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# The Impact of Quality Regulation on the Decisions of a Global Supply Chain

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**Abstract** In this study, we investigate the impact of quality regulation on the quality of investment and the pricing decisions of a global supply chain, where products are produced by a manufacturer in one country, but sold by a retailer in another country to its market. In particular, the quality of the products is regulated by policy makers of the importer country. We consider two cases of supply chain structures: vertical integration and a decentralized setting. A numerical example of a global supply chain where the manufacturer in China takes orders from a retailer in another country, one which enforces quality regulations, is presented to illustrate some related issues. Finally, conclusions are drawn and some topics for future work are suggested.

**Keywords** Global supply chain; Quality; Regulation; Make-to-order

## 1 Introduction

The rapid increase of China's share of international trade has been a significant feature of the global economy. Against the backdrop of the globalization of trade, China has become one of the world's primary manufacturing centers [1]. People around the world find that their life is increasingly concerned with products 'made in China'. Based on data from China's Customs Express, China's share of international trade is about 3 trillion U.S. dollars, which was over 50% of its GDP in 2010. A typical international trade scenario is a global supply chain where a manufacturer produces products in China, but a retailer sells the products in another country.

Global supply chain management is nowadays one of the most active research topics in global logistics [2], [3]. A 21st Century Logistics framework was developed at Michigan State University, which investigated the relationship between supply chain competencies and performance. The investigation showed that a competent supply chain led to improved performance. In a global supply chain, quality reflects broader service measures used to enhance customer loyalty, based on the logic that superior service attracts and keeps key customers [4]. Compared with common supply chains, global supply chains are operated in a more complex environment [5]-[7].

Supply chain quality is a key component in achieving a competitive advantage, and quality management practices are significantly correlated with players' strategies which influence tangible business results and customer satisfaction levels [8]. Although higher quality can be a reason for higher price, it can also result in higher costs. At the same time, quality and price influence demand and profits [9], [10]. Just like the definition of quality in [1], [10], we use the term ''quality'' to refer to both design and performance quality characteristics of interest to the consumer when evaluating the product offered by the supply chain. "Quality" may refer to characteristics such as the performance of a computer, the energy efficiency of a vehicle or the nutritional ingredients of a particular food.

In fact, quality is an issue that policy makers of importer countries must concern themselves with. In European countries, permission to import automobiles is only granted to vehicles that comply with a regulatory index for greenhouse gas (GHG) emission standards [11]. In the food industry, the level of some food additives must not exceed certain levels. The paper closest to our study is [1], which analyzes the quality investment and pricing decisions of a supplier-manufacturer supply chain. Our study differs from [1] in that we investigate the case that a global supply chain consists of a manufacturer in one country and a retailer in another country, where the quality of products is regulated by policy makers of the country importing the goods.

In this study, we consider the case that the policy makers of the importer country may regulate the quality of the imported products. We investigate the impacts of quality regulation on the investment in quality and the pricing decisions of a global supply chain, where products are produced by a manufacturer in one country but sold by a retailer in another country. We consider two cases of supply chain structures: vertical integration and a decentralized setting. Then, a numerical example of a global supply chain where the manufacturer in China takes orders from a retailer in another country is presented to illustrate related issues. Finally, conclusions are drawn and some topics for future work are suggested.

## 2 Description of the Problem

The following notation is used in the model:

$i$ supply chain structure $i$ ($i$ =I, D);

$x_i$ quality of products in the $i$ th supply chain structure;

$p_i$ price per unit in the $i$ th supply chain structure;

$x_0$ threshold value for the quality of products set by the policy maker;

$w$ wholesale price per unit of product to the retailer;

$v_M$ variable production cost per unit of the manufacturer;

$v_R$ variable retail cost per unit of the retailer;

$c$ fixed cost related to quality;

$\alpha$ the demand responsiveness to quality of product;

$\beta$ the demand responsiveness to price of product.

We have following assumptions.

**Assumption 1**. $p_i > w + v_R$ and $w > v_R$.

**Assumption 2**. Quality of products can be measured and no less than the threshold value set by the policy maker. The quality of a product, for example, may relate to its level of energy consumption, GHG emissions, or nutritional value.

