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Capacity investment under cost sharing contracts

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ABSTRACT

Capacity planning is widely applied in various industries, such as electric utilities, shipping industries and automobile industries. However, because of market uncertainty and inaccurate industry wide demand forecasts, manufacturers may take a high risk in capacity investment. This paper investigates the role of a retailer in a manufacturer's capacity investment strategies. Two capacity sharing contracts are introduced, i.e., the full capacity cost sharing contract (FCCSC) and the partial capacity cost sharing contract (PCCSC). In both contracts, a retailer shares the capacity cost with a manufacturer. Differently, in the FCCSC, a retailer shares a fraction of the capacity cost with the manufacturer. However, in the PCCSC, a retailer shares capacity cost only when the manufacturer's capacity level exceeds a certain threshold. We find that the retailer would share more cost but less capacity quantity in the PCCSC than that in the FCCSC. We also find that in the PCCSC, when the threshold of capacity level is sufficiently high, the retailer would choose the PCCSC while the manufacturer would choose the FCCSC. Conversely, when the threshold of the capacity level is small, the retailer would choose the FCCSC, while the manufacturer would choose the PCCSC. There exists a certain interval in which both players would choose the PCCSC.

1. Introduction

Capacity choice is a key decision influencing firms' operating and manufacturing process (Kouvelis and Tian, 2014) and capacity building is a long-term continual process that requires substantial capital resources. Because of market uncertainty and inaccurate industry wide demand forecasts, manufacturers may make wrong decisions about capacity building. For example, in 1974, the U.S. electric utilities predicted a forecast of 7% annual growth in demand and decided to double generate the capacity by the mid-1980s. However, the actual load only grew by 2% in 1975–1985. Thus, the excess generating capacity created huge losses in the industry (1988 Barnett[1]). To prevent the negative effect of excess capacity, at present, manufacturers are usually cautious toward capacity building and often build insufficient manufacturing capacity (Jin and Wu, 2007). This insufficient production, as a result, leads to denied orders and dissatisfied customers and eventually influences the firms' profits in the long-term. Another example of insufficient production is the U.S. telecommunications industry. During the late 1990s, the telephone network grew rapidly, and the manufacturers faced great challenges from capacity shortages. Although the need for capacity expansion had received close attention, manufacturers often took a wait-and-see policy due to the significant financial risk. Similarly, in the semiconductor industry, at least $500 million is required to build a semiconductor fabrication plant (fab). However, the demand uncertainly would be as high as 80% with their forecast. Therefore, for a manufacturer, taking a conservative capacity strategy would decrease his financial risk as well as cost. On the other hand, it makes the downside retailer suffer from capacity shortage if there is excessive demand. In sum, it is meaningful and necessary to take measures to help the manufacturers mitigate the risk of building manufacturing capacity.

By offering a capacity cost sharing contract, a retailer (she) may share the cost of capacity investment with a manufacturer (he) to help him mitigate the risk of capacity building. This approach favors the manufacturer because it decreases the cost he needs to pay for building manufacturing capacity. On the other hand, it may motivate the manufacturer to expand the production line and produce more products to reduce the capacity shortage and increase the market share. When more demand is satisfied, the retailer's sales volume may increase and she can benefit as well.

From this perspective, we consider a supply chain which consists of a manufacturer and a retailer. Considering the uncertain demand, the retailer offers the manufacturer a take-it-or-leave-it capacity cost sharing contract and specifies the fraction of the capacity cost she would like to share with the manufacturer. Upon seeing the capacity cost sharing

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[1] https://hbr.org/1988/07/four-steps-to-forecast-total-market-demand.

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contract offered by the retailer, the manufacturer decides the manufacturing capacity and sells the products to the retailer to meet the customer demand. In this paper, we introduce two capacity cost sharing contracts, i.e., the full capacity cost sharing contract (FCCSC) and the partial capacity cost sharing contract (PCCSC) and make a comparison between the two contracts to investigate which contract is better under different scenarios. In the FCCSC, a retailer shares a fraction of the capacity cost with the manufacturer for all of the production capacity. While in the PCCSC, a retailer shares a fraction of the capacity cost with a manufacturer for the capacity level which exceeds a certain threshold. We aim to address the following research questions in this paper:

(1) What are the impacts of the FCCSC and the PCCSC on the retailer's cost sharing strategies?
(2) How would the manufacturer choose the capacity decision strategies under each of the two capacity cost sharing contracts?
(3) What are the profitability implications of the two contracts for the whole supply chain?
(4) Which contract would be better off under different scenarios?

To solve the above research questions, we propose a two-stage sequential decision model to analyze the manufacturer and retailer's decision strategies. In the first stage, the retailer, acting as a Stackelberg leader, offers the manufacturer a take-it-or-leave-it contract, specifying the fraction of the capacity cost she would like to share with the manufacturer. Upon seeing the capacity cost sharing contract, the manufacturer, acting as a follower, chooses the capacity level that he would like to build. We apply backward induction to characterize a sub-game Nash equilibrium.

