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Flexible capacity strategy with multiple market periods under demand uncertainty and investment constraint

Liu Yang [a], C.T. Ng [b,*]

[a] Business School, University of International Business and Economics, Chaoyang District, Beijing 100029, China
[b] Department of Logistics and Maritime Studies, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong Special Administrative Region, China

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ABSTRACT

We establish a flexible capacity strategy model with multiple market periods under demand uncertainty and investment constraints. In the model, a firm makes its capacity decision under a financial budget constraint at the beginning of the planning horizon which embraces n market periods. In each market period, the firm goes through three decision-making stages: the safety production stage, the additional production stage and the optimal sales stage. We formulate the problem and obtain the optimal capacity, the optimal safety production, the optimal additional production and the optimal sales of each market period under different situations. We find that there are two thresholds for the unit capacity cost. When the capacity cost is very low, the optimal capacity is determined by its financial budget; when the capacity cost is very high, the firm keeps its optimal capacity at its safety production level; and when the cost is in between of the two thresholds, the optimal capacity is determined by the capacity cost, the number of market periods and the unit cost of additional production. Further, we explore the endogenous safety production level. We verify the conditions under which the firm has different optimal safety production levels. Finally, we prove that the firm can benefit from the investment only when the designed planning horizon is longer than a threshold. Moreover, we also derive the formulae for the above three thresholds.

1. Introduction

Nowadays firms are facing incredible challenges ever, particularly due to volatile demand, fierce competition and critical financial environment. Worldwide financial crises make firms more cautious about their capacity investments. Meanwhile, the customer demand is getting more unpredictable and uncertain. To deal with these challenges, firms are doing their best to adopt different methods. On the one hand, firms are trying to get more flexibility in adjusting their productions to deal with demand uncertainty. On the other hand, firms need to keep and increase their market shares under competition and, therefore, they will keep at the lowest production level at least. Due to the competition pressure and fear of being forgotten by the customers, firms are not likely to stop their productions even when there is little demand. For example, manufacturers still produce ice cream even in winter when there is little demand. As a result, an appropriate ability in adjusting production is needed for a firm to survive, while keeping a suitable level of operation. Furthermore, a firm needs financial support when it builds up its capacity at the beginning of a planning horizon over multiple market periods. This financial support is so critical to the success of a capacity strategy. The financial budget often determines the affordability of a firm's capacity investment, and, therefore, determines a firm's capacity upper bound.

This paper investigates the flexible capacity strategy in terms of the firms' ability in adjusting its production level under demand uncertainty. Particularly, we explore a firm's flexibility throughout two stages: (1) production adjustment stage and (2) optimal sales stage. Furthermore, we integrate the financial budget into the model to formulate a firm's financial consideration at the beginning of the planning horizon, which is over multiple market periods. To do so, we propose a general model which is able to present a firm's flexibility to adjust the production, with full consideration of the financial investment constraint and the planning horizon of the business.

In the proposed model, the planning horizon includes n production/market periods. At the beginning of the planning horizon, the firm makes its capacity investment decision, i.e., determining its optimal capacity, aiming at maximizing the total profit over the n periods under the financial budget constraint. In each production period, the firm makes a safety production decision before the demand information is known. This safety production decision is due to some reasons, such as: (i) sustaining its market share in a competitive market; (ii) keeping its customers to remember the products; (iii) promoting its products to some potential markets;

* Corresponding author. Tel.: +852 2766 7364; fax: +852 2330 2704.
E-mail addresses: lgtctng@polyu.edu.hk, danielng@polyu.edu.hk (C.T. Ng).

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and (iv) dealing with some unexpected and urgent demand. After knowing the real demand in each market, the firm decides whether to make additional production to meet the unsatisfied demand and by how much, under the capacity constraint. To capture the interaction among a firm's supply, market demand and market price, we adopt the responsive pricing. It means that the product price in the market is determined by the real demand and the total supply in the market. The responsive pricing has been adopted by a few previous studies, such as Van Mieghem and Dada (1999), Goyal and Netessine (2007), Anand and Girotra (2007).

As the capacity strategy is usually a relatively long-term decision, it often involves a great amount of capital and multiple cycles of consumption (demand). Some capacity investment, such as purchasing new equipment and recruiting new staff, usually covers at least a few market periods before the next capacity investment. Furthermore, the multiple period model is a generalization of the single period model. Therefore, results of the multiple period model can be applied to the single period model, but the converse is not true.

