Game Theoretic Approach for Global Manufacturing Planning under Risk and Uncertainty

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Key Words: global manufacturing, quality, supply chain optimization, game theoretic model

Abstract

We present a game theoretic model in which one manufacturer and its suppliers are coordinated. Quality of products from suppliers is considered on the decision process. Due to fluctuation of demand resulting from varying quality levels from suppliers, manufacturers are subject to financial risk. A game theoretic approach to resolve coordination between manufacturers and suppliers under risk and uncertainty is proposed. The objective is to help decision making for global manufacturing in order to improve quality in competitive global business. Computational experiments are conducted to demonstrate the effectiveness of the proposed algorithm.

1. Introduction

Today’s global economy has a growing impact on the economic futures of companies. Many companies in the global business environment are facing fierce competition on price and quality simultaneously. Customers make their decisions to purchase the product from firms based on both its price and quality. In order to survive in global competition, companies are embracing global integration and coordination of supply chain planning. In this paper, we propose a game theoretic approach to coordinate manufacturers and suppliers in order to improve quality of products under risk. The model proposed in this paper aims to help decision making between manufacturers and suppliers in order to improve the quality level under risk and investigate the effect of uncertainty on the model.

Nowadays, outsourcing suppliers to countries such as China or India has become popular. Companies establish their factories globally to decrease cost. It is a fact that those countries can provide lower manufacturing cost. However, in order to win in global business, competition is shifting from price to quality in many industries in order to achieve high customer satisfaction (Gans, 2002). Our work is motivated to help decision making for global manufacturing planning in order to achieve high customer satisfaction with low costs. Quality levels of those low-cost countries are varying. Meanwhile, the manufacturer is also facing the challenge of archiving high customer satisfaction in order to optimize profits. In our paper, we try to coordinate manufacturers and suppliers in order improve quality. In addition, competition among suppliers is also considered. It is a reality that the existence of competition is one of main drives to improve quality for companies. In practice, demand is always influenced by quality of products and price. Therefore, we assume that demand from customers is decided by quality levels of products which are purchased from suppliers.

This paper considers one manufacturer and its suppliers who are involved in purchasing, producing and selling products. Suppliers determine prices of products which are purchased by the manufacturer. The purchased quantity is decided by the manufacturer. Suppliers try to improve the level of quality of products in order to increase demand from customers. The increase of demand stimulates the manufacturer to purchase more products from suppliers. The relationship is modeled by noncooperative game that the manufacturer as a leader and the supplier as a follower. The manufacturer determines production and purchased quantity based on primary demand. The primary demand function is linear in quality and price (Dixit, 1979).

Quality levels and prices are determined by suppliers after the manufacturer’s action.

2. Global manufacturing planning model

In our model, we consider one manufacturer and its outsourcing suppliers. The manufacturer purchases parts of products from outsourcing suppliers from different countries, such as China, India or Brazil. Then, the manufacturer produces finished products in order to satisfy demand from regional customers. The demand depends on quality levels of products from suppliers.

As we state before, we assume that the demand from customers depends on the levels of quality. We assume two suppliers labelled $i$ and $j$ $(i, j = 1, 2, i \neq j)$ compete each other. They provide the same product with different prices and quality to the manufacturer.

Extending the demand function proposed by Xie et al. (2011), the primary demand function for supplier $i$ is linear in quality and price. Let $p_i$ denote price of products provided by supplier $i$, and $x_i, x_j$ denote quality for supplier $i$ and supplier $j$, respectively.

$$q_i(x_i) = k_1 x_i - \lambda x_i + \mu x_i - x_j$$

where $k_1 + k_j = 1$. $k_1$ represents the intrinsic demand potential for supplier $i$. We consider the competition between suppliers. In order to gain more demand, suppliers should improve quality and reduce price. Therefore, $\mu$ is competition intensity denoting the competitive effects of quality. According to quality improvement strategy, the primary demand function $q_i$ should has a positive correlation with its supplier $i$’s quality, that is, $\mu > 0$. Once supplier improves its quality, the demand is affected more than its competitor. This policy encourages suppliers to improve quality to compete in order to gain more demand.

Similar to other studies by Banker et al. (1998) and Xie et al. (2011), the cost function for supplier $i$ is given by

$$c_i = (v_i + \alpha x_i)q_i + f + \Phi x_i^2$$


where \( f + \Phi X_i^2 \) is a fixed cost function for supplier \( i \) which is increasing and convex in the quality level \( X_i \). \( \Phi X_i^2 \) is the marginal cost for the supplier in the quality level \( X_i \). In this paper, we consider global manufacturing. Thus, for competing suppliers from different countries, they could have different price of prices \( P_i \) and price of investment in quality \( X_i^2 \).