We find that the manufacturer would build a higher level of capacity in the PCCSC. Furthermore, the retailer would share much more cost but less capacity quantities in the PCCSC than that in the FCCSC. On the other hand, when the threshold of capacity level is sufficiently high, the retailer would choose the PCCSC while the manufacturer would choose the FCCSC. When the threshold of capacity level belongs to a certain range, both players would choose the PCCSC. When the capacity level is small enough, the retailer would choose the FCCSC while the manufacturer would choose the PCCSC.

The remainder of the paper is organized as follows. We review relevant literature in Section 2. In Section 3, we give model notations and assumptions. In Section 4, we introduce the two capacity cost sharing contracts and give the manufacturer's optimal quantity decision and the retailer's best capacity sharing strategy. In Section 5, we compare the two contracts and analyze which contract would be better under different scenarios. Section 6 gives a numerical example to discuss the impacts of the manufacturer's bargaining power on supply chain performance. We present the study's conclusion in Section 7.

2. Literature review

This paper is closely related to two streams of literature: the literature on operations management research that studies capacity management and the literature on supply chain contracting.

Several papers address the issue of capacity investment in the supply chain (Kouvelis and Milner, 2002; Mathur and Shah, 2008; Xie et al., 2014). For example, Kouvelis and Milner (2002) study the capacity investment and outsourcing problems for the supply chain considering demand uncertainty and multi-periods. Swinney et al. (2011), on the other hand, analyze the competitive capacity investment decisions considering both established firms and new firms. These researchers find that high demand uncertainty and cost would lead to new firms investing first before the uncertainty has been resolved. Niroomand et al. (2012) discuss the allocation of its capacity investment considering different manufacturing systems, i.e., dedicated manufacturing, flexible manufacturing and reconfigurable manufacturing and investigate how the capacity portfolio of manufacturing systems would be chosen under various conditions. Chen et al. (2014) discuss the capacity expansion and allocation in the Transistor-Liquid Crystal Display (TFT-LCD) industry and use a linear programming model to find the suitable timing and choice of the investment strategies. Zhang and Du (2010) study the multi-product newsvendor problem with limited capacity as well as outsourcing. Cachon and Lariviere (2001) demonstrate that compared with the integrated system, the decentralized system provides less capacity.

Numerous papers in the supply chain contracting literature examine the capacity investment problems (Eppen and Iyer, 1997; Li and Atkins, 2002; Gan et al., 2004). Erkoc and Wu (2005) study how to design capacity reservation contracts for the make-to-order high-tech products with demand uncertainty. They show that the capacity reservation associated with capacity expansion can reduce the supplier's risk. Jin and Wu (2007) propose a deductible reservation (DR) contract to discuss the capacity investment problem and show that a DR contract can be more channel coordinated compared with take-or-pay contracts. Taylor and Plambeck (2007) study how supply chain partners should employ relational contracts to provide incentives for capacity investment. Durango-Cohen and Yano (2006) propose a "forecast-commitment" contract in which the supplier makes a production commitment based on the customer's forecast. They find that the contract can reduce the customer's incentive to over forecast and moderate the supplier's motivation to underproduce. In this paper, we propose two different capacity cost sharing contracts, in which a retailer shares the capacity cost with the manufacturer to encourage him to produce more products before the selling season begins and compare which contract would be better under various conditions.

3. Assumptions and model description

Before introducing our mathematical model and deriving our conclusions, we first give the model descriptions, notations and assumptions.

3.1. Assumptions

Assumption 1. *The demand of the product D in advance of the selling season has the following multiplicative functional form* $D(p) = y(p)\xi$ (Wang et al., 2004; Li et al., 2009).

The multiplicative demand is a form of demand widely used in the literature. Here, ξ is a random variable and obeys uniform distribution and is supported on $[A, B]$ with $B \geq A \geq 0$. $y(p)$ is a decreasing function of the selling price p and takes the form of

$$y(p) = ap^{-b} \text{ where } a > 0,\ \ b > 1. \tag{1}$$

In this equation, a is a scaling parameter and b is the price-elasticity index of demand. The greater the value of the price-elasticity index, the more sensitive the demand is for the price change. If b is larger than 1, a product is defined as price elastic. Conversely, if b is 1 or less, a product is defined as price inelastic. Here, we assume that $b > 1$ to avoid tricky cases.

Assumption 2. *Both the retailer and the manufacturer are risk-neutral, and the information is symmetrical for channel members.*

3.2. Model description

We consider a supply chain consisting of one risk-neutral retailer and one risk-neutral manufacturer with uncertain and price-sensitive demand. The quantity of product released to the market is q. Prior to producing product, the manufacturer needs to invest in production capacity K. The capacity determines the maximum production. In our model, capacity investment occurs at the time before the selling season that the demand information is not revealed. The production quantity q is determined when the selling season comes, which is when the demand