The inequalities in **Assumption 1** ensure that each player in a decentralized supply chain makes a positive profit. The primary demand function for the product in the $i$ th supply chain structure is decided by $x_i$ and $p_i$ as follows.

$$D_i = a + \alpha x_i - \beta p_i \tag{1}$$

where $a$ is potential intrinsic demand, $\alpha$ is the demand responsiveness to quality of the product, and $\beta$ is the demand responsiveness to price.

The fixed cost is expressed as

$$C_i = f + c x_i^2 \tag{2}$$

which is increasing and convex in quality level $x_i$ [1].

Within a given social system, the business flow of a global supply chain and quality regulation are shown in **Fig. 1**, where the policy maker sets the threshold value of quality regulation and checks to make sure that products sold by a retailer are no less than the threshold value set by the policy maker. Both the supplier and the manufacturer know the distribution of the demand and they organize the production for demand.

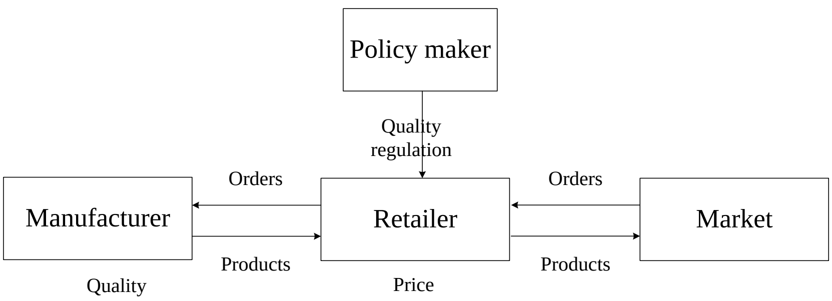


**Fig. 1 Business flow of a global supply chain with quality regulation.**

In following sections, we investigate the impact of $x_0$ on the quality and price decided by the global supply chain.

# 3 Decisions of a Global Supply Chain

In this section, $x_i$ and $p_i$ are decision variables and other variables are exogenous variables, which are known to both the manufacturer and the retailer in the supply chain. We consider the two cases of the supply chain structure: an integrated supply chain and a decentralized setting, where the optimal quality and price of products are analyzed.

## 3.1 Vertical Integration

In a global supply chain with vertical integration, $i = I$, decision-making is centralized. The decision-maker observes the distribution of demand and threshold value $x_0$ of quality level. After the quality level and price have been set by the global supply chain, orders are then placed and demand is realized.

The profit $\prod_I$ of the supply chain is

$$\prod_I = (p_I - v)(a + \alpha x_I - \beta p_I) - f - c x_I^2 \tag{3}$$

where $v = v_M + v_R$.

When there is no quality regulation, **Proposition 1** quantifies the optimal quality level of the manufacturer and price of the retailer.

**Proposition 1** *In an integrated supply chain, when* $4\beta c > \alpha^2$*, there are unique optimal solutions for quality and price, and* $a - \beta v > 0$*. If there is no quality regulation, the equilibrium solutions for quality and price of products are as follows*

$$x_I^* = \frac{\alpha(a - \beta v)}{4\beta c - \alpha^2}, \tag{4}$$

*and*

$$p_I^* = v + \frac{2c(a - \beta v)}{4\beta c - \alpha^2}. \tag{5}$$

Proof. Straightforward and therefore omitted.

From **Proposition 1**, we have **Theorem 1** as follows.

**Theorem 1** *In an integrated global supply chain, the relationship between regulation and quality, price of products are as follows:*

*If* $x_0 \le \frac{\alpha(a - \beta v)}{4\beta c - \alpha^2}$, *the optimal quality level and price of products are* $x_I^* = \frac{\alpha(a - \beta v)}{4\beta c - \alpha^2}$ *and* $p_I^* = v + \frac{2c(a - \beta v)}{4\beta c - \alpha^2}$;

*If* $\frac{\alpha(a - \beta v)}{4\beta c - \alpha^2} < x_0 < \frac{\alpha(a - \beta v) + 2\sqrt{\beta[c(a - \beta v)^2 - (4\beta c - \alpha^2) f]}}{4\beta c - \alpha^2}$, *the optimal quality and price of products are* $x_I^* = x_0$ *and* $p_I^* = v + \frac{\alpha x_0 + (a - \beta v)}{2\beta}$;

*If* $x_0 \ge \frac{\alpha(a - \beta v) + 2\sqrt{\beta[c(a - \beta v)^2 - (4\beta c - \alpha^2) f]}}{4\beta c - \alpha^2}$, *the global supply chain will not enter into the market.*

Proof. See the appendix.

