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Strategic choice of flexible production technology using game theory approach

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ABSTRACT

This paper examines the conditions under which a firm would choose a flexible production technology or a dedicated technology in a duopoly environment. We model this technology choice by having two firms simultaneously select from two production technologies in the first stage and subsequently take in a Cournot production quantity subgame. Conditions under which technology equilibriums exist are given. We find that the premium a firm is willing to pay for flexibility increases as the market size increases and the product substitutability decreases. We also find that Prisoner's Dilemma does not necessarily occur in the production technology game, which is different from previous studies.

1. Introduction

The environment faced by manufacturing firms is increasingly uncertain because of fast and dramatic changes in customer expectations, competition, and technology [1]. Many manufacturing firms have faced the decision of whether or not to invest into what is known as flexible manufacturing systems (FMS). Examples of implementations of these new systems abound in the auto-mobile, machine tool, aerospace, heavy machinery, electronics and military equipment industries [2]. FMS brings a firm the ability to accommodate with various internal and external changes, thus promotes the performance and competitiveness of the firm. FMS also provides a firm the ability to produce multiple products simultaneously and enter multiple markets. However, FMS also makes firms compete more fiercely if they produce the same product type and sell them in the same market. In this paper we analyze firms' strategic choices of flexible production technology, and the factors that affect the choices.

Our study is motivated by many practical examples on firms' decisions to invest in FMS. We have observed that in some industries, most firms invest for flexible production technology. For example, in the tri-networks (telecommunications network, the cable TV network and the Internet) industry in China, the "big three" (i.e. China Telecom, China Mobile and China Unicom) have invested heavily for the advanced flexible cable technology. The flexible cable technology enables the firm to enter the three network markets simultaneously. In contrast, in some other industries, most firms invest for dedicated production technology. For example, in the auto industry in China, several main firms almost focus on one auto type. Jiefang trucks, Hongqi cars and Ankai buses are famous brands in China. There are also some industries where both flexible and dedicated technologies coexist in most firms. Upton [3] studied 61 plants in North America in the paper industry with quite comparable products (e.g., letter-size paper) and finds that, some firms have adopted flexible production technology while others have not. As a result, products manufactured by different companies—and hence using different technologies—compete directly in the market.

It is plausible that a firm's decision on technology investment is mainly determined by the cost differential between flexible and dedicated technology. For example, it does not increase much cost to invest for the flexible cable technology than a dedicated cable technology; however, it is much more expensive to build a flexible auto production line, which can produce different auto types than to build a dedicated one. Nevertheless, there may be some other factors that also affect firms' decision in common markets, e.g. correlation between products' demand, competitors' decisions. Then how do the possible factors affect the decisions of firm managers on technology investment? In other words, how to strategically select the technology in a competitive market? This is an important problem facing firm strategic managers.

In this paper, we aim to investigate the impact of possible factors on a firm's strategic choice of technology. Specifically, three main factors are considered, i.e. the cost differential between different technologies, the correlation between products'

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demand, and competitors' decisions. We model the technology choice as a two-stage non-cooperative duopoly game. In the first stage, two firms simultaneously select from two production technologies. If a firm chooses to invest in the flexible technology, it can produce two products and enter both markets. If a firm chooses to invest in a dedicated technology, it can only produce one product and enter only one market. Given a set of technologies chosen by the firms in the first stage, firms take in a subgame—Cournot production quantity game in the second stage. We seek a subgame-perfect equilibrium in such a game. In a similar background, Röller and Tombak [2] addressed that if both firms select the flexible technology (one equilibrium), then the firms will be trapped in a Prisoner's dilemma-like situation, i.e. both firms investing in flexible technology is detrimental to both firms. However, as will be described in our paper, we find that the "Prisoner's dilemma" does not necessarily occur in this equilibrium.

To keep the model simple, we in this paper do not take customer behavior into account, such as customers' brand preference. It is assumed that customers do not have brand preference for the same product type. Considering customer behavior, the demand function can be revised to reflect customers' preference and thus the manufacturing planning results should be different. Some authors have made some attempts to model customers' behavior in manufacturing planning. For example, Makris and Chryssolouris [28] developed a model to estimate the probability that a customer actually place an order once he has received a potential delivery date for a product. Using a market simulation model, Pasek et al. [29] investigated customers' behavior in decision under the mass-customization conditions.

