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A dynamic duopoly investment game without commitment under uncertain market expansion☆

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ABSTRACT

We model capacity-building investments in a homogeneous product duopoly facing uncertain demand growth. Capacity building is achieved through the addition of production units that are durable and lumpy and whose cost is irreversible. While building their capacity over time, firms compete *à la Cournot* in the product market given their installed capacity. There is no exogenous order of moves, no commitment regarding future decisions, and no finite horizon. We investigate Markov Perfect Equilibrium (*MPE*) paths of the investment game, which may include episodes during which firms invest at different times, a preemption pattern, and episodes in which firms invest simultaneously, a tacit collusion pattern. These episodes may alternate and are typically several. When firms have yet to invest in capacity, the sole pattern that is *MPE*-compatible is a preemption episode: firms invest at different times but have equal value. The first such investment may occur earlier and therefore be riskier than socially optimal. When both firms hold capacity, tacit collusion episodes may be *MPE*-compatible: firms invest simultaneously at a postponed time (hence holding back production in the meantime), thereby generating an investment wave in the industry. Such investment episodes are more likely with higher demand volatility, faster market growth, and lower cost of capital (discount rate).

1. Introduction

Investment games played by competing firms in oligopolistic markets typically share the following stylized characteristics: (i) the development of the market is uncertain, but firms have similar knowledge of the underlying random process generating the market development; (ii) firms' production capacities are built over time through additional units of significant size; (iii) investments in real assets are substantially irreversible; (iv) firms compete in the product market, given their installed production capacities, while they can at the same time develop those capacities; (v) any firm may invest at any time as the market develops and as its competitors build their own capacity; (vi) at the industry level, new investments sometimes come in waves with firms building new plants simultaneously and sometimes in sequences with firms investing at different dates; (vii) as the market matures, absent drastic innovations, capacity building eventually comes to an end determined by the potential market size, with capacities remaining essentially the same for an indefinite time.

We develop a duopoly model with features (i) to (v) above, which generates results (vi) and (vii) among others. More specifically, we consider a homogeneous product duopoly industry whose market demand is growing in a stochastic way. Firms compete continuously *à la Cournot* on the product market and they build up their capacity over time through the acquisition of lumpy units of capacity. There is no assumed or forced order of moves in capacity building, and no commitment on future investments or strategies. Rather, firms invest at chosen market development levels as they hold investment options to be exercised strategically at freely chosen dates. We characterize the value of the investment options to be exercised at the chosen timings and the value of the firms holding them.

Investments are assumed irreversible and consist of indivisible capacity units that do not depreciate. Hence, capacity can only increase in discrete jumps. Market development is exogenous, stochastic, continuous, and its current level is observed by the duopolists. A state of

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the game is characterized by a triplet composed of the current demand level and each duopolist's installed capacity. In any given state, a firm may decide to invest or not in one or more additional units of capacity; hence, either both firms invest in one or more capacity units, only one firm does, or neither firm does. The timing of each investment is thus linked to the stochastic state of market development, thus is itself stochastic.

The present investment game is a dynamic game with no exogenously specified end. However it is not an infinitely repeated game as the continuation game is defined according to three state variables namely firms' capacities and market size that are changing over time. We characterize the Markov Perfect Equilibria (*MPE*) of this investment game. A *MPE* investment path takes the form of a sequence of investment decisions by each firm as the market evolves, while firms continuously compete day to day *à la Cournot* on the product market given their installed capacity and the attained level of demand.

Fudenberg and Tirole (1983, 1985) studied investment games involving a single investment by each player and found that two types of *MPE* may exist. One involves simultaneous or joint investment, called tacit-collusion or under-investment equilibrium because the joint investment is postponed, meaning that the firms tacitly restrict their joint production capacity, thereby lessening the day to day Cournot competition. A second type of *MPE* has investments occurring at different dates and was called a diffusion or preemption *MPE* because they emerge from early move strategies aiming at preventing the other player from investing first. In a preemption *MPE*, industry capacity is larger, potential rents are dissipated, and firms obtain identical payoffs despite the asymmetry in the timing of their investments.

