Horizontal Information Sharing in the Cluster Supply Chain

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Abstract

Cluster supply chain is a supply chain network system based on the industry clusters, which had developed rapidly in theoretical and practical in China recently. Characteristics of the cluster, such as, geographical proximity and the existence of social network, enable the participants of it to communicate quickly and obtain large amount of information. However, the fierce competition between these homogeneous companies within the cluster often leads to the pollution of the information transmission environment by outdated, overlapped, or false information. This paper studied the horizontal technical information sharing problem in the cluster supply chain based on the Cournot competition model. Unlike prior studies’ conclusion that there is no incentive for companies with horizontal competition to voluntarily share their private information, our analysis showed that, information sharing can be achieved in the context of cluster supply chain when there exists cooperative innovation between companies within the cluster.

Key words: horizontal information sharing, cluster supply chain, cooperative innovation

1. Introduction

The development of industrial clusters has become a global economic
phenomenon in the context of rapid technologies change and globalization. Successful cases include Silicon Valley and Boston 128 Route in the United States, network clusters of Sen Dier area and perfume bottle clusters of Bresle Valley in France, and clusters designing and manufacturing clothes all over Italy. In China, most companies are small and medium enterprises (SMEs) with the characteristics of small size, low level of technology and low management efficiency. In order to enhance the international competitiveness of those SMEs quickly, governments in China have issued various preferential policies to encourage the formation and development of all kinds of clusters like high-tech zones, industrial parks, and economic development areas such as Technical Zone of Zhongguancun in Beijing, High-Tech Zone of East Lake in Wuhan which attract plenty of investments and resources and contribute a lot to the increase of Chinese GDP. The rapid development and impressive economic performance of industrial clusters attract people’s attentions on trend of region centralization.

In order to improve the efficiency of the internal operation of the cluster and play its core strengths, companies in the cluster continue to integrate the resources of their suppliers and customers as well as the resources of those external service providers like distribution companies and banks, thus a complicated supply chain network in the setting of industrial cluster gradually forms, which is called cluster supply chain. The cluster supply chain is aggregate in a special region, around some core enterprise and form network structure by cooperation among companies from the upstream and the downstream. A typical example is the “star network” of Nokia industrial park in China. As a leader of this network, Nokia attracts its main parts suppliers into the industrial park. All the companies in the park jointly establish a complete supply chain to aggregate and reallocate all kinds of resources, such as, information, logistics,
There are two kinds of connections between companies in the cluster supply chain. One is the vertical relationship which refers to the contact between the upstream and the downstream companies. For example, the manufacturer and its supplier can make use of their geographical proximity to obtain the benefits of Just-in-Time manufacturing and reduce transportation costs. Another kind of connection is the horizontal relationship, which refers to the sharing of knowledge, information and other resources between those companies in different supply chains who are at the same level of the value chain. In clusters, horizontal relationship contains both competition and cooperation. On one hand, competition occurs because companies at the same level of the value chain compete for common raw materials, customers, and human resources. On the other hand, these companies cooperate with each other to extend market, cultivate and maintain the common brand of the cluster, and develop new technology.

This paper studies the problem of technical cooperation and information sharing between those horizontally related companies in the context of cluster supply chain. Characteristics of the cluster, such as, geographical proximity and the existence of social network, enable the participants of it to communicate quickly and obtain large amount of information. However, the question of whether horizontal information sharing brings benefits to these companies in the cluster has not been fully answered. This paper tries to fill this gap. The remaining parts of this paper are organized as follows. Section 2 summarizes related literatures about information sharing in the supply chain and co-opetition relationship in cluster supply chain. Section 3 constructs the model of horizontal technical information sharing with symmetric cost information. The decision process consists of two stages, with Stage I for each firm in
the cluster to decide its amount of technical information and Stage II for each firm to decide its production quantity. We analyze the model of making the decision of Stage I in a decentralized way and a centralized way respectively and compared these two cases. Section 4 constructs the model of horizontal technical cooperation with asymmetric cost information, and analyzes the value of horizontally sharing the cost information. Section 5 summarizes the main conclusions and also points out several promising directions for future researches.

2. Related Literature

Cluster theory is widely studied since Marshall (1961) who first took systemic researches on the cluster phenomenon from the aspect of classical economics. However, there are fewer researches about cluster supply chain, and most of the existing studies are qualitative analyses about the structure, characteristics, or the relationship between participants of it. The most related quantitative literatures are those about the co-opetition relationship of the cluster supply chain. Li et al. (2004) couple the industrial clusters and supply chains, and first put forward the concept of cluster supply chains. Li et al. (2006a, b) research the definition and characteristics of cluster supply chains, and analyze the co-opetition relationship among chains with a dynamic game model. Qi et al. (2006) analyze the co-opetition relationship between firms at the same level of the value chain but in different supply chains, and obtain the conditions of achieving cooperation in equilibrium.

In this study, we consider the information sharing in the cluster supply chain. Since Lee (1997) suggests relieving the “bullwhip effect” via information sharing, the problem of information sharing in the supply chain has become a hot research topic. Existing researches of this topic can be classified into two groups, one group is about
the value of information sharing, and another group is about the incentive mechanisms of information sharing. Researches of the second group can be further classified into two subgroups, one is about incentives of sharing demand information (Cachon, 2001; Lariviere, 2002; Gong, 2004; etc.), and the other is about incentives of sharing cost information (Corbett, 2000, 2001, 2004; Albert Ha, 2001; etc.).

