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The measurement of market power: short-run, long-run, and dynamic adjustment models

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CHAPTER 1. INTRODUCTION

The measurement of market power has been one of the prime concerns of industrial organization economists. Obviously it is important for practical reasons because it can frequently provide valuable information for the design of public policy towards monopoly and anti-competitive practices. As a result, during the past decades, many industrial economists have developed various approaches to measuring market power.

Traditionally, SCP (structure-conduct-performance) researchers have relied heavily on the relationship between market performance and market structure as a way of making inferences about market power. But their studies have not always been clearly based on a well-defined theoretical model. Alternatively, since the late 1970s, new empirical techniques have been developed to estimate market power using structural models based on the neoclassical theory of a firm's behavior. Some of these methods make inferences about market power from a firm's or an industry's response to cost conditions. Others make such inferences from a firm's or an industry's response to variation in the elasticity of output demand, or by detecting multiple pricing regimes. However, most of these recent studies have been based on static optimization models. In particular, with regard to the determination of the capital input in oligopoly models, most previous empirical studies have specified investment behavior within either short-run or long-run equilibrium frameworks. For example, Roberts (1984) developed a short-run equilibrium model in a homogenous product oligopoly and estimated price-cost margins for the U.S. coffee roasting industry. Bernstein (1991) showed that there is significant oligopoly power for some Canadian industries producing multiple outputs, again using a short-run equilibrium approach. The common characteristic of these "short-run equilibrium" empirical models is that, while it is recognized that the capital input decision is not made in the same way as decisions about other factors, no explanation of the evolution of capital stocks is provided by the model. Capital is essentially exogenous.

On the other hand, others have modeled firms' oligopolistic market behavior in the long-run equilibrium framework, assuming all input factors, including capital, costlessly adjust without delay to satisfy marginal revenue product equals marginal factor cost conditions in every period. This class of model has been empirically implemented by Appelbaum (1979) for the U.S. crude petroleum and natural gas industry, and Appelbaum (1982) for the U.S. rubber, textile, electrical machinery, and tobacco industries. Gollop and Roberts (1979) also developed a model that can identify the interdependent behavior among firms in an oligopolistic industry based on an assumption of long-run equilibrium. Capital is endogenous in these models.

However, the standard long-run equilibrium assumption for the capital stock is often inappropriate where there are substantial adjustment costs[1] in capital accumulation, so that investment decisions are intertemporally made. Hence measures of market power based on models incorporating the long-run equilibrium assumption may not be very informative. As noted in Pindyck (1985), ignoring an intertemporal aspect of firms' decision problems may

[1] Eisner and Stolz (1963) first introduced adjustment costs into the neoclassical theory of the firm in an effort to construct a dynamic framework capable of yielding a demand for investment. Later work by Berndt, Fuss, and Waverman (1980) developed a dynamic model in which capital is quasi-fixed and subject to quadratic adjustment costs.

lead to inferences of the extent of market power that are misleading. In this sense, the non-competitive pricing behavior of firms needs also to be described in a model where a firm's optimal capital stock decisions are intertemporally made in the face of adjustment costs. Reflecting this view, Bernstein (1994) analyzed non-competitive pricing behavior in a dynamic cost of adjustment framework and tested for the existence of price-margins in the Canadian softwood lumber industry. In a different approach, considering the intertemporal dependence between fims with respect to advertising expenditures, Roberts and Samuelson (1988) estimated "dynamic conjectural variations" for firms in the U.S. cigarette industry.

Theoretical analyses of investment in imperfectly competitive industries have highlighted the strategic aspects of capital acquisition decisions. For example, strategic behavior in capital investment has been developed by Spence (1977, 1979), Dixit (1979, 1980), Brander and Spencer (1983), and others. This class of studies examines firm behavior in dynamic games in which an irreversible commitment in capital investment in an early stage of the game enables a firm to favorably influence the market outcome in a subsequent stage. Empirically, the main body of the literature has tried only to capture preemptive behavior of a dominant firm to deter or to delay investment by rival firms (Reynolds, 1986; Gilbert and Lieberman, 1987; and Hall, 1990). This sort of strategic effect of capital investment has often been ignored, however, in NEIO empirical studies of market power.

The objective of this dissertation is to measure the degree of market power within the context of each of three models; short-run, and long-run equilibrium models, and a dynamic cost of adjustment model with strategic capital investment; and to see how inferences of market power differ across the three cases. In particular, we will use the adjustment cost model to study dynamic oligopolistic behavior of firms with strategic investment. This research builds on previous theoretical work as well as on our theoretical model developed in Chapter 3, and recent developments in applied econometrics. Our research presents an industry analysis of market structure and demonstrates the use of theory-consistent models following the new empirical industrial organization (NEIO) tradition. The models' differences in this dissertation center on the role of investment in capital (equipment and structures). First, a short-run model is estimated in which demand for the non-capital inputs is conditioned on the existing capital stock but there is no explicit modeling of the demand for capital. Second, a long-run model is estimated with no adjustment costs so that capital appears as any other input: Its employment level is determined each period by a marginal condition equating marginal revenue product with the factor's price. Third, a dynamic cost of adjustment model is estimated, which generalizes both the short- and long-run models: Inputs and outputs are chosen to maximize the expected present value of a future flow of revenues net of production and adjustment costs. Time-series data are used to reveal the degree of market power through a system of equations including a supply relation, a demand function and a set of input demand (capital, labor, and intermediate material inputs) functions for each model.

