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Supply quality management with wholesale price and revenue-sharing contracts under horizontal competition

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ABSTRACT

In a number of industries (e.g., the airplane industry, aerospace industry, auto industry, or computer industry), certain suppliers essentially have a monopoly on the production technology for key components, and inevitably manufacturers in these industries have common suppliers. A key part of manufacturers' work with suppliers concerns improving the quality of their respective products, which gives rise to a collaborative activity usually termed as "supply quality management". When the manufacturers are competitors, they do not wish to see a common supplier dividing his involvement in quality improvement unequally between themselves and their rivals. However, as the suppliers collaborate with several manufacturers, it is highly questionable whether their efforts will be strictly equivalent for each manufacturer. In this paper, a non-cooperative dynamic game is formulated in which a single supplier collaborates with two manufacturers on design quality improvements for their respective products. The manufacturers compete for market demand both on price and design quality. The paper analyzes how each party should allocate resources for quality improvement over time. In order to take into account the potential coordinating power of the compensation scheme adopted in this type of decentralized setting, we compare the possible outcomes under a wholesale price contract and a revenue-sharing contract.

1. Introduction

In a number of industries (e.g., the airplane industry, aerospace industry, auto industry, or computer industry), certain suppliers essentially have a monopoly on the production technology of key components, and inevitably manufacturers in these industries have common suppliers. In the plane making business, for instance, the two major rival players Boeing and Airbus share up to twelve strategic suppliers (Michaels and Lunsford, 2004) so that their supply chains are both competing and interdependent.

A key part of manufacturers' work with suppliers concerns improving the quality of their respective products, which gives rise to a collaborative activity usually termed as "supply quality management". When the manufacturers are competitors, they do not wish to see a common supplier dividing his involvement in quality improvement unequally between themselves and their rivals. However, as the suppliers cooperate with several manufacturers, it is highly questionable whether their efforts will be strictly equivalent for each manufacturer. Given the empirical evidence on the decisive importance of quality management for supply chain success (Morash, 2001; Smets, 2004), it is interesting to study how vertical coordination affects the players' optimal allocation of efforts for quality improvement in the context of horizontal competition at the manufacturing level.

It has been shown that coordinated supply chains perform better in quality improvement than uncoordinated supply chains. For instance, Kim and El Ouardighi (2007) consider the problem of optimal effort allocation between design quality improvement for an existing product and development of a new product, in a one manufacturer-one supplier supply chain. Using qualitative and numerical methods, they find that the uncoordinated chain pays more attention to new product development, while the coordinated chain focuses more on the quality of the existing product. Given that the degree of coordination in a supply chain can affect the chain members' quality improvement effort, it is difficult to consider the issue of supply quality management in competing and interdependent supply chains without taking into account the impact of coordination, if any, in a decentralized setting.

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Supply chain contracts are generally considered as a useful tool to bring supply chain actors in a decentralized setting to operate in coordination. Different models of supply chain contracts have been developed in the literature, and one model considered 'very attractive' is the revenue-sharing contract (RSC) (Cachon and Lariviere, 2005). Under a RSC, each manufacturer pays the supplier a fixed transfer price for each unit purchased, plus a fixed percentage of her own sales revenue.

The RSC is viewed as a valuable alternative to the wholesale price contract (WPC) (Cachon and Lariviere, 2001), in which the supplier merely charges the retailer a fixed per-unit price. Although the WPC is commonly observed in practice because it is simple to implement and cheap to administer, it can engender a double marginalization effect. This effect arises when a supplier sells a product to a retailer who is facing a downward sloping demand curve (e.g. Bresnahan and Reiss, 1985): the retailer is not concerned with the supplier's profit when fixing the retail price, and as a result the retail price is higher than in a centralized chain. The advantage of the RSC over a WPC is that it mitigates this double marginalization effect (e.g., Chen et al., 2001) and can significantly increase the supply chain profits, for example by more than 10% in the video rental industry (Mortimer, 2008).

To date, comparisons between RSCs and WPCs in supply quality management have been limited to one important but specific dimension of quality, namely conformance quality, which refers to the extent to which a product conforms to a given design quality standard (Garvin, 1988). In the setup of a one supplier/one retailer supply chain in which improved conformance quality can enhance current customer loyalty, El Ouardighi et al. (2008) show that chain members should invest more in quality under a RSC than under a WPC over time.