Studies of the value of information sharing answer three questions: whether sharing information creates value, how much is the value of information sharing, and which factors affect the value of information sharing. For the question of “whether sharing information creates value”, most researches give the positive answer, however, several studies conclude that sharing information brings no benefit. For example, Graves(1999) points out that sharing information cannot increase the profit of the supply chain under the optimal prediction mode. For the question of “how much is the value of information sharing”, results of different researches are quite different. For the question of “which factors affect the value of information sharing”, most researches figure out those factors of demand variance, lead time, capacity, cost structure, and so on.

Li(2002), Zhang(2002) and Raghunathan(2003) study the value of information sharing in the supply chain consisting of an upstream firm and multiple competing downstream firms. Li(2002) points out that vertical information sharing has two effects, the direct effect and the leakage effect. He finds that sharing demand information always benefits the manufacturer, but does not benefit the retailers; also, sharing cost information always benefits the manufacturer, but benefits retailers only under certain conditions. Zhang(2002) finds that the optimal information-sharing strategies of retailers don’t depend on the type of competition (Cournot or Bertrand), and retailers have no incentive to voluntarily share their cost information with the
manufacturer. Raghunathan (2003) points out that retailers only get a small part of the benefits of information sharing when their demands are highly correlated. Refik (1997) and Gavimeni (1999) consider the value of information sharing when the supplier’s capacity is limited. In addition, some literatures consider the value of sharing upstream information, such as, Chen and Yu (2005), as well as Chen (2007) who study the value of sharing lead time information and cost information, respectively.

Literatures mentioned above are all about vertical information sharing, and there are some studies on the value of horizontal information sharing between competing firms. Vives (1984) studies the problem of sharing demand information between two firms producing differentiated products and finds that, no information sharing is the unique equilibrium under Cournot competition with substitutes or Bertrand competition with implements, and complete information sharing is the unique equilibrium under Cournot competition with implements or Bertrand competition with substitutes. Gal-Or (1985) studies the value of sharing demand information between multiple firms under Cournot competition and finds that no information sharing is the only symmetric Nash equilibrium. Based on the study of Vives (1984), Gal-Or (1986) studies the value of sharing cost information, and points out that complete information sharing is the dominant strategy under Cournot competition, and no information sharing is the dominant strategy under Bertrand competition.

3. The Model with Symmetric Cost Information

There are \( n(n \geq 3) \) firms who manufacture the same product in the cluster and they face a common market. The inverse demand function is \( p(Q) = a - bQ = a - b \sum_{j=1}^{n} q_j \), where \( Q \) is the total supply provided by the cluster, \( q_j \) is the production quantity of the \( j \)th firm, \( j=1,2,\ldots,n \). \( p(Q) \) is the unit retail price of the product when
total supply equals $Q$. Both $a$ and $b$ are positive and constant, and $\sum_{j=1}^{n} q_j < a/b$.

Assume that the unit production cost of the $i$th firm, $c_i (i = 1, 2, \ldots, n)$, decreases when the total amount of technical information in the cluster increases, which is denoted by $c_i = c_i^0 - \sum_{j=1}^{n} x_j$, where $c_i^0$ is the initial unit production cost of the $i$th firm, $x_j$ is the amount of technical information acquired by the $j$th firm in the cluster, and $\sum_{j=1}^{n} x_j < c_i^0$, $i = 1, 2, \ldots, n$. Since the geographical proximity of firms in the cluster, transmission and adoption of new technical information in the cluster is very quickly. So we assume that the technical information obtained by any firm in the cluster can be totally and immediately adopted by other firms in the same cluster.

Sharing technical information within the cluster can be regarded as a type of cooperative innovation mechanism. Acquisition of technical information is costly and we assume that any firm in the cluster pays the same cost to obtain the same amount of technical information. The total cost is $\frac{1}{2}x^2$ if the amount of technical information acquired is $x$. Let vectors $q = (q_1, q_2, \ldots, q_n)$ and $x = (x_1, x_2, \ldots, x_n)$. Here, two technical assumptions are given, that’s, $a > \frac{1}{n} \sum_{j=1}^{n} c_j^0$ and $b \geq 2$. In this section, we assume that competition structure, demand function and initial unit production costs of all the firms in the cluster are common knowledge.

The decision process of the firms in the cluster consists of two stages. In Stage I, each firm decides its amount of technical information $x_j (j = 1, 2, \ldots, n)$; in Stage II, each firm decides its production quantity $q_j (j = 1, 2, \ldots, n)$. The decisions in Stage I can be made in a decentralized way or a centralized way, and we analyze and compare these two cases in the following.

3.1 Decentralized Decision Making in Stage I

Assume that each firm in the cluster makes its own decision independently in
Stage I, that’s, each firm decides its own amount of technical information. We analyze this game using the method of backward induction.

In Stage II, each firm decides its own production quantity with the aim of maximizing its own profit. The profit function of the $i$th ($i = 1, 2, ..., n$) firm is

$$
\pi_i(q, x) = (p(Q) - c_i)q_i - \frac{1}{2}x_i^2 = (a - b \sum_{j=1}^{n} q_j - c^0_i + \sum_{j=1}^{n} x_j)q_i - \frac{1}{2}x_i^2
$$

(3-1)

Calculate the first derivative of $\pi_i(q, x)$ with respect of $q_i$ and let it equal zero, we obtain

$$
\frac{\partial \pi_i(q, x)}{\partial q_i} = -b q_i + (a - b \sum_{j=1}^{n} q_j - c^0_i + \sum_{j=1}^{n} x_j) = 0, \quad i = 1, 2, ..., n
$$

(3-2)

Add the $n$ equations in (3-2) and do some algebraic simplification, we get

$$
\sum_{j=1}^{n} q_j = \frac{1}{(n+1)b} (na - \sum_{j=1}^{n} c^0_j + n \sum_{j=1}^{n} x_j)
$$

(3-3)

Substitute (3-3) into (3-2), we get the equilibrium production quantity of each firm as

$$
q_i(x) = \frac{1}{b(n+1)} (a - (n+1)c^0_i + \sum_{j=1}^{n} c^0_j + \sum_{j=1}^{n} x_j)
$$

$$
= \frac{1}{b(n+1)} (a - nc^0_i + \sum_{j=1}^{n} c^0_j + \sum_{j=1}^{n} x_j), \quad i = 1, 2, ..., n
$$

(3-4)

We conclude from the above equation that the equilibrium production quantity of the $i$th ($i = 1, 2, ..., n$) firm decreases with its own initial production cost $c^0_i$, but increases with parameter $a$, other firms’ initial production costs $c^0_j$ ($j \neq i$) and the total amount of technical information in the cluster, $\sum_{j=1}^{n} x_j$.