### 3.2 Decentralized Setting

In a global supply chain with a decentralized setting, $i$ =*D*, Nash's non-cooperative game is implemented between the manufacturer and the retailer. The manufacturer's profit $\prod_D^M$ and the retailer's profit $\prod_D^R$ are

$$\prod_D^M = (w - v_M)(a + \alpha x_D - \beta p_D) - f - cx_D^2, \tag{6}$$

$$\prod_D^R = (p_D - w - v_R)(a + \alpha x_D - \beta p_D). \tag{7}$$

Therefore, the profit of the supply chain is

$$\prod_D = (p_D - v)(a + \alpha x_D - \beta p_D) - f - cx_D^2. \tag{8}$$

The objectives of the manufacturer and the retailer are to maximize their respective expected profits in Eq. (6) and in Eq. (7).

**Proposition 2** *In a global supply chain with decentralized setting, there are unique optimal solutions for quality and price, and* $\alpha(w - v_M) + 2c[a - \beta(w + v_R)] > 0$. *If there is no regulation, the equilibrium solutions for quality level and price of products are as follows*

$$x_D^* = \frac{\alpha(w - v_M)}{2c}, \tag{9}$$

*and*

$$p_D^* = w + v_R + \frac{\alpha x_D^* + a - (w + v_R)\beta}{2\beta}. \tag{10}$$

Proof. Straightforward and therefore omitted.

From **Proposition 2**, we have **Theorem 2** as follows:

**Theorem 2** *In a global supply chain with decentralized setting, the relationship between regulation and quality level, price of products are as follows:*

*If* $x_0 \le \frac{\alpha(w - v_M)}{2c}$, *the optimal quality and price of products are* $x_D^* = \frac{\alpha(w - v_M)}{2c}$ *and* $p_D^* = w + v_R + \frac{\alpha x_D^* + a - (w + v_R)\beta}{2\beta}$;

*If* $\frac{\alpha(w - v_M)}{2c} < x_0 < \frac{\alpha(w - v_M) + \sqrt{\alpha^2 (w - v_M)^2 + 8c(w - v_M)[a - \beta(w + v_R)] - 16cf}}{4c}$, *the optimal quality and price of products are* $x_D^* = x_0$ *and* $p_D^* = w + v_R + \frac{\alpha x_0 + a - (w + v_R)\beta}{2\beta}$;

*If* $x_0 \ge \frac{\alpha(w - v_M) + \sqrt{\alpha^2 (w - v_M)^2 + 8c(w - v_M)[a - \beta(w + v_R)] - 16cf}}{4c}$, *the supply chain will not enter into the market.*

Proof. Similar to that of Theorem 1 and therefore omitted.

In the following section, we use numerical experiments to illustrate the problems and discuss some related issues.

# 4 An example

In this section, we illustrate some related issues of quality regulation in the global supply chain by using numerical experiments. Let $a$=600, $\alpha$=8, $\beta$=10, $c$=50, $v_M$=3, $v_R$=2, $f$=800 and $w$=22. Here $\alpha < \beta$ indicates that market demand is more sensitive to price than to quality level, which is particularly reasonable in current business environment. Furthermore, in order to reflect the impact of quality regulation on related issues, we set the threshold value $x_0 \in$ [0, 14.31].

## 4.1 Quality and Price

In a global supply chain with vertical integration, the quality level will be set at 2.27, i.e. the optimal quality level, as long as $x_0 \leq 2.27$. When 2.27< $x_0$ <14.31, the quality level set by the global supply chain is $x_0$. However, when $x_0 \geq 14.31$, the profit of the global supply chain is not positive, which leads to the withdraw of the global supply chain from the market.

