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Decision Support

Competition through capacity investment under asymmetric existing capacities and costs

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ABSTRACT

This paper discusses the way that different operational characteristics including existing capacity, scale economies, and production policy have an important influence on the capacity outcomes when firms compete in the market place. We formulate a game-theoretical model where each firm has an existing capacity and faces both fixed and variable costs in purchasing additional capacity. Specifically, the firms simultaneously (or sequentially) make their expansion decisions, and then simultaneously decide their production decisions with these outputs being capacity constrained. We also compare our results with cases where production has to match capacity. By characterizing the firms' capacity and production choices in equilibrium, our analysis shows that the operational factors play a crucial role in determining what happens. The modeling and analysis in the paper gives insight into the way that the ability to use less production capacity than has been built will undermine the commitment value of existing capacity. If a commitment to full production is not possible, sinking operational costs can enable a firm to keep some preemptive advantage. We also show that the existence of fixed costs can introduce cases where there are either no pure strategy equilibrium or multiple equilibria. The managerial implications of our analysis are noted in the discussion. Our central contribution in this paper is the innovative integration of the strategic analysis of capacity expansion and well-known (s, S) policy in operations and supply chain theory.

1. Introduction

The objective of this paper is to increase our understanding of how the competitive asymmetries between existing capacities and between investment/production costs affect firm capacity decisions. When a firm faces a challenge from a competitor who can introduce new capacity (either an incumbent firm with existing capacity or a potential entrant), it can be hard to decide whether to respond aggressively to rivals through adding capacity (Hayes, Pisano, Upton, & Wheelwright, 2005). The firm needs to make a trade-off: making no response or making too small a capacity addition will result in accommodating the rival, while making too large a capacity addition will result in unused capacity or depressed prices. Furthermore, capacity decisions affect most, if not all, other operating decisions including production planning and inventory levels, human resource decisions, and decisions on logistics and distribution (Hendricks, Singhal, & Wiedman, 1995). So capacity response in a competitive environment is a crucial operations challenge with a significant impact on firm profitability. An important feature of this paper is that the combined impact of existing capacities and fixed costs of investment is considered in our formal analysis. Thus we can shed light on the means by which ex ante asymmetries in operational factors can influence the firm decision on responding to its rival's capacity expansion.

1.1. Background

There are two linked ideas that are important in understanding strategic capacity decisions. First, there is the notion that capacity can be accumulated. A firm may have some pre-existing capacity which is then added to by further investment. The second idea is that capacity acts as a constraint on production. Indeed, a firm's capacity is often defined as its maximum production rate. But research on competitive capacity investment has often dropped the second of these ideas: while maintaining the idea of accumulation, problems of analytic tractability have frequently led researchers to assume that a firm makes decisions on production and capacity at the same time (e.g., Anand & Girotra, 2007; Goyal & Netessine, 2007; Swinney, Cachon, & Netessine, 2011). This leads to a

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clearance strategy in which a firm will use all of its capacity in production even if this turns out to be to its disadvantage. In our view this is only an appropriate model in cases where a firm has no option to make production decisions before discovering its rival's capacity choices (such as may occur if there are long lead times for major components); or, needs to maintain high capacity utilization because of high fixed costs of starting and stopping the production process; or, has available some mechanism to make a credible full production commitment to preempt the market (Hayes et al., 2005). Hence even though we use the terminology of a clearance *strategy*, as is normal in the operations management literature (see Van Mieghem & Dada, 1999), we do not mean to imply that a firm necessarily makes a choice about the strategy to use. It is more likely that a clearance strategy is a consequence of industry structure (Lieberman, 1987b; Goyal & Netessine, 2007).

In many circumstances firms first invest in capacity through building a factory or production line, and then operate the production facility over a period of months or years. When decisions on production quantities are made at a later time, it is often not possible to commit to a certain production level at the time when the capacity investment is made. In such cases firms may well choose to produce at a lower level than their maximum capacity (Hayes et al., 2005) and we refer to this as a *holdback* strategy following the operations management literature (see Van Mieghem & Dada, 1999). Note that we view the production policy, either holdback or clearance, as a fixed characteristic of the industry, but in practice the situation can be more complicated as firms need to make adjustments over time in response to market conditions. For instance in semiconductor manufacturing a firm may need to cut production when demand levels are falling, since if it sells all its capacity to the marketplace the resulting surplus production can push prices even lower (Wu, Erkoc, & Karabuk, 2005). In this case the degree to which holdback is employed is a function of changing market conditions which are unknown at the outset. However, in this paper we concentrate on the simplest case in which a production quantity is set only once (following the operations literature including Anupindi & Jiang (2008)) and uncertainty in market conditions is sufficiently small that it can be ignored (following the economics literature including Dixit (1980)).