In Stage I, each firm decides its own amount of technical information with the aim of maximizing its own profit. Substitute equations (3-3) and (3-4) into (3-1), we get the profit function of the $i$th ($i = 1, 2, ..., n$) firm in the cluster:

$$
\pi_i(x) = \frac{1}{b(n+1)^2} (a - (n + 1)c^0_i + \sum_{j=1}^{n} c^0_j + \sum_{j=1}^{n} x_j)^2 - \frac{1}{2}x_i^2
$$

(3-5)
Calculate the first derivative of $\pi_i(x)$ with respect of $x_i$ and let it equal zero, we obtain

$$\frac{\partial \pi_i(x)}{\partial x_i} = \frac{2}{b(n+1)^2} \left( a - (n + 1)c_i^0 + \sum_{j=1}^{n} c_j^0 + \sum_{j=1}^{n} x_j \right) - x_i = 0, \quad i = 1,2,\ldots,n$$

(3-6)

Add the $n$ equations in (3-6) and do some algebraic simplification, we get

$$\sum_{j=1}^{n} x_j = \frac{2}{b(n+1)^2-2n} \left( na - \sum_{j=1}^{n} c_j^0 \right)$$

(3-7)

We conclude from equation (3-7) that the optimal total amount of technical information in the cluster, $\sum_{j=1}^{n} x_j$, increases with parameter $a$, but decreases with the initial production costs, $c_j^0 (i = 1,2,\ldots,n)$, of firms in the cluster.

Substituting equation (3-7) into equation (3-6) and (3-4), we get the optimal amount of technical information and production quantity as follows.

$$x_{i}^{*D} = \frac{2}{n+1} \left( \frac{n+1}{b(n+1)^2-2n} a - \frac{1}{b} c_i^0 + \frac{b(n+1)-2}{b(n+1)^2-2n} \sum_{j=1, j\neq i}^{n} c_j^0 \right)$$

$$= \frac{2}{n+1} \left( \frac{n+1}{b(n+1)^2-2n} a + \frac{(b(n+1)-2)(b(n+1)^2-2n)}{b(n+1)^2-2n} c_i^0 + \frac{b(n+1)-2}{b(n+1)^2-2n} \sum_{j=1, j\neq i}^{n} c_j^0 \right)$$

$$q_{i}^{*D} = \frac{n+1}{b(n+1)^2-2n} a - \frac{1}{b} c_i^0 + \frac{(b(n+1)-2)}{b(n+1)^2-2n} \sum_{j=1}^{n} c_j^0$$

and $q_{i}^{*D} = \frac{n+1}{2} x_{i}^{*D}$.

So, the optimal amount of technical information, $x_{i}^{*D}$, and the optimal production quantity, $q_{i}^{*D}$, of the $i$th ($i = 1,2,\ldots,n$) firm increase with the parameter $a$ and other firms’ initial production costs $c_j^0 (j \neq i)$, but decrease with its own initial production cost $c_i^0$.

The optimal profit of the $i$th ($i = 1,2,\ldots,n$) firm is

$$\pi_{i}^{*D} = b(q_{i}^{*D})^2 - \frac{1}{2}(x_{i}^{*D})^2 = \frac{b(n+1)^2-2}{4} (x_{i}^{*D})^2$$

$$= \frac{b(n+1)^2-2}{(b(n+1)^2-2n)^2} \left( a - \frac{b(n+1)^2-2n}{b(n+1)} c_i^0 + \frac{b(n+1)-2}{b(n+1)} \sum_{j=1}^{n} c_j^0 \right)^2$$
Since $b \geq 2$, each firm gets a positive profit, and each firm’s profit increases with its optimal amount of technical information and optimal production quantity.

Since $\sum_{j=1}^{n} q_j < a/b$ and $\sum_{j=1}^{n} x_j < c_i^0$, $i = 1, 2, ..., n$, parameters of the model should satisfy the following conditions:

\[
a > \frac{b(n+1)}{2n - b(n+1)} \sum_{j=1}^{n} c_j^0
\]

\[
a < \frac{b(n+1)^2 - 2n}{2n} \min\{c_1^0, c_2^0, ..., c_n^0\} + \frac{1}{n} \sum_{j=1}^{n} c_j^0
\]

When $b \geq 2$, the right hand of the first condition is negative, so the first condition must stand. Combining the second condition with the technical assumption $a > \frac{1}{n} \sum_{j=1}^{n} c_j^0$, we obtain

\[
\frac{1}{n} \sum_{j=1}^{n} c_j^0 < a < \frac{b(n+1)^2 - 2n}{2n} \min\{c_1^0, c_2^0, ..., c_n^0\} + \frac{1}{n} \sum_{j=1}^{n} c_j^0
\]

3.2 Centralized Decision Making in Stage I

Assume there is a central decision maker in the cluster who decides each firm’s amount of technical information. We analyze this game using the method of backward induction.