3. Pareto efficient solution

We apply Stackelberg game to this problem where the manufacturer is a leader and suppliers are followers. We also consider competition between supplier \( i \) and supplier \( j \) \((i \neq j = 1,2)\) in this problem. The equilibrium of Stackelberg game is usually solved by a backward induction procedure. It generally works as follows. The follower’s (supplier) problem must be first solved to get the reaction function of the leader’s (manufacturer) decision results. The manufacturer’s decision problem is solved considering all possible reactions of its followers for maximizing the profits. We introduce Pareto efficient solutions to resolve competition between suppliers. In this work, we assume that two suppliers make decisions simultaneously. We derive the optimal response functions by minimizing the total sum of objective functions.

The Pareto efficient solutions can be characterized by maximizing:

\[
Z = \theta \Pi_i + (1 - \theta) \Pi_j, 0 \leq \theta \leq 1
\]

where \( \Pi_i \) and \( \Pi_j \) represent objective functions of total profits for supplier \( i \) and supplier \( j \).

Solution Algorithm

**Step 0:** Initialize parameters of the manufacturer’s and retailer’s model

**Step 1:** Derive retailer’s best response functions by retailer’s model

**Step 2:** Initialize \( W_i \) and \( W_j \) and derive optimal \( X_i^* \) and \( X_j^* \) by substituting the given \( W_i \) and \( W_j \) in retailer’s best response functions.

**Step 3:** Solve manufacturer’s objective function \( \Pi_m \) by substituting \( X_i^* \), \( X_j^* \), \( W_i \) and \( W_j \) and generate optimal solutions

4. Computational experiments

This section presents the numerical example which is aimed at illustrating the features of the proposed models and demonstrating the performance of the algorithm. We set there are two suppliers and one manufacturer in the model. In the computational experiment, GAMS 23.6 is used. Parameters used in the computational example are shown in Table 1 for the manufacturer and suppliers. Table 2 shows the results of this computational example.

We conduct small size problems to demonstrate the features of the model. Two computational results are obtained while prices of products offered by two suppliers are different. We can notice that when the price is increased, suppliers must improve both of their quality in order to compete.

**Table 1: Parameters**

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Supplier</th>
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<tbody>
<tr>
<td>( r )</td>
<td>20</td>
</tr>
<tr>
<td>( e )</td>
<td>3</td>
</tr>
<tr>
<td>( b )</td>
<td>1</td>
</tr>
<tr>
<td>( Q )</td>
<td>50</td>
</tr>
<tr>
<td>( a )</td>
<td>20</td>
</tr>
<tr>
<td>( k_i )</td>
<td>0.5</td>
</tr>
<tr>
<td>( \mu )</td>
<td>2</td>
</tr>
<tr>
<td>( \lambda )</td>
<td>1</td>
</tr>
</tbody>
</table>

**Table 2: Computational results**

<table>
<thead>
<tr>
<th>Example 1</th>
<th>Example 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>( W_i )</td>
<td>( W_j )</td>
</tr>
<tr>
<td>( X_i )</td>
<td>( X_j )</td>
</tr>
<tr>
<td>( Y )</td>
<td>( Y )</td>
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The total profit of the manufacturer is not increased in the case, because the demand also depends on the price of the products. Thus, the manufacturer and suppliers should try to optimize quality of products as well as the price in order to obtain more profits in this game theoretic model. In the next step, we examine more detailed impact of different parameters.

5. Conclusion and future works

This paper has formulated a global manufacturing planning problem associating with quality considerations as a Stackelberg game model. We consider that demand from customers is linear in quality of products from suppliers and prices. Our primary interest is to involve competition between suppliers in this game theoretic model. Nowadays, in order to gain demand and increase profits, global suppliers have to compete in price and quality. We analyze this problem as a Stackelberg game where the manufacturer is a leader and the supplier is a follower. It is assumed that two supplier make their decisions simultaneously. The computational examples are conducted to illustrate the effectiveness of the proposed method and also impact of price and quality in this game theoretic model. In the future, it is very interesting to consider the situation that suppliers do not make decisions simultaneously. We consider each supplier’s response function separately, and find the equilibrium.

**References**


