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Abstract

Prior research on firm strategy in the presence of learning curves suggests that if learning is highly appropriable, early entrants can achieve sustained competitive advantage by rapidly building capacity and by pricing aggressively to preempt competition. However these studies all presume (1) rational actors and (2) equilibrium, implying markets clear at all points in time. We consider the robustness of the aggressive strategy in the presence of (1) boundedly rational agents and (2) a capacity acquisition lag. Agents are endowed with high local rationality but imperfect understanding of the feedback structure of the market; they use intendedly rational heuristics to forecast demand, acquire capacity, and set prices. These heuristics are grounded in empirical study and experimental test. Using a simulation of the duopoly case we show the aggressive learning curve strategy becomes suboptimal when the market is dynamically complex. When capacity cannot be adjusted instantaneously, forecasting errors leading to excess capacity can overwhelm the cost advantage conferred by the learning curve. We explore the sensitivity of the results to the feedback complexity of the market and the rationality of the agents' decision making procedures. The results highlight the danger of extrapolating from equilibrium models of rational actors to the formulation of strategic prescriptions and demonstrate how disequilibrium behavior and bounded rationality can be incorporated into strategic analysis to form a 'behavioral game theory' amenable to rigorous analysis.

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1. Introduction

Learning curves have been identified in a wide variety of industries (Dutton and Thomas, 1984), and an extensive theoretical literature has explored their strategic implications. A learning curve creates a positive feedback loop by which a small initial market share advantage leads to greater production experience, lower unit costs, lower prices and still greater market share advantage. In general, the literature suggests that in the presence of learning curves – and when learning is privately appropriable – firms should pursue an aggressive strategy in which they seek to preempt their rivals, expand output and reduce price below the short-run profit maximizing level (Spence, 1981; Fudenberg and Tirole, 1983, 1986; Tirole, 1990). Intuitively, such aggressive strategies are superior because they increase both industry demand and the aggressive firm's share of that demand, boosting cumulative volume, reducing future costs and building sustained competitive advantage until the firm dominates the market. The desirability of aggressive strategies in industries with learning curves has diffused widely in business education, the popular business literature, management texts, and public policy debates (Rothschild 1990, Hax and Majluf, 1984; Oster, 1990; Porter, 1980; Krugman, 1990), and learning curve strategies appear to have led to sustained advantage in industries such as synthetic fibers, bulk chemicals and disposable diapers (Shaw and Shaw 1984; Lieberman 1984, Ghemawat 1984, Porter 1984).

However in many industries, including televisions, VCRs, semiconductors, toys and games, lighting equipment, snowmobiles, hand calculators, tennis equipment, bicycles, chain saws, running shoes and vacuum cleaners, aggressive pricing and capacity expansion have led to substantial overcapacity and price wars that have destroyed industry profitability (Beinhocker, 1991; Salter, 1969; Porter, 1980; Saporito, 1992; The Economist, 1991; Business Week, 1992).

Existing models that consider the competitive implications of the learning curve utilize the traditional assumption that markets clear at all points in time. Market clearing in turn implies that a firm's production capacity and other resources can be adjusted instantaneously to equilibrium levels, or, if there are capacity adjustment lags, that firms have perfect foresight such that they can forecast their capacity requirements far enough in advance to bring the required capacity on line just as it is needed. Neither assumption is valid: it takes time to build new factories, expand existing ones, and decommission obsolete ones (Mayer 1960, Jorgenson and Stephenson 1967), and forecasting over typical planning horizons remains difficult and error-prone (Armstrong 1985, Makridakis et al. 1982, Makridakis et al. 1993). The presumption in the literature is that capacity adjustment and forecast error correction are fast relative to the dynamics of the learning curve so that the assumption of perfect market clearing is a reasonable approximation.

In this paper we show that relaxing the assumptions of instantaneous market clearing and perfect foresight leads, in a variety of plausible circumstances, to competitive dynamics significantly different from those predicted by much of the existing literature. We begin with a review of the literature on strategy in the presence of learning curves. We then develop a model in which the assumptions of market clearing and rationality are replaced by a disequilibrium, behavioral framework in which firms face lags in adjusting capacity and use boundedly rational decision heuristics to set prices and forecast demand. We use the model to explore the impact of an aggressive learning-curve strategy in a variety of environments.

When the dynamics of the market are sufficiently slow, delays in information acquisition, decision making, and system response are sufficiently short, and the cognitive demands on the firms are sufficiently low, behavioral theory yields predictions observationally indistinguishable from those of equilibrium models. However in more dynamic environments, in which boundedly rational forecasting techniques become less accurate, the aggressive learning curve strategies prescribed in the game theory literature become inferior, as aggressive expansion leads to excess capacity. We close with implications for the study of strategic competition in general, arguing that the neoclassical assumptions of equilibrium and rationality may in many realistic circumstances prove to be a dangerous guide to action and a weak basis for empirical research.

2. Models of Learning Curve Strategy

Learning curves are a familiar phenomena. Numerous empirical studies have documented their existence in a wide variety of industries, as Hax and Majluf (1984, 112) note, "ranging from broiler chickens to integrated circuits" (see Dutton and Thomas 1984 for a review).