We will assume full information and in this case a firm can deduce its competitor's capacity investment decisions at the time that it makes its own investment. Thus no further information becomes available and there is nothing to stop a production decision being made at the time of investment (as occurs for example in Rhim, Ho, & Karmarkar (2003)). But holdback production simply reflects the common circumstance that there is no mechanism for commitment to such a production decision in advance (Chen, Venkataraman, Black, & MacMillan, 2002; Hayes et al., 2005). It is unclear in the literature whether, with holdback production, there might be a situation where in equilibrium a firm invests in capacity and this is not used. For example we might guess that when an aggressive large investment can ensure that a competitor will not invest, then this may lead to an equilibrium solution where the investing firm ends with more capacity than is needed. Our detailed analysis will show that this never happens in the holdback setting. Nevertheless using holdback will result in different equilibrium outcomes than the clearance case when only one of the firms invests.

The history of Du Pont fighting with Kerr-McGee in the U.S. bulk chemical industry (see Ghemawat, 1984) illustrates the fact that *lead time* is important in strategic capacity investment. In this case, the challenger in the industry, Kerr-McGee, announced its own capacity investment plan before the expansion of the incumbent, Du Pont, had fully materialized. The presence of significant lead time for adding capacity provided Kerr-McGee with the ability to force its competitor, Du Pont, to revise its initial capacity plan. This strategic response to a capacity expansion announcement meant that Du Pont was unable to increase its market share and allowed Kerr-McGee to avoid being in the strategically disadvantaged position of investment follower. This case shows that given the long lead time involved in capacity expansion, neither firm can move fast enough to establish a leader–follower environment. Koeva (2000) indicates that average lead time for significant capacity investments is 26 months for a range of 23 industries including utilities, chemical plants, and rubber processing plants. Thus, when there is a long lead time, capacity investment is best considered as a simultaneous move competition rather than a sequential move competition.

There is often a significant fixed cost that is incurred in capacity expansion in capital-intensive sectors for line production and process industries such as semiconductors, petrochemicals and flat-panel-monitor manufacturing, where production capacity is expensive and can take a long time to build (Hayes et al., 2005; Wu et al., 2005). In an empirical study of the U.S. petroleum refining industry, Asano (2002) shows that the size of fixed cost of investment is important to firms' investment decisions regardless of firm size. From the point of view of capacity strategy, we might expect that a fixed cost will raise a hurdle against small levels of investment and may make it easier for an incumbent to deter a new entrant by building excess capacity (e.g., Rhim et al., 2003).

In this paper, we will try to unravel the impact of a number of different operational factors mentioned above that can play a part in determining the outcomes of competitive capacity expansion.

1.2. Summary of analysis

We propose a game-theoretical model explicitly addressing the four factors we have mentioned: existing capacity, lead time, production policy, and investment fixed costs. Our work differs from the majority of papers in this area by explicitly considering the ex-ante asymmetries that exist in both existing capacities and investment costs.

By including a pre-existing capacity endowment for the two firms we are able to model both cases with an incumbent and an entrant. We will give a complete analysis including situations where one of the firms has a capacity endowment which is larger than would be optimal. This may happen when the game we analyze comes after some decisions on preliminary investment that are made with an uncertain forecast of the market size. Thus our model can be useful in analyzing the later stages of a more extended strategic competition with uncertainty at the first stage about final demand. Specifically, we are able to discuss a situation in which an incumbent firm has already taken the opportunity to build or buy additional capacity prior to an entering firm deciding on its capacity investment. In this environment an incumbent firm can still take the opportunity to build more capacity at the same time as the entering firm and our model is designed to reflect this.

We model a duopoly where each firm decides to invest (*INV*) or not to invest (*NI*), and then chooses its capacity expansion level if it selects the *INV* strategy. The two firms produce the same or perfectly substitutable product; they both have access to the same deterministic forecast of demand; and, at the production stage, they know the capacity level of the other firm. Thus, after the capacity investment decisions have been made (the *capacity game*), the firms can evaluate their profit in a capacity-constrained *production game*. The market price is a function of the total production amount offered to the market by the two firms, and the production policy available to each firm (holdback or clearance) is fixed according to the industry structure.

We first characterize the pure-strategy Nash equilibrium in the production game and develop a best response function for each firm, given the capacity of its competitor, as a function of the initial