In Stage II, each firm decides its own production quantity with the aim of maximizing its own profit. The analyses of this stage is the same as that of the Stage II in section 3.1, and we can also get the equation of the total production quantity, (3-3), the equation of each firm’s production quantity, (3-4), and the equation of each firm’s profit, (3-5).

In Stage I, the central decision maker decides each firm’s amount of technical information, with the aim of maximizing the total profit of all the firms in the cluster.

According to equation (3-5), the total profit of the cluster is

\[
\pi(x) = \sum_{i=1}^{n} \left[ \frac{1}{b(n+1)^2} \left( a - (n + 1)c_i^0 + \sum_{j=1}^{n} c_j^0 + \sum_{j=1}^{n} x_j \right)^2 - \frac{1}{2} x_i^2 \right] \quad (3-8)
\]

Calculate the first derivative of $\pi(x)$ with respect of $x_i$ and let it equal zero,
we obtain

$$\frac{\partial \pi(x)}{\partial x_i} = \frac{2}{b(n+1)^2} \sum_{i=1}^{n} (a - (n + 1) c_i + \sum_{j=1}^{n} c_j + \sum_{j=1}^{n} x_j) - x_i = 0, \quad i = 1, 2, ..., n$$

(3-9)

Add the $n$ equations in (3-9) and do some algebraic simplification, we get

$$\sum_{j=1}^{n} x_j = \frac{2n}{b(n+1)^2-2n^2} \left( na - \sum_{j=1}^{n} c_j \right)$$

(3-10)

Comparing equation (3-10) with equation (3-7), we get Theorem 1.

**Theorem 1** When $a > \frac{1}{n} \sum_{j=1}^{n} c_j^0$ and $b \geq 2$, no matter decisions of Stage I are made in a decentralized or centralized way, the optimal total amount of technical information in the cluster, $\sum_{j=1}^{n} x_j$, increases with parameter $a$, but decreases with the initial production costs, $c_j^0 (i = 1, 2, ..., n)$, of firms in the cluster. However, making decisions of Stage I in a centralized way can increase the total amount of technical information in the cluster.

Proof: Comparing equation (3-10) with (3-7), we can find that the optimal total amount of technical information in the cluster, $\sum_{j=1}^{n} x_j$, of the centralized decision-making case is $\left( \frac{n(b(n+1))^2-2n}{b(n+1)^2-2n^2} \right)$ times that of the decentralized case. Since $b \geq 2$, we know $\frac{n(b(n+1))^2-2n}{b(n+1)^2-2n^2} > 1$. Done.

Substituting equation (3-10) into (3-9), we obtain the optimal amount of technical information of the $i$th ($i = 1, 2, ..., n$) firm as

$$x_i^{*C} = \frac{2}{b(n+1)^2-2n^2} \left( na - \sum_{j=1}^{n} c_j \right)$$

We can conclude from the above equation that $x_i^{*C}$ increases with the parameter $a$, but decreases with the initial production costs of all the firms in the cluster, $c_j^0 (j = 1, 2, ..., n)$. Comparing $x_i^{*C}$ with $x_i^{*D}$, we get Theorem 2.

**Theorem 2** When $a > \frac{1}{n} \sum_{j=1}^{n} c_j^0$ and $b \geq 2$, comparing $x_i^{*C}$ with $x_i^{*D}$ results
in the following conclusions: (1) Under the decentralized decision-making case, firms with different initial production costs should acquire different amount of technical information, those with lower initial costs should acquire more technical information; under the centralized decision-making case, every firm in the cluster should acquire the same amount of technical information, even if their initial costs are different. (2) Under the decentralized decision-making case, $x_i^{D}$ increase with the initial costs of other firms in the cluster, $c_j^0 (j \neq i)$; under the centralized decision-making case, the conclusion is the opposite. (3) No matter decisions of Stage I are made in a decentralized way or a centralized way, the optimal amount of technical information of each firm increase with parameter a, but decrease with its own initial production cost.

Substituting equation (3-10) into (3-4), we get the optimal production quantity of the $i$th ($i = 1, 2, ..., n$) firm as

$$q_i^{C} = \frac{n+1}{b(b(n+1)^2-2n^2)} a - \frac{1}{b} c_i^0 + \frac{b(n+1)-2n}{b(b(n+1)^2-2n^2)} \sum_{j=1}^{n} c_j^0$$

$$= \frac{n+1}{b(n+1)^2-2n^2} a + \frac{b(n+1)-2n-(b(n+1)^2-2n^2)}{b(n(n+1)^2-2n^2)} c_i^0 + \frac{b(n+1)-2n}{b(n(n+1)^2-2n^2)} \sum_{j=1, j \neq i}^{n} c_j^0$$

Comparing $q_i^{C}$ with $q_i^{D}$, we get Theorem 3.

**Theorem 3** When $a > \frac{1}{n} \sum_{j=1}^{n} c_j^0$ and $b \geq 2$, no matter decisions of Stage I are made in a decentralized or centralized way, the optimal production quantity of each firm in the cluster increases with parameter $a$ and other firms’ initial production costs $c_j^0 (j \neq i)$, but decreases with its own initial production costs $c_i^0$.

The optimal profit of the $i$th ($i = 1, 2, ..., n$) firm is

$$\pi_i^{C} = \frac{1}{b(b(n+1)^2-2n^2)^2} \left( b(n+1)a - (b(n+1)^2 - 2n^2)c_i^0 + (b(n+1) - 2n) \sum_{j=1}^{n} c_j^0 \right)^2$$
Since \( \sum_{j=1}^{n} q_j < a/b \) and \( \sum_{j=1}^{n} x_j < c_i^0, \ i = 1,2,\ldots,n \), so the parameters of the model should satisfy the following conditions:

\[
(2n^2 - b(n + 1))a < b(n + 1)\sum_{j=1}^{n} c_j^0
\]

\[
a < \frac{b(n+1)^2 - 2n^2}{2n^2} \min\{c_1^0, c_2^0, \ldots, c_n^0\} + \frac{1}{n} \sum_{j=1}^{n} c_j^0
\]

The comparison of optimal solution and optimal profit between the decentralized and centralized decision-making cases is complicated, because it depends on parameters \( a, b \), and \( c_i^0 (i = 1,2,\ldots,n) \). Here, we only make a simple comparison under the special case when \( c_1^0 = c_2^0 = \ldots = c_n^0 = c \), the results are shown in Table 3-1, where \( a > c, \ b \geq 2 \). Main conclusions are summarized in Theorem 4.