This dissertation is organized into nine chapters. After introductory remarks in this Chapter, Chapter 2 provides a review of NEIO studies for measuring market power, including discussion of two classes of NEIO approaches and references to some relevant papers. Chapter 3 provides a theoretical rationale for the strategic investment behavior of non-competitive firms. First, theoretical studies on firm's strategic capital investment behavior in oligopoly models are reviewed. In particular, Chapter 3 analyzes the strategic capital investment behavior of firms within a simple duopoly model as in Brander and Spencer (1983). Then, it derives an illustrative strategic investment model by generalizing Brander and Spencer's results slightly by allowing for investment over time subject to convex adjustment costs. Chapter 4 develops a theoretical foundation for measuring market power in the context of a dynamic cost-of-adjustment model with a strategic effect of capital investment and also makes clear its theoretical distinctions from the short-run and long-run static model specifications. Chapter 5 translates the theoretical models presented in Chapter 4 into estimable models, and introduces the hypotheses to be tested. First, a functional form will be selected. Next, the econometric specifications for three equilibrium models will be derived. Finally, some properties of the cost function in terms of industry-level variables will be discussed. Chapter 6 discusses the estimation methods. First, the statistical properties of Chapter 5's model's equations are discussed. NL3SLS (non-linear three stage least squares) is suggested as an estimation method for the two static equilibrium models. In addition, following Schankerman and Nadiri (1986), a specification test will be proposed to see whether the long-run equilibrium model is consistent with the data. Finally, a methodology suggested by Hansen and Singleton (1982) is proposed for the estimation of the dynamic adjustment cost model. Chapter 7 provides some background information on the particular industry used as an application: The U.S. electrical transformer industry for the 1958-91 time period. Descriptions of the variables and sources of the data are also given here. Chapter 8 discusses the empirical results for the U.S. transformer industry from the application of each of the empirical models. A summary is provided in Chapter 9.

CHAPTER 2. "NEIO" APPROACH TO MEASURING MARKET POWER

2.1 Introduction

"Market power" refers to a divergence between price and marginal cost. NEIO studies for measuring market power can be broadly divided into static models and intertemporal models, each based on a different aspect of a firm's optimizing behavior. Both methods discussed in this chapter use the latest econometric techniques to estimate structural parameters and to test structural hypotheses. The static models reviewed in this chapter are concerned with pricing in oligopolistic industries without considering decision variables' intertemporal links between periods, while the intertemporal models focus more on such effects as dynamic optimizing and strategic behavior over time in measuring market power.

For many decades, economists have conducted SCP studies that investigate the major factors determining market power. These analyses often involved regressing price-cost margins on market share, concentration ratios, barriers to entry, and other aspects of market structure using industry cross-sectional data. The attractiveness of this approach lies in its straightforwardness and its ability to produce some useful stylized facts. However, the approach has also been criticized on the basis of the data and methods used. Two important problems have been identified: First, many of these studies suffer from substantial measurement error or related statistical problems. Second, more importantly, most of these studies use *ad hoc* regression equations with no theoretical foundation so they rarely, if ever, yield consistent estimates of structural parameters. The NEIO is partly motivated by those criticisms of the SCP paradigm. The NEIO approach is based on the following central ideas: (i) economic marginal cost (MC) cannot be directly observed, so it should be estimated within the context of a theoretical model; (ii) institutional details of industries affect firms' conduct, so studies should focus on individual industries using time-series data; (iii) analysis should be conducted subject to restrictions implied by neoclassical theories of the optimizing firm and; (iv) as a result of the theory-consistent approach to empirical modeling, the particular mechanism responsible for the identification of market behavior is made clear.

An example of a stylized NEIO model will serve to illustrate these characteristics. The dependent variables are market price, P_t, and each firm's quantity, y_{it}. Throughout, i is used to index firms and t is used to index time periods. The inverse market demand function for the product is written as:

(2.1) $P_t = D(Y_t, z_t, \delta, \varepsilon_{dt})$,

where Y_t is aggregate industry output (i.e., $Y_t = \Sigma_i y_{it}$), z_t is a vector of variables shifting demand, δ is a vector of unknown parameters of the demand function, and ε_{dt} is an error term. The total cost function for the ith firm is given by:

(2.2) $C_{it} = C(y_{it}, W_{it}, R_{it}, \Gamma, \varepsilon_{cit})$,

where W_{it} is the vector of factor prices paid by firm i at observation t, R_{it} consists of other variables that shift cost, Γ is a vector of unknown parameters, and the ε_{cit} are error terms. The definition of marginal cost follows from (2.2):

(2.3) $MC = C_y(y_{it}, W_{it}, R_{it}, \Gamma, \varepsilon_{cit})$,

where the subscript denotes partial differentiation. A range of oligopoly conduct can be described by general supply relations:

(2.4) $P_t = C_y(y_{it}, W_{it}, R_