In a decentralized setting, the global supply chain will set its quality level at 1.52 as long as $x_0 \leq 1.52$. When 1.52< $x_0$ <8.04, the quality level of the global supply chain is $x_0$. However, when $x_0 \geq 8.04$, the global supply chain will withdraw from the market.

## 4.2 Consumer Surplus

From Eq. (11), we can obtain the consumer surplus provided by the global supply chain with two cases of structure. Obviously, regulation has a significant effect on consumer surplus. An integrated supply chain can achieve a higher consumer surplus than that of a decentralized supply chain. On the whole, consumer surplus increases in $x_0$ when $x_0$ is more than the optimal quality level without regulation, i.e. 1.52< $x_0$ <8.04 in a decentralized setting or 2.27< $x_0$ <14.31 in an integrated supply chain.

## 4.3 Profits

With all possible $x_0$, an integrated supply chain can achieve a higher profit than that of a decentralized supply chain.

On the whole, profits of both supply chains decrease in $x_0$ when $x_0$ is more than the optimal quality level without regulation, i.e. 1.52< $x_0$ <8.04 in a decentralized setting or 2.27< $x_0$ <14.31 in an integrated supply chain.

In a decentralized setting, when $x_0$ is more than the optimal quality level without regulation, i.e. 1.52< $x_0$ <8.04, the profit of the manufacturer decreases in

$x_0$ while that of the retailer increases in $x_0$.

From observations of the experiments, we can see that vertical integration, which brings higher consumer surplus and profit, might be a Pareto Improvement for a global supply chain with a decentralized setting.

# 5 Conclusions

In this study, we investigated the impact of quality regulation on quality level and price set by a global supply chain in two cases of supply chain structures: an integrated supply chain and a decentralized setting. A numerical study was used to illustrate some related issues and some observations were made.

The results of the investigation suggest that both regulation and supply chain structure have significant impacts on quality, price, consumer surplus and profits. There may be different potentials of quality level provided by the two supply chains. Based on the observations, an integrated supply chain has a higher potential quality level than that of a decentralized one. Hence, the policy maker should set the threshold value of quality level with respect to a decentralized setting. Or else, decentralized supply chains may withdraw from the market when the threshold value of quality level approaches a certain level under which an integrated supply chain can still gain profit. Furthermore, the policy maker should try to prompt a decentralized setting to achieve coordination between players, which allows for more consumer surplus.

In regard to future work, coordination of a global supply chain with quality regulation, regulation of a global supply chain with uncertain demand, and competing supply chains are expected to be worth further study.

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## Appendix

**Proof of Theorem 1**

If the threshold value of quality level $x_0 \le \frac{\alpha(a-\beta v)}{4\beta c-\alpha^2}$, the global supply chain can achieve maximal profit when the quality level and the price of products are $x_I^* = \frac{\alpha(a-\beta v)}{4\beta c-\alpha^2}$ and $p_I^* = v + \frac{2c(a-\beta v)}{4\beta c-\alpha^2}$, respectively.

When $x_0 > \frac{\alpha(a-\beta v)}{4\beta c-\alpha^2}$, profit $\prod_I$ of the global supply chain decreases in $x_0$. In particular, when $x_0 = \frac{\alpha(a-\beta v)+2\sqrt{\beta[c(a-\beta v)^2-(4\beta c-\alpha^2)f]}}{4\beta c-\alpha^2}$, the profit

$\prod_I = (p_I - v)(a + \alpha x_0 - \beta p_I) - f - cx_0^2 = 0$, where the price of products is $p_I^* = v + \dfrac{\alpha x_0 + (a - \beta v)}{2\beta}$.

Therefore, when there is $\dfrac{\alpha(a-\beta v)}{4\beta c - \alpha^2} < x_0 < \dfrac{\alpha(a-\beta v) + 2\sqrt{\beta[c(a-\beta v)^2 - (4\beta c - \alpha^2)f]}}{4\beta c - \alpha^2}$, the global supply chain will set its quality of products as $x_0$.

When $x_0 \geq \dfrac{\alpha(a-\beta v) + 2\sqrt{\beta[c(a-\beta v)^2 - (4\beta c - \alpha^2)f]}}{4\beta c - \alpha^2}$, profit $\prod_I$ of the global supply chain is not positive. As a result, the global supply chain will not enter into the market.

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