The paper is organized as follows. In Section 2, we review the related literature in flexible technology choice. In Section 3, we describe the problem investigated in this paper, and provide the specifications of the basic model. In Section 4, we present technology equilibriums in the duopoly game, where conditions for the equilibriums are given. In Section 5, we analyze the conditions for "Prisoner's dilemma" to occur in the technology game. In Section 6, we summarize our findings and give some future research directions.

2. Literature review

In the past half century, flexible manufacturing technology has been widely used in manufacturing industry and extensively studied by scholars. Many scholars have done a lot of work on the concept and measurement of manufacturing flexibility. Sethi and Sethi [19] critically reviewed the literature, classified manufacturing flexibility into eleven types, and summarized the concept, purpose, means and measurement method for each type of flexibility. Kumar [20] proposed a method for measuring manufacturing flexibility using the concept of entropic. Chryssolouris and his group members have published many results regarding the concept and measurement of manufacturing flexibility [21–27]. He et al. [30] proposed a method to guide flexibility investment by quantifying required flexibility level and available flexibility level, and then determining a best-suited flexible configuration. These research results provide some theoretical basis for flexible technology investment.

There is also abundant research on flexible production technology investment, which can be classified into three streams. Papers in the first stream investigate flexibility improvement for a centralized manufacturing system. For example, Jordan and Graves [4] proposed three guidelines to add flexibility in the context of process flexibility for a single-stage manufacturing system, which is called "chaining principle" in the literature [5]. This work was extended to multistage manufacturing systems by Graves and Tomlin [6]. Considering Bill of Material (BOM) of products, Hua and He [5] further developed guidelines to improve process flexibility of machine lines and manufacturing system. The main point of these studies is that flexible capacity arranged in a right way will make the resulted manufacturing or service system with high flexibility and well performance. Based on the assumption that there is a central planner responsible for the whole system, most of these studies conclude that flexible technology is always better than dedicated technology for the system to achieve outstanding performance. Different from these papers, this paper concentrates on the flexible technology choice in decentralized manufacturing system. A decentralized manufacturing system is composed of multiple autonomous firms, which produce multiple products and sell them in a whole market. There is no central planner who is responsible for the whole system.

The second stream of literature considers investment in flexible versus dedicated technology/capacity for one or more firms. In these papers, technology choice is made given that the firm has decided to produce a certain number of products, i.e. flexible technology is not considered as a necessity to enter a new market. Fine and Freund [7] modeled a firm manufacturing n products within two decision stages. In the first stage, the firm must choose the capacity levels for the n dedicated resources as well as for the one flexible resource that can manufacture all n products. In the second stage (when demand is realized), the firm decides on production quantities given the capacity constraints. Fine and Freund [7] showed that the decision to invest in flexibility is based on the cost differential between the dedicated and flexible technologies. Van Mieghem [8] developed a similar model and finds that flexibility is beneficial even with perfect positive correlation if product margins are different. Bish and Wang [9] studied the optimal resource investment decision faced by a two-product, price-setting firm that operates in a monopolistic setting and employs a postponed pricing scheme. The firm has the option to invest in dedicated resources as well as a more expensive, flexible resource that can satisfy both products. Bish and Wang [9] provided the structure of the firm's optimal resource investment strategy as a function of demand parameters and investment costs, and shows that the flexible resource investment decision follows a threshold policy. Goyal and Netessine [10] explored the impact of competition on a firm's choice of technology (product-flexible or product-dedicated) and capacity investment decisions. They modeled two firms competing with each other in two markets characterized by price-dependent and uncertain demand, and showed that the firms may respond to competition by adopting a technology, which is the same as or different from what the competitor adopts. Our paper differs from these papers in that we regard the flexible technology as a necessity of a firm to enter a new market, not just a pure technology of production.

Papers in the third stream of literature look at the strategic value of flexibility as entering a new market or deterring the market entry of rivals. Röller and Tombak [2] and Kim et al. [11] examined the market conditions under which firms would choose a more flexible production technology to enter their rival's market. They assume that the two products are substitutes. They use a two-stage game in which firms choose between flexible and less flexible production technologies in the first stage and subsequently choose output. For substitutable products, they find that firms are trapped in a Prisoner's dilemma-like situation: while each can choose one market and make a monopoly profit in it, both firms invade both markets by choosing flexible technology, and thus earn less profit. They also find that the mixed technology