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Supply quality management with optimal wholesale price and revenue sharing contracts: A two-stage game approach

Fouad El Ouardighi *,[1]

ESSEC Business School, Avenue Bernard Hirsch, 95021 Cergy Pontoise, France

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ABSTRACT

One of the main priorities of companies involved in supply chains is improving the quality of their products. However, as in other parts of supply chain management, decentralized decision-making in supply quality management is prevalent, which causes inefficiencies such as the well-known double marginalization phenomenon. Coordinating schemes, such as the revenue sharing contract, can contribute to mitigating this phenomenon. In this paper, we investigate the potential coordinating power of the revenue sharing contract in a supply chain with one manufacturer and one supplier that collaborate to improve the design quality of a particular finished product. We set the cooperative outcome as a benchmark and compare the efficiency of an optimal revenue sharing contract with an optimal wholesale price contract in improving design quality in the setup of a non-cooperative two-stage game.

1. Introduction

Since the seminal papers by Reyniers and Tapiero (1995, 1996), it has been widely acknowledged that quality management should be implemented across the supply chain instead of within a single company only (Kogan and Tapiero, 2007). This is confirmed in a recent empirical study (Smets, 2004) where a sample of 750 companies located in Europe and North America ranked quality improvement as the main priority for the supply chains in which they are involved. The main conclusion is that firms need to collaborate with their supply chain partners to improve their final product's quality.

Among the many dimensions of quality (Garvin, 1988), design quality is the most effective leverage that contributes to improving final product quality (Zhu et al., 2009). Design quality represents the set of product attributes or features that enhance the match with the customer's needs, and differs from another important dimension of quality, namely, conformance quality which refers to the extent to which the product conforms to a given quality standard reflecting the customer's expectations (e.g., El Ouardighi et al., 2008, 2013).

It has been shown that coordinated supply chains perform better in design quality improvement than uncoordinated supply chains (Kim and El Ouardighi, 2007). This result is confirmed in an empirical study by Fynes et al. (2005), based on data collected from 200 suppliers in the electronics industry in Ireland. The authors show that design quality is substantially impacted by supply chain relationship quality, defined as the degree to which supply chain members are engaged in an active, long-term working relationship through communication, trust, adaptation, commitment, interdependence, and cooperation.

In a decentralized supply chain, the main cause of insufficient quality is the double marginalization effect, which results in lower market coverage, and lesser consumer surplus and profits (Economides, 1999). Double marginalization is usually associated with a wholesale price contract (e.g., Perakis and Roels, 2007), under which the supplier charges the retailer a price per unit purchased. The existing literature has suggested various contractual alternatives to the wholesale price contract (WPC) that contribute to mitigating the double marginalization effect and coordinating the supply chain (e.g., Cachon, 2003). One of the most popular is the revenue sharing contract (RSC), under which a manufacturer pays a supplier a lower transfer price per unit purchased plus a percentage of the manufacturer's revenue.

Using a static framework, Cachon and Lariviere (2005) showed that whereas in a WPC the transfer price should be set above the marginal cost, in the RSC the optimal transfer price should be below the marginal cost. In general, a supplier must balance the costs of running an RSC with the profit sacrificed by using the WPC. Assuming a dynamic setup, Jørgensen (2011) studied the intertemporal coordination in a manufacturer–retailer chain over a finite time horizon. The contract parameters, notably the

* Tel.: +331 34 43 33 20; fax: +331 34 43 30 01.
E-mail address: elouardighi@essec.fr

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transfer price and the share of the manufacturer in the retailer's revenue, are time-dependent decisions of the manufacturer that writes the contract, and are determined by solving the manufacturer's optimization problem.

Although the time-dependency assumption aims to provide a general description that includes the particular case of invariant contract parameters, it seems questionable that these parameters would be continuously changing over time such that a new contract should be signed at each period of time between supply chain members. In fact, for a time-dependent contract parameter, the main feature of a WPC, that is a fixed transfer price for each component, vanishes. In contrast, time-dependent parameters under an RSC significantly reduce interest in such a contract as a potential alternative to WPC, because it adds considerable complexity in terms of contract administration.

In practice, contract parameters are often agreed on from the outset of the game. At this initial stage, the trade-off consists in comparing the possible contractual options, i.e., either WPC or RSC, based on their optimal payoffs. It is rational to suppose that both players will in fact implement a contractual option if and only if each player's profit in this case is higher than what each player can get otherwise. Once the more profitable contractual option is adopted, the parameters remain fixed throughout the game. Therefore, the supply chain game can be conceptualized as a two-stage game. In the first stage, the players agree on the type of contractual option to be implemented. In the second stage, the players make their decisions non-cooperatively.