Table 3-1 Comparison of the decentralized and centralized decision-making case

<table>
<thead>
<tr>
<th>The amount of technical information</th>
<th>Decentralized decision making</th>
<th>Centralized decision making</th>
</tr>
</thead>
<tbody>
<tr>
<td>( x_i^D = \frac{2}{b(n+1)^2 - 2n^2} (a-c) )</td>
<td>( x_i^C = \frac{2n}{b(n+1)^2 - 2n^2} (a-c) )</td>
<td></td>
</tr>
<tr>
<td>Production quantity</td>
<td>( q_i^D = \frac{n+1}{b(n+1)^2 - 2n^2} (a-c) )</td>
<td>( q_i^C = \frac{n+1}{b(n+1)^2 - 2n^2} (a-c) )</td>
</tr>
<tr>
<td>Profit</td>
<td>( \pi_i^D = \frac{b(n+1)^2 - 2}{(b(n+1)^2 - 2n^2)^2} (a-c)^2 )</td>
<td>( \pi_i^C = \frac{1}{b(n+1)^2 - 2n^2} (a-c)^2 )</td>
</tr>
</tbody>
</table>

**Theorem 4** When \( c_1^0 = c_2^0 = \ldots = c_n^0 = c < a \) and \( b \geq 2 \), \( x_i^C > x_i^D \), \( q_i^C > q_i^D \), \( \pi_i^C > \pi_i^D \).

Proof:

\[
x_i^C - x_i^D = \frac{2b(n+1)^2(n-1)}{(b(n+1)^2-2n^2)(b(n+1)^2-2n)} (a-c) > 0;
\]

\[
q_i^C - q_i^D = \frac{2n(n^2-1)}{(b(n+1)^2-2n^2)(b(n+1)^2-2n)} (a-c) > 0;
\]

\[
\pi_i^C - \pi_i^D = \frac{2b(n^2-1)^2}{(b(n+1)^2-2n^2)(b(n+1)^2-2n)^2} (a-c)^2 > 0.
\]
4. The Model with Asymmetric Cost Information

The model of section 3 is based on the assumption that every firm in the cluster accurately knows the initial production costs of all the firms in the same cluster. However, in practice, each firm knows its own cost information better than other firms, that’s, it usually owns private information about its own cost. This section studies the technical information decisions and the production quantity decisions in this context and analyzes the value of horizontal information sharing.

Assumptions of this section are almost the same as those of section 3, the only difference is that we assume the actual initial cost of the first firm, \( c_1^0 \), is its private information, and other firms in the cluster only know that \( c_1^0 \) can be \( c_1^{0H} \) or \( c_1^{0L} \) with probability \( \xi \) and \((1-\xi)\), respectively, \( 0 \leq \xi \leq 1 \). In this section, the amount of technical information and the production quantity of each firm are both decided in a decentralized way. We still analyze the game using the method of backward induction.

4.1 Stage II

Assume the first firm adopts separating strategy in Stage I, that’s, it chooses different amount of technical information \( x_1 \) under high cost condition \( c_1^{0H} \) and low cost condition \( c_1^{0L} \). So, in Stage II, other firms in the cluster can accurately infer the actual initial cost of the first firm according to \( x_1 \). In other words, the first firm doesn’t have private information any longer in Stage II. Therefore, the analysis of Stage II in this section is the same as that in section 3.1, and we can also get the equation (3-4) of each firm’s production quantity. When the initial cost of the first firm is high or low (denotes by superscripts “H” and “L”), the equilibrium production quantity of each firm under Cournot competition is as follows:
where vector $x_{-1} = (x_2, x_3, ..., x_n)$ denotes the amount of technical information acquired by other firms in the cluster.

### 4.2 Stage I

Since the analysis of Stage II in this section is the same as that in section 3.1, the profit function of each firm here is the same as shown in equation (3-5). So, when the initial cost of the first firm is $c_1^{0H}$ or $c_1^{0L}$, its profit function is

$$
\pi_1^H(x_1^H, x_{-1}) = \frac{1}{b(n+1)^2} \left( a - nc_1^{0H} + \sum_{j=2}^{n} c_j^0 + x_1^H + \sum_{j=2}^{n} x_j \right)^2 - \frac{1}{2} (x_1^H)^2 \quad (4-5)
$$

$$
\pi_1^L(x_1^L, x_{-1}) = \frac{1}{b(n+1)^2} \left( a - nc_1^{0L} + \sum_{j=2}^{n} c_j^0 + x_1^L + \sum_{j=2}^{n} x_j \right)^2 - \frac{1}{2} (x_1^L)^2 \quad (4-6)
$$

Calculate the first derivative of $\pi_1^H(x_1^H, x_{-1})$ with respect of $x_1^H$ and let it equal zero, we obtain

$$
\frac{\partial \pi_1^H(x_1^H, x_{-1})}{\partial x_1^H} = \frac{2}{b(n+1)^2} \left( a - nc_1^{0H} + \sum_{j=2}^{n} c_j^0 + x_1^H + \sum_{j=2}^{n} x_j \right) - x_1^H = 0
$$