Spence (1979) examines the effect of competitive asymmetries on investment decisions in growth markets where there are learning effects. He notes that learning curves allow for creation of asymmetric advantage and thus create an incentive to preempt rivals. Spence (1981) further quantifies optimal production policy under a learning curve, finding that if firms can perfectly appropriate all the benefits of learning, and if they can be sure of a first mover position, then they should expand output beyond the short-run profit maximizing level in order to capture learning-induced cost advantage. Fudenberg and Tirole (1986) and Tirole (1990) present a dynamic analysis of a duopoly with a learning curve. Under quantity competition they find that an aggressive strategy always dominates. Under price competition the aggressive strategy succeeds in deterring rival entry and in causing rival exit, but when two existing players prefer accommodation there is no clearly dominant strategy a priori.

Other studies have examined the sensitivity of these results to differing demand conditions and appropriability assumptions. Majd and Pindyck (1989) show that uncertainty in future prices reduces the optimal expansion of output beyond the static equilibrium level. Ghemawat and Spence (1985) show that when the effects of learning spill over to competitors the incentives to expand output are also reduced. Similar conclusions are found in the literature on the effects of learning on international trade (Krugman, 1987).

Kalish (1983) addresses the interaction between learning and product diffusion dynamics (word of mouth, saturation). Word of mouth creates a shadow benefit of current sales that reinforces the incentive to cut price and expand production as current output builds the installed base of customers who in turn convey information on the benefits of the product to those who have not yet purchased, accelerating product adoption.

In sum, the literature suggests that if learning is appropriable, if price is not highly uncertain, and if rivals can be relied on to behave rationally, then firms should pursue an aggressive strategy of preemption, higher output and lower prices. This recommendation has diffused widely in business education, the popular business literature, and public policy debates (Oster, 1990; Krugman, 1990). All these models assume equilibrium and market clearing so that the firm's capacity is always equal to demand, implying either that there are no capacity adjustment delays or that firms have perfect foresight so that they can forecast demand sufficiently far in advance to ensure that they always have exactly the correct capacity.

3. A Boundedly Rational, Disequilibrium Model

To explore the robustness of the learning curve literature to the assumptions of perfect foresight and instantaneous market clearing, we developed a disequilibrium, behavioral model of competitive dynamics in the presence of learning. Following Kalish (1983), we assume that the market goes through a life-cycle of growth, peak, and saturation. In contrast to the literature, we assume capacity adjusts with a lag, and that firms have only a limited ability to forecast future sales. These assumptions are consistent with a long tradition of experimental and empirical evidence (Brehmer 1992, Collopy and Armstrong 1992, Diehl and Sterman 1995, Kampmann 1992, Mahajan et al. 1990, Paich and Sterman 1993, Parker 1994, Rao 1985, Sterman 1989a, 1989b, 1994). In models assuming instantaneous market clearing and perfect foresight, the market clearing price can be derived as a necessary property of equilibrium, given the capacity decision. However in disequilibrium settings, both price and capacity targets must be determined. Here we draw on the literature cited above and the well-established tradition of boundedly rational models, and assume that firms set prices with intendedly rational decision heuristics (Cyert and March, 1963/1992; Forrester 1961; Simon 1976, 1979, 1982; Morecroft 1985).

The model is formulated in continuous time as a set of nonlinear differential equations. Since no analytic solution to the model is known, we use simulation to explore its dynamics[1] While the model portrays an industry with an arbitrary number of firms $i = \{1, ..., n\}$, we restrict ourselves to $n = 2$ in the simulation experiments below. We begin by laying out the equations describing the dynamics of demand. These are based on the standard Bass diffusion model (Bass, 1969; Mahajan et al. 1990). We then describe the physical and institutional structure of the firm, including order fulfillment, revenue and cost, the capacity acquisition lag, and the learning curve. Finally we discuss firm strategy. This section is the heart of the model and contains the key behavioral assumptions regarding demand forecasting, target capacity, and pricing.

Industry Demand

The total industry order rate, Q^O, is the sum of the initial and replacement purchase rates, Q^I and Q^R (time subscripts are omitted for clarity):

$$Q^O = Q^I + Q^R. \quad (1)$$

Initial orders are given by the product of the rate at which households choose to adopt the product and thus enter the market and the average number of units ordered per household, μ. The adoption rate is the rate of change of the number of adopters, M, thus:

$$Q^I = \mu(dM/dt). \quad (2)$$

Households are divided into adopters of the product, M, and potential adopters, N. Following the standard Bass diffusion model adoption arises through an autonomous component and through word of mouth encounters with those who already own the product:

$$dM/dt = N(\alpha + \beta M/POP) \quad (3)$$

where α is a constant fractional propensity for potential adopters to adopt, β is the fractional rate at which potential adopters choose to adopt given that they have an encounter with an adopter, and the ratio M/POP is the probability that a given nonadopter encounters an adopter (POP is the total number of households).

The number of potential adopters remaining, N, is the difference between the number of people who will ever adopt the product, M^*, and the number that have adopted the product to date:

$$N = MAX(0, M^* - M) \quad (4)$$

where the MAX function ensures that N remains nonnegative even in the case where M^* drops below M (as could happen if the price suddenly rose after $M \approx M^*$).

The number of people who will eventually choose to adopt, M^*, is the equilibrium industry demand and is a function of the price of the product. For simplicity we assume a linear demand curve between the constraints $0 \leq M^* \leq POP$:

$$M^* = MAX(0, MIN(POP, POP^* + \sigma(P^{min} - P^*))) \quad (5)$$

where σ is the slope of the demand curve, P^{min} is the lowest price currently available in the market, and the reference price P^* is the price at which M^* equals the reference population POP^*.