The issue of supply chain coordination related to quality considerations has recently gained growing attention. Zhu et al. (2007) explored the roles of different parties in a supply chain in quality improvement. They show that the buyer's involvement can have a significant impact on the profits of the parties and of the supply chain as a whole, and he cannot cede the responsibility of quality improvement to the supplier in many cases. Xie et al. (2011a) investigated quality investment and price decision of a supply chain with uncertain demand in international trade. Due to volatility of orders from buyers, the supply chain's members are subject to financial risk and supposed to be risk-averse in quality investment and price decision. It is shown that, compared to a risk-neutral supply chain, a risk-averse supply chain has lower, same and higher quality of products in a vertically integrated supply chain, a supply chain with manufacturer's leadership, and a supply chain with supplier's leadership, respectively. Xie et al. (2011b) considered two supply chains, each involving one supplier and one manufacturer that offer a given product at the same price but compete on quality. Different supply chain configurations are compared in the context of Nash equilibrium. Xie et al. (2014) investigated conformance quality in a supply chain game from the viewpoint of the leadership in the supply chain. Ma et al. (2013) investigated the issue of coordination in a one manufacturer–one retailer supply chain, where the demand depends on the retailer's sales effort and manufacturer's quality improvement efforts. They show that a two-part tariff contract alone or combined with the quality effort cost sharing model is ineffective in coordinating the supply chain, and suggest a coordinating contract that integrates the endeavors of the manufacturer and the retailer. Feng et al. (2014) proposed a variant of the revenue sharing contract dedicated both to improve the reliability of the members of a multi-stage supply chain, and to coordinate the supply chain.

So far, the problem of analytical determination of optimal contracting related to design quality collaboration in a supply chain has been disregarded in the literature (El Ouardighi and Kim, 2010; El Ouardighi and Kogan, 2013). In particular, an open question is how optimal WPC and RSC differ in terms of supply quality management. Also, do these contracts coordinate the supply chain in terms of pricing, quality and payoffs of supply chain members? To investigate this issue, we analyze the pricing and improvement effort decisions in a one manufacturer–one supplier supply chain that is governed either by a WPC or an RSC. We model the strategic interaction between the supplier and the manufacturer as a noncooperative two-stage game and relax the assumption of time-dependent contract parameters. We adopt a scenario in which the relationship between supply chain members at the first stage of the game depends on the type of contract considered (WPC or RSC). That is, under both WPC and RSC, the transfer price is exclusively under the supplier's control, while under an RSC, the level of the sharing parameter can be decided only by the manufacturer. As a Stackelberg leader, the supplier can determine an optimal WPC by setting the transfer price that maximizes its own best interest. In search of an optimal RSC as a viable alternative to the optimal WPC, the supplier can instead concede a more advantageous transfer price for the manufacturer than under the optimal WPC. In turn, the manufacturer sets the sharing parameter value that maximizes the supply chain's best interest. The supplier then compares the resulting payoffs with that obtained from the optimal WPC, and decides whether to accept or reject the optimal RSC.

As a key component of the problem, design quality is interpreted as a stock variable in which changes are determined by the players' investment decisions. Due to the cumulative nature of design quality, we adopt a differential game of finite duration. The suggested model is shown to have the state-separability property (Dockner et al., 1985), which implies that the second stage of the game admits a unique and subgame (Markov) perfect equilibrium in both Nash and Stackelberg games, i.e., irrespective of whether moves are simultaneous or sequential (Dockner et al., 2000).

The paper is organized as follows. In the next section, we formulate a two-stage game model where a manufacturer and its supplier first agree on the choice of an optimal contractual scheme and then collaborate to improve the design quality of a particular product. In Section 3, we characterize the cooperative solution of the game, which serves as a benchmark for assessment of the ability of the contracts in the non-cooperative game to induce greater design quality and payoffs, and lower sales price. Section 4 analyzes the model in a non-cooperative setting. The results are then compared in Section 5 and an extension of the optimal RSC is suggested to achieve perfect coordination of the supply chain. Section 6 provides numerical illustrations. Section 7 concludes the paper.

2. Model

We consider a supply chain with one manufacturer and one supplier. The manufacturer purchases a specific part from the supplier, which is used in its finished product. The two supply chain members invest in design quality of the finished product over time, that is, they allocate individual resources to improve the set of product attributes or features that enhance the match of the finished product with the customer's needs (Garvin, 1988).

We first describe the dynamics of design quality. Let $Q(t) > 0$ represent the design quality level at time t for the manufacturer's product, which is assumed to evolve over time according to the following differential equation:

$$\dot{Q}(t) = u(t) + v(t) \quad Q(0) = Q_0 > 0 \tag{1}$$

where $u(t) \geq 0$ and $v(t) \geq 0$ denote the respective efforts by the manufacturer and the supplier to improve product quality. This specification is standard in the existing literature (e.g., El Ouardighi and Kim, 2010; El Ouardighi and Kogan, 2013; Kim and El Ouardighi, 2007; Mukhopadhyay and Kouvelis, 1997).