So,

$$
x_1^H = \frac{2}{b(n+1)^2} \left( a - nc_1^{0H} + \sum_{j=2}^{n} c_j^0 + \sum_{j=2}^{n} x_j \right) \quad (4-7)
$$

Similarly,

$$
x_1^L = \frac{2}{b(n+1)^2} \left( a - nc_1^{0L} + \sum_{j=2}^{n} c_j^0 + \sum_{j=2}^{n} x_j \right) \quad (4-8)
$$

We conclude from equations (4-7) and (4-8) that the optimal amount of technical
information of the first firm decreases with its own initial cost $c_i^0$, but increases with parameter $a$, the initial cost of other firms, $c_j^0 (j = 2, 3, ..., n)$, and the total amount of technical information of other firms, $\sum_{j=2}^{n} x_j$. In addition, when the initial cost of the first firm is $c_i^{0H}$, the first firm will choose smaller amount of technical information; when the initial cost of the first firm is $c_i^{0L}$, the first firm will choose larger amount of technical information. That’s, the first firm adopts separating strategy just as our assumption.

For convenience, let $c_i^0 = \xi c_i^{0H} + (1 - \xi) c_i^{0L}$, $x_i = \xi x_i^{H} + (1 - \xi) x_i^{L}$, then

$$x_1 = \frac{2}{b(n+1)^2-2} \left( a + \sum_{j=2}^{n} c_j^0 + \sum_{j=2}^{n} x_j \right) - \frac{2\xi c_0^0}{b(n+1)^2-2}$$

(4-9)

The profit function of the $i$th ($i = 2, 3, ..., n$) firm except the first firm is

$$\pi_i(x) = \xi \left[ \frac{1}{b(n+1)^2} \left( a - (n + 1)c_i^0 + c_i^{0H} + \sum_{j=2}^{n} c_j^0 + x_1^H + \sum_{j=2}^{n} x_j \right)^2 - \frac{1}{2} x_i^2 \right]
+ (1 - \xi) \left[ \frac{1}{b(n+1)^2} \left( a - (n + 1)c_i^0 + c_i^{0L} + \sum_{j=2}^{n} c_j^0 + x_1^L + \sum_{j=2}^{n} x_j \right)^2 - \frac{1}{2} x_i^2 \right],$$

$$i = 2, 3, ..., n$$

(4-10)

Calculate the first derivative of $\pi_i(x)$ with respect of $x_i$ and let it equal zero, we obtain

$$\frac{\partial \pi_i(x)}{\partial x_i} = \frac{2}{b(n+1)^2} \left( a - (n + 1)c_i^0 + c_i^{0H} + \sum_{j=2}^{n} c_j^0 + x_1 + \sum_{j=2}^{n} x_j \right) - x_i = 0$$

Replacing $x_1$ in the above equation with equation (4-9) results in

$$\frac{\partial \pi_i(x)}{\partial x_i} = \frac{2}{b(n+1)(b(n+1)^2-2)} \left[ b(n+1)a - (b(n+1)^2 - 2)c_i^0 + (b(n+1) - 2)c_i^0 
+ b(n + 1) \sum_{j=2}^{n} c_j^0 + b(n + 1) \sum_{j=2}^{n} x_j \right] - x_i = 0, \quad i = 2, 3, ..., n$$

(4-11)

Add the ($n-1$) equations in (4-11) and do some algebraic simplification, we get

$$\sum_{j=2}^{n} x_j = \frac{2(n-1)}{b(n+1)^2-2n} a + \frac{2(n-1)(b(n+1)^2-2)}{b(n+1)(b(n+1)^2-2n)} c_i^0 - \frac{4(b(n+1)-1)}{b(n+1)(b(n+1)^2-2n)} \sum_{j=2}^{n} c_j^0$$

(4-12)

Substituting equation (4-12) into equations (4-7) and (4-8), we obtain the optimal
amount of technical information of the first firm when its initial cost is $c_1^{0H}$ (or $c_1^{0L}$) as follows:

$$x_1^{H*} (\text{or } x_1^{L*}) = \frac{2}{b(n+1)^2-2n} a - \frac{2n}{b(n+1)^2-2n} c_1^{0H} (\text{or } c_1^{0L})$$

$$+ \frac{4(n-1)(b(n+1)-2)}{b(n+1)(b(n+1)^2-2)(b(n+1)^2-2n)} c_1^{0} + \frac{2b(n+1)(b(n+1)^2-2n)-8(b(n+1)-1)}{b(n+1)(b(n+1)^2-2)(b(n+1)^2-2n)} \sum_{j=2}^{n} c_j^{0}$$

Substituting equation (4-12) into (4-11), we obtain the optimal amount of technical information of the $i$th ($i = 2, 3, ..., n$) firm as follows:

$$x_i^{H*} = \frac{2}{b(n+1)^2-2n} a + \frac{2(b(n+1)-2)}{b(n+1)(b(n+1)^2-2n)} c_1^{0} - \frac{2}{b(n+1)} c_i^{0}$$

$$+ \frac{2b(n+1)(b(n+1)^2-2n)-8(b(n+1)-1)}{b(n+1)(b(n+1)^2-2)(b(n+1)^2-2n)} \sum_{j=2}^{n} c_j^{0}, \quad i = 2, 3, ..., n$$