Differing from most studies in the literature which assumed firms to put all produced products into the market, we explore a firm's flexibility in two stages: determining the optimal sales and making additional production decision. We solve for the optimal safety production, the optimal additional production and the optimal sales of each period under four different situations. Second, we solve for the optimal capacity over the entire planning horizon under the financial budget constraint. We show that there are two thresholds of the unit capacity cost. When the unit capacity cost is very low, the firm builds up the capacity to its upper bound which is determined by its financial budget; when the unit capacity cost is very high, the firm only builds the capacity to maintain at the lowest production level; and when the unit capacity cost is in between of the two thresholds, we obtain the analytical solution for the optimal capacity. Third, we analyze the impact of the planning horizon on the optimal capacity of the firm. We find that the firm benefits from the investment only when the designed planning horizon is longer than a threshold. Furthermore, a numerical example demonstrates that the optimal capacity is concavely increasing in the number of market periods. Finally, we explore the endogenous flexibility by investigating the safety production level in each market period. Interestingly, we find that higher flexibility is not always beneficial to the firm. Depending on the situations, there are different optimal safety production levels to maximize the firm's expected profit.

The rest of the paper is organized as follows: In Section 2, we review the recent research in the literature and find out a research gap. In Section 3, we introduce a styled multiple-period capacity strategy model. In Section 4, we formulate the production decisions in each period under demand uncertainty. In Section 5, we investigate the endogenous safety production level that leads to the maximum profit over the entire planning horizon. In Section 6, we conduct some discussion with respect to our partial flexibility. Finally, we draw conclusions, explore management insights, and provide suggestions for further research in Section 7.

2. Literature review

Flexible capacity strategies have been investigated extensively in the past two decades. Comprehensive reviews include Sethi and Sethi (1990), De Groote (1994), Van Hoek (2001), Van Mieghem (2003) and Volling, Matzke, Grunewald, and Spengler (2013). Flexible capacity strategy has been regarded as an effective and efficient method to improve a firm's ability to hedge against demand uncertainty and increase the firm's competitiveness by many studies, such as, Fine and Freund (1990), Rőller and Tombak (1993), Lee and Tang (1997), Van Mieghem (1998), Aviv and Federgruen (2001), Buxey (2005), Malhotra and Mackelprang (2012) and Georgiadis and Athanasiou (2013). Gerwin (1993) established a research agenda with respect to the uncertainty type and the adaptive method. His study classified the capacity flexibility into seven categories, which are different but highly relevant to each other.

Focusing on the timing of postponement, Van Mieghem and Dada (1999) investigated six alternative strategies. They considered that the firm could postpone a few decisions including capacity, production, sales and pricing. Based on the comparison of the six alternatives, they concluded that *production and pricing* postponement strategy is the most effective strategy to maximize a firm's expected profit. Assuming market clearance, Anupindi and Jiang (2008) extended the *production and pricing* postponement strategy in Van Mieghem and Dada (1999) to a duopoly model. They showed the equivalence of the equilibrium under quantity competition and price competition when two firms adopt the flexible strategies. Recently, Choi, Narasimhan, and Kim (2012) applied the postponement strategy in a global supply chain. Their results suggested the timing of postponement has a significant effect on the overall cost efficiency. However, these studies only investigated the problem in a single period. They did not consider the impact of the planning horizon which embraces multiple market periods.

Considering a firm's ability in switching between different products to deal with the demand uncertainty, Bish, Muriel, and Biller (2005) studied a capacity allocation mechanism in a two-plant two-product manufacturing setting under a make-to-order environment. Chod and Rudi (2005) addressed a similar issue under responsive pricing. Other similar studies include Bish and Wang (2004) and Goyal and Netessine (2007). Under the setting of these studies, a firm makes its production decisions as long as they have received the demand information. In other words, there was an ideal make-to-order environment that firms could keep the production as zero if the demand is too low to obtain positive profits. Contrary to these studies, this paper investigates a bounded flexibility in which a firm has to make a safety production level, meanwhile the firm is also constrained by its financial budget over the planning horizon. Our model is more general and realistic than these studies as it also covers the possibility of zero safety production level. Furthermore, our model can be treated as a partial flexibility model as the total production level in each period cannot be less than the safety production level.

Iravani, Van Oyen, and Sims (2005) analyzed a type of operational flexibility, namely the structural flexibility, which can be created by using multipurpose resources such as cross-trained labors, flexible machines or flexible factories. Anand and Girotra (2007) studied early/delay differentiation as a strategic decision of firms in competition. They showed that, under plausible conditions, the benefit associated with delay differentiation can be significantly diminished. Some research incorporated other business factors into the investigation of flexible capacity. Yang, Ng, and Cheng (2011) studied the impact of technology investment under flexible capacity strategy; Li and Womber (2012) considered scheduling in optimizing the supply chain configuration, Moon, Yi, and Ngai (2012) proposed an instrument for measuring supply chain flexibility for the textile and clothing companies through an empirical study. Köber and Heinecke (2012) conducted a case study at the agricultural machinery of a manufacturer with volatile and seasonal demand. Their results showed the combination of make-to-order and make-to-stock is an appealing production strategy. Other relating studies include Hallgren and Olhager (2009), Vickery, Dröge, and Markland (1997) and Patel, Terjesen, and Li (2012). To the best of our knowledge, there has been little research to investigate the partial flexible capacity strategy over multiple market periods. This research is perhaps to fill part of