings, the production cost is approximately five times as large as the sum of the two coordination costs. Therefore, all the total cost curves in this scenario reflect the shape (inverted U-shape) of the production cost curve.

4.2.5 Scenario 3

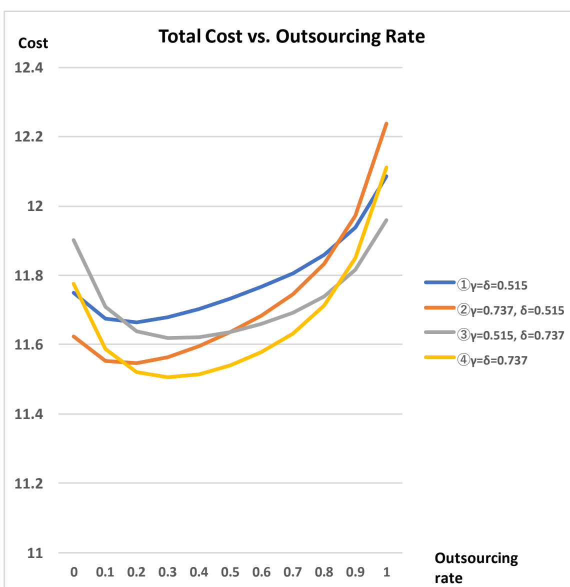
Figure 9 describes the relationship between the total cost and the outsourcing rate in Scenario 3. As shown in Scenario1, the in-house production learning rate (α) and the vendor production learning rate (β) are assumed to be low in this scenario; therefore, $\alpha = \beta = 0.074$ is used for simulation.

Four curves are described in Figure 9, with the four combinations of the internal coordination learning rate (γ) and the external coordination learning rate (δ), referring to Table 2, shown in the legend of the figure (①~④).

The difference between this scenario and the other two scenarios is that a higher learning rate (0.737) is used, instead of 0.074 for γ and δ combinations. The inverted U-shaped ① ($\gamma = \delta = 0.515$) curve was already shown in Scenario 1. Curves ② through ④ are also inverted U-shaped because each of them has a higher coordination learning rate combination (γ, δ) than that of ①.

As explained in Scenario 1, when the outsourcing rate becomes higher for the internal coordination cost curve and the integration rate becomes higher for the external coordination cost curve, there are rapidly increasing additional costs. It is estimated that the inverted U-shaped curve of the production cost under the production organisation is transformed into a U-shaped curve of the total cost under the company-wide organisation when the loss incurred by complete outsourcing and complete integration is larger than the cost effectiveness realised by doing so.

Figure 9 Scenario 3: total cost vs. outsourcing rate ($\alpha = \beta = 0.074$) (see online version for colours)



4.2.6 Simulation summary and managerial insights

The findings of the three scenarios can be summarised with the four results of Scenario 1 in Table 4. The extreme cases in Scenarios 2 and 3 support the results of Scenario 1.

If a firm has small room (a low learning rate) for both internal and external coordination proficiencies, it is suggested that a make or buy strategy should be adopted [Result 1]. If it has large room (a high learning rate) both for those proficiencies, a mixed (make and buy) strategy should be adopted [Result 4].

When a firm has larger internal coordination proficiency room than external coordination proficiency room, it is suggested that an integration strategy should be adopted [Result 2]. If it is the opposite, an outsourcing strategy should be adopted [Result 3].

The managerial insights described above are based on the simulation settings used in this study. However, the simulation results suggest that managers should consider their coordination capability for make and/or buy decisions.

Table 4 Simulation results: managerial insights

		Internal coordination learning rate	
		Low	*High*
External coordination learning rate	Low	[Result 1] Inverted U-shaped curve Make or buy strategy (Scenario 1-①)	[Result 2] Soaring curve Integration strategy (Scenario 1-②)
	High	[Result 3] Declining curve Outsourcing strategy (Scenario 1-③)	[Result 4] U-shaped curve Mixed strategy (Scenario 1-④)

5 Implications and conclusions

The simulation results in this study have several implications.