Substituting $x_1^{H*}$ and equation (4-12) into equations (4-1) and (4-2), we obtain that, when the initial cost of the first firm is $c_1^{0H}$, the optimal production quantity and the optimal profit of each firm are as follows:

$$q_1^{H*} = \frac{n+1}{b(n+1)^2-2n} a + \frac{2(n-1)(b(n+1)-2)}{b(n+1)(b(n+1)^2-2)(b(n+1)^2-2n)} c_1^{0} - \frac{n(n+1)}{b(n+1)^2-2} c_1^{0H}$$

$$+ \frac{b(n+1)-2}{b(n+1)^2-2n} \sum_{j=2}^{n} c_j^{0}$$

$$q_i^{H*} = \frac{n+1}{b(n+1)^2-2n} a - \frac{1}{b} c_i^{0} + \frac{2(n-1)(b(n+1)-2)}{b(n+1)(b(n+1)^2-2)(b(n+1)^2-2n)} c_1^{0} + \frac{b(n+1)-2}{b(n+1)^2-2} c_1^{0H}$$

$$+ \frac{b(n+1)-2}{b(n+1)^2-2n} \sum_{j=2}^{n} c_j^{0}$$

where $q_1^{H*} = \frac{n+1}{2} x_1^{H*}$.

$$\pi_1^{H*} = b(q_1^{H*})^2 - \frac{1}{2} (x_1^{H*})^2$$

$$\pi_i^{H*} = b(q_i^{H*})^2 - \frac{1}{2} (x_i^{H*})^2, \quad i = 2, 3, ..., n$$

Substituting $x_i^{L*}$ and equation (4-12) into equations (4-3) and (4-4), we obtain that, when the initial cost of the first firm is $c_1^{0L}$, the optimal production quantity and the optimal profit of each firm are as follows:
\[ q_{1*}^L = \frac{n+1}{b(n+1)^2-2n}a + \frac{2(n-1)(b(n+1)-2)}{b(n+1)^2-2(b(n+1)^2-2n)}c_{10}^L \]

\[ = \frac{n(n+1)}{b(n+1)^2-2}c_{10}^L \]

\[ + \frac{b(n+1)-2}{b(b(n+1)^2-2n)} \sum_{j=2}^{n} c_{j}^0 \]

\[ q_{1*}^H = \frac{n+1}{b(n+1)^2-2n}a - \frac{1}{b}c_{10}^H + \frac{2(n-1)(b(n+1)-2)}{b(n+1)^2-2(b(n+1)^2-2n)}c_{10}^L \]

\[ + \frac{b(n+1)-2}{b(b(n+1)^2-2n)} \sum_{j=2}^{n} c_{j}^0 \]

where \[ q_{1*}^L = \frac{n+1}{2}x_{1*}^L. \]

\[ \pi_{1*}^L = b(q_{1*}^L)^2 - \frac{1}{2}(x_{1*}^L)^2 \]

\[ \pi_{1*}^H = b(q_{1*}^H)^2 - \frac{1}{2}(x_{1*}^H)^2, \quad i = 2, 3, ..., n \]

Next, we take the special case when the actual initial cost of the first firm, \( c_{10}^O \), equals the initial cost of other firms in the cluster as an example, that's, \( c_{1*}^0 = c_2^0 = \ldots = c_n^0 = c \), in order to compare the optimal solution under the condition of symmetric cost information and that under the condition of asymmetric cost information. \( c_{1*}^0 = c_{1*}^H \) or \( c_{1*}^0 = c_{1*}^L \). \( c_{1*}^0 = \xi c_{1*}^0 + (1 - \xi)c_{1*}^L \). \( c_{1*}^0 > c_{1*}^0 > c_{1*}^L \). Thus we obtain Theorem 5.

**Theorem 5** When the actual initial cost of the first firm is \( c_{1*}^H \) and \( c_{1*}^H = c_{1*}^0 = \ldots = c_{1*}^0 = c \), we get the following conclusions: (1) If the first firm share its private cost information with other firms in the cluster, the optimal amount of technical information and the optimal production quantity of each firm are both larger compared with the no information sharing case; (2) Sharing its private cost information with other firms in the cluster can increase the first firm’s profit; however, only if

\[ (b(n + 1) - 2) \left( \frac{(n+1)^2}{b(n+1)^2-2} - \frac{(n+1)}{b(n+1)^2-2n} + \frac{(b(n+1)^2-2)^2}{b(n+1)^2(b(n+1)^2-2n)^2} \right) (c - c_{1*}^0) \]

\[ + \left( \frac{b(n+1)^2}{b(n+1)^2-2n} - \frac{2(b(n+1)^2-2)^2}{(n+1)(b(n+1)^2-2n)^2} \right) (a - c) < 0 \]  \hspace{1cm} (4-13)
other firms except the first firm can benefit from information sharing. When the actual initial cost of the first firm is \( c_1^{0L} \) and \( c_1^{0L} = c_2^0 = \cdots = c_n^0 = c \), the results are the opposite.

**Proof:** When the first firm shares its private cost information with other firms in the cluster, the optimal amount of technical information \( x_i^D \), the optimal production quantity \( q_i^D \), and the optimal profit \( \pi_i^D \) of each firm are just as shown in the column “Decentralized Decision Making” of the Table 3-1.

When the actual initial cost of the first firm is \( c_1^{0H} \), \( c_1^{0H} = c_2^0 = \cdots = c_n^0 = c \), and the first firm doesn’t share its private cost information with other firms, the optimal amount of technical information and the optimal production quantity of each firm are as follows:

\[
x_1^{H*} = \frac{2}{b(n+1)} \left( \frac{b(n+1)}{b(n+1)^2 - 2n} \right) a + \frac{2(n-1)(b(n+1)-2)}{b(n+1)^2 - 2n} c_1^0 - \frac{b^2(n+1)^3 + 2bn(n+1) - 4b(n+1) - 4(n-1)}{(b(n+1)^2 - 2n)(b(n+1)^2 - 2n)} c
\]

\[
x_1^* = \frac{2}{b(n+1)^2 - 2n} (a - c) = x_1^D
\]