We consider an investment game involving multiple investments and admitting one or several investment paths as equilibria. In the investment game we develop and analyze in the present paper, *MPE* investment paths will typically be composed of different episodes, each one starting from a state characterized by the current market development and the firms' installed capacities resulting from past decisions. Two types of episodes may appear along any given *MPE* investment path: episodes during which firms invest at different times, in a preemption or intense competition mode, and episodes during which firms invest simultaneously, in a tacit collusion mode. When an episode along a *MPE* investment path has one firm investing earlier than the other, we say by analogy with the Fudenberg–Tirole's single-investment game that there is "preemption" during that episode, no matter what the sequence of previous or subsequent investments may be: potential incremental rents are dissipated, and firms have identical incremental value. The first investment occurs precisely at the time when the market development level leaves the other firm indifferent between preempting or investing later: hence, no firm gains by moving first. When an episode along a *MPE* investment path has both firms investing simultaneously, we say that there is "tacit collusion" during that episode. Indeed, such simultaneous investment takes place at a *higher* market development level, hence later, than the levels at which firms would invest if they were to invest at different times. Industry supply is then lower during the relevant market development interval than it would be otherwise, thereby generating tacit collusion rents for the firms: capacity building is postponed, production is lower, and prices and profits are increased relative to the levels that would prevail otherwise, that is, over the same market development interval if the firms were to invest at different times in a preemption episode. We characterize the factors and conditions for which along a given *MPE* investment path one may encounter both preemption episodes and tacit-collusion ones.[1]

Our model is able to address the following questions at some level of generality: What is the link between the level of market or industry development and the intensity of competition? Do simultaneous investments or investment waves signal intense competition or tacit collusion? Can investments occur earlier than in perfect competition or in a social optimum? What is the role and effect of demand volatility, market growth rate, and cost of capital on the intensity of competition?

More precisely, our main results are as follows. If firms start from a symmetric position of zero capacity when the level of market development is low, the first *MPE*-compatible investment episode[2] is necessarily a preemption episode, with only one active firm although both firms have necessarily the same value. Eventually the investment game will come to an end either with both firms having enough capacity to produce and sell the unconstrained Cournot quantity, if there is no tacit collusion at the end of the game, or both firms forever maintaining their capacities at a lower level, if the game ends with a tacit-collusion episode. Between the initial state of zero capacities with a low market development and the end of the game, two types of investment episodes may appear along any *MPE* path of the investment game. Starting in *any* state (market development level, installed capacities) in which further investment is profitable in the future for both firms, there exists a *MPE*-compatible preemption episode during which firms invest at different times. In *some* states, which we characterize, there exists also *MPE*-compatible tacit collusion episodes during which both firms invest at the same time. In *MPE*-compatible preemption episodes, incremental rents are equalized and partly dissipated. In *MPE*-compatible tacit collusion episodes, firms exercise market power by postponing their respective next investment until market development reaches a threshold that exceeds the level at which either firm would have invested in a preemption episode. Firms then invest simultaneously, thereby generating an investment wave in the industry. *MPE*-compatible tacit collusion episodes are typically several in a given state, which are all Pareto-superior from the firms' viewpoint to the *MPE*-compatible preemption episode in that given state. Furthermore, the market development trigger level at which the joint investment would maximize combined profits is *MPE*-compatible only if firms are of equal size. Hence, when firms differ in size, tacit collusion falls short of maximizing combined profits. Nevertheless, an investment wave indicates that tacit collusion has occurred and has resulted in a successful exercise of market power.[3] We show that higher market volatility, faster expected market growth, as well as lower cost of capital enlarge the set of conditions under which *MPE*-compatible tacit collusion episodes exist. However, no such *MPE*-compatible tacit collusion episode exists in the early stages of market development, that is, when at least one firm holds no capacity.

Even though the investment game has no finite horizon, it eventually comes to an end at some stochastic time, that is, in a state from which no further investment is undertaken by the firms. We characterize these endgame conditions. This allows us to use backward induction to characterize the *MPE*-compatible investment sequences. As discussed further below, this result is closely dependent on the way we model market demand growth. If along a *MPE*-compatible investment sequence, a point is reached where endgame conditions are close to be met while firms have different capacities, then the smaller firm will be the sole investor for a while, possibly for the remainder of the game. Thus, while firms may be of different sizes along the equilibrium path, no size advantage can be maintained forever.

[1] While there is a large literature on tacit collusion in infinitely repeated games, dynamic investment games are much less well understood. For example, it is well known that collusive equilibria exist in infinitely repeated games provided firms are sufficiently patient, that is, the discount factor is sufficiently large as shown for instance in Dutta (1995a, 1995b). However, no such result exists in general for non repeated games.

[2] We use the terminology "*MPE*-compatible " to refer to an investment episode that is part of a *MPE* investment path.

[3] Some authors found that investment waves sometimes indicate harsh preemptive competition, as for instance in a preemptive race to acquire a dominant position. Here investment waves indicate tacit collusive behavior with both firms postponing their respective acquisition of capacity units, hence holding back production and raising prices and profits in the meantime.