Regarding the production cost, as the integration rate increases, the in-house production knowledge is accumulated, resulting in a reduction in the in-house production cost. The higher the in-house production learning rate, the larger the effect on cost reduction the firm can achieve by integration. On the other hand, as the outsourcing rate increases, vendor production knowledge is accumulated, reducing the vendor production cost. The higher the vendor production learning rate, the larger the effect on cost reduction the firm can achieve by outsourcing.

A firm with production learning capability can reduce its production cost by utilising in-house production. On the other hand, the firm can reduce its production cost by obtaining vendor production learning capability through outsourcing. As explained in Figure 6, whether to make or buy depends on the size of the production learning rate between the firm and the vendor. The firm can reduce the production cost through integration if its production learning rate is higher than that of the vendor, or by outsourcing if it is lower than that.

As for the total cost, the size of the internal coordination learning rate and the external coordination learning rate influence a sourcing decision. The internal coordination cost and external coordination cost are reduced when the integration rate and the outsourcing rate increase, respectively. In other words, when the outsourcing rate and integration rate become higher for the internal coordination cost curve and the external coordination cost curve, respectively, there are rapidly increasing additional costs. This study shows that the inverted U-shaped curve of the production cost under the production organisation is transformed into a U-shaped curve of the total cost under the company-wide organisation when the loss incurred by complete outsourcing and complete integration is larger than the cost effectiveness realised by doing so. Showing this by introducing a learning model of outsourcing is the main contribution of this study.

The internal coordination cost is the cost of coordinating, managing, and integrating the 'to be integrated' activities for which the firm can utilise its coordination learning capability. If such activities are outsourced, the loss becomes larger and additional costs are incurred. The higher the outsourcing rate and internal coordination learning rate, the more rapidly increasing costs the firm may incur to coordinate, manage, and integrate outsourced activities.

For example, outsourced goods or services from the market must be integrated into the internal system of a firm to monitor and manage inventory, quality, and sales progress, which would incur additional increasing costs. Educational costs for marketing and sales employees may also increase. If those products or services were produced in-house, the room for proficiency in internal coordination could be large, because employees are very familiar with their own systems and products. Therefore, I introduced relatively high learning rates for internal coordination costs.

The external coordination cost is the cost of coordinating, managing, and integrating the 'to be outsourced' activities for which the firm can utilise its coordination learning capability. If such activities are integrated, the loss becomes larger and additional costs are incurred. The higher the integration rate and external coordination learning rate, the more rapidly increasing costs the firm may incur to coordinate, manage, and integrate integrated activities.

For example, when goods or services are produced in-house, decisions on investment must be made by top management by considering priorities among the investment projects. In addition, investigation, application, and management of patents would also be required. If a firm has transactions between business units, transfer prices would have to be negotiated and coordinated in its headquarters. If those products or services were outsourced, the room for proficiency in external coordination could be large, because employees are skilled in negotiating and coordinating with capable suppliers. Therefore, I introduced relatively high learning rates for external coordination costs as well.

When the production proficiency for Japanese manufacturers is high (proficiency rate 95%) and their coordination proficiency is low (proficiency rate 60% to 70%), the relationship between the total cost of a firm and the outsourcing rate becomes U-shaped.

Finally, this study has two limitations. First, except for the four learning rates, all the other parameters are assumed to be fixed when conducting each simulation. Since the shape of the total cost curve depends on these fixed factors, further research will be required in strategic decision making. Second, the numeric values used in the simulations refer to the preceding studies (Anderson and Parker, 2002; Cha et al., 2008) and to Japanese electronic device manufacturing companies. In the future, empirical studies using practical values will be key to developing stronger support to explain the relationship between firm performance (cost reduction) and outsourcing.

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