\[
x_i^* = \frac{2}{b(n+1)^2 - 2n} a + \frac{2(n-1)(b(n+1)-2)}{b(n+1)(b(n+1)^2 - 2n)} c_1^0 - \frac{4b^2(n+1)^3 - 4b(n+1)^3 + 4b(n+1)(n+2) + 8b(n+1)(b(n+1)^2 - 2n)}{(b(n+1)(b(n+1)^2 - 2n)) c
\]

\[
q_i^{H*} = \frac{n+1}{2} x_1^*
\]

\[
q_1^{H*} = \frac{1}{b} \left( \frac{b(n+1)}{b(n+1)^2 - 2n} \right) a + \frac{2(n-1)(b(n+1)-2)}{b(n+1)^2 - 2n} c_1^0 - \frac{b^2(n+1)^3 + 2bn(n+1) - 4b(n+1) - 4(n-1)}{(b(n+1)^2 - 2n)(b(n+1)^2 - 2n)} c
\]

\[
q_i^* = \frac{1}{b} \left( \frac{b(n+1)}{b(n+1)^2 - 2n} \right) a + \frac{2(n-1)(b(n+1)-2)}{b(n+1)^2 - 2n} c_1^0 - \frac{b^2(n+1)^3 + 2bn(n+1)(n-2) - 4(n-1)}{(b(n+1)^2 - 2n)(b(n+1)^2 - 2n)} c
\]
\[ i = 2, 3, \ldots, n \]

Since \( x_1^{H^*} < x_1^{D} \), so

\[ \pi_i^{H^*} = \frac{b(n+1)^2-2}{4} \left( x_1^{H^*} \right)^2 < \frac{b(n+1)^2-2}{4} \left( x_1^{D} \right)^2 = \pi_i^{D} \]

That’s, Sharing its private cost information with other firms in the cluster can increase the first firm’s profit. For other firms in the cluster except the first firm, since

\[ \frac{2}{n+1} q_i^{H^*} - x_i^* = \frac{2(b(n+1)-2)}{b(n+1)(b(n+1)^2-2)} (c - c_1^0) \]

\[ x_i^{*D} - x_i^* = \frac{2(b(n+1)-2)}{b(n+1)(b(n+1)^2-2n)} (c - c_1^0) \]

Let

\[ \varepsilon_1 = \frac{n+1}{2}, \quad \frac{2(b(n+1)-2)}{b(n+1)(b(n+1)^2-2)} (c - c_1^0) = \frac{b(n+1)-2}{b(n+1)(b(n+1)^2-2)} (c - c_1^0) \]

\[ \varepsilon_2 = \frac{2(b(n+1)-2)}{b(n+1)(b(n+1)^2-2n)} (c - c_1^0) \]

Then \( \varepsilon_1, \varepsilon_2 > 0 \), \( \varepsilon_2 = \frac{2(b(n+1)^2-2)}{(n+1)(b(n+1)^2-2n)} \varepsilon_1 \), and \( q_i^{H^*} = \frac{n+1}{2} (\varepsilon_1 + x_i^*) \), \( x_i^* = x_i^{*D} - \varepsilon_2 \). So the profit of the ith \( (i = 1, 2, \ldots, n) \) firm is

\[ \pi_i^{H^*} = b(q_i^{H^*})^2 - \frac{1}{2} (x_i^*)^2 \]

\[ \pi_i^{H^*} = \frac{b(n+1)^2}{4} \left( \varepsilon_1 + x_i^* \right)^2 - \frac{1}{2} \left( x_i^* \right)^2 \]

\[ \pi_i^{H^*} = \pi_i^{D} + \frac{b(n+1)^2}{4} \left( \varepsilon_1^2 + 2 \varepsilon_1 (x_i^{*D} - \varepsilon_2) \right) + \frac{b(n+1)^2-2}{4} (\varepsilon_2^2 - 2 \varepsilon_2 x_i^{*D}) \]

Only if the following condition stands, \( \pi_i^{H^*} < \pi_i^{*D} \).
Replacing into the above condition results in \( (4 - 13) \).

When the actual initial cost of the first firm is \( c_1 \) and \( c \), we can get the conclusions similarly.

### 5. Conclusion

This paper studies the problem of horizontal technical cooperation and information sharing in the context of cluster supply chain. Based on the Cournot competition model, section 3 constructs the model of horizontal technical information sharing with symmetric cost information and analyzes both the decentralized and centralized decision making case. Comparison shows that centralized decision making can increase the total amount of technical information in the cluster and enable every firm of the cluster to produce at a lower cost. In addition, when all the firms have the same initial production cost, centralized decision making can increase the profits of all the firms compared with the decentralized decision making case. Section 4 constructs the model of horizontal technical cooperation with asymmetric cost information, and analyzes the value of horizontally sharing the cost information. Results show that, whether sharing cost information brings benefits to each firm in the cluster depends on the specific operating environment.

Based on this paper, there are several promising directions for future researches. First, we assume that any technical information acquired by one firm of the cluster can be totally adopted by other firms in the same cluster, however, in reality, different firms may have different adoption rates because of different closeness of the
relationship between them. For example, since contact between firm 1 and firm 2 is more frequent, the adoption rate between them may be 90%; however, since contact between firm 1 and firm 3 is infrequent, the adoption rate between them may be only 20%. The closeness of relationship between firms in the cluster may influence the conclusions of this paper. Second, this paper assumes that every firm in the cluster pays the same cost to obtain the same amount of technical information, but in fact, some firms may have cost advantage of acquiring technology. How to encourage these firms to obtain more technical information for the cluster is a problem worth of considering. Finally, this paper only makes a simple analysis of the value of horizontal information sharing in the context of cluster supply chain, studying incentives for firms to share their information is very meaningful.

References