This paper extends knowledge of the situation in which a supplier is serving two price-competing manufacturers. To do so, we use another essential and complementary dimension of quality, that is, design quality, which refers to the set of product attributes or features that enhance the match with the customer's needs (Garvin, 1988). In a setup consisting of interdependent, competing chains we investigate how the compensation scheme adopted (WPC or RSC) can affect design quality competition at the manufacturing level *via* the way the players allocate their quality improvement efforts. In doing so, we analyze how any mitigation of the double marginalization effect through a RSC affects supply quality management in the context of horizontal competition at the manufacturing level.

The paper is organized as follows. Section 2 presents a dynamic game model where a single supplier collaborates with two competing manufacturers in improving the quality of their respective products. Section 3 analyzes the three players' differential game in a decentralized setting and compares the outcomes obtained under WPC and RSC. To gain additional insights into the optimal dynamic behavior of the players, a numerical study is conducted in Section 4. Section 5 draws the key managerial implications from the analytical and numerical analyses.

2. A stylized non-cooperative differential game model

We consider a situation with three players: two duopolistic manufacturers and a monopolist supplier. This configuration belongs to the category of interdependent, competing supply chains (El Ouardighi et al., 2009), that is, supply chains which share common members and compete for market demand. Both manufacturers purchase a similar part from their supplier, which is used in their respective finished products. The manufacturers' products are in competition for the final demand market. Each manufacturer invests in quality improvement for her product, and the monopolist supplier is supposed to collaborate in each manufacturer's quality improvement activity.

Quality here means design quality, i.e., the set of product attributes or features that enhance the match with the customer's needs (Garvin, 1988). In this sense, quality improvement activity aims to increase the desirability of the product, notably through the implementation and use of dedicated tools such as quality function deployment (QFD), Taguchi arrays, Ishikawa diagrams, etc. Although the adoption of such tools is generally costly in terms of instantaneous effort, it does not necessarily incur an extra cost per unit produced.

Let $Q_i(t) > 0$ represent the design quality level at time t for manufacturer i's product, for which quality improvement is given by:

$$\dot{Q}_1(t) = u_1(t) + v_1(t) \quad Q_1(0) = Q_{10} > 0, \tag{1}$$

$$\dot{Q}_2(t) = u_2(t) + v_2(t) \quad Q_2(0) = Q_{20} > 0, \tag{2}$$

where $u_i(t) \geqslant 0$ and $v_i(t) \geqslant 0$ denote the respective effort input by manufacturer i and the monopolist supplier to manufacturer i's product quality, $i = 1, 2$. Note that a similar representation of the evolution of design quality is used by Mukhopadhyay and Kouvelis (1997) in the context of a dynamic game model of duopolistic competition.

We assume that manufacturer i's final demand, $D_i(t),\ i = 1, 2$, is determined both by price and quality competition on the duopoly market, as follows:

$$D_i(t) = \alpha - \beta(p_i(t) - p_{3-i}(t)) + \delta(Q_i(t) - Q_{3-i}(t)), \tag{3}$$

where $\alpha \gg 0$, and β and δ are symmetric positive constants for the sake of simplicity.

In Eq. (3), manufacturer i's demand is:

- A decreasing function of the differential between her own price, $p_i(t) \geqslant 0$, and the rival firm's price, $p_{3-i}(t) \geqslant 0$, and
- An increasing function of the differential between her own quality, $Q_i(t)$, and the rival firm's quality, $Q_{3-i}(t),\ i = 1, 2$.

In the case where both manufacturers have constant design quality ($\dot{Q}_i = 0,\ \forall\ i$), Eq. (3) would reduce to a standard Bertrand demand function where manufacturer i's demand shows a linear decrease in own price and a linear increase in the rival manufacturer's price. Manufacturer i's demand equation thus provides an extension to the situation in which both manufacturers also compete on design quality.

We assume that each manufacturer enters into either a WPC or a RSC with the supplier. A two-parameter scheme is therefore used, where:

- The first parameter is the transfer price (supposed constant), $c_i > 0$, paid by manufacturer i to the supplier for each unit purchased, and
- The second parameter is the supplier's share (supposed constant) in manufacturer i's sales revenue, $\omega_i,\ \omega_i \in [0, 1[,\ i = 1, 2$.

The parameter values are such that $c_i > 0$ and $\omega_i = 0$ for a WPC, while $c_i > 0$ and $\omega_i \in]0, 1[$ for a RSC. The assumption of fixed contract parameters lies with the fact that, in the real world, when companies sign a contract, it is usual for them to specify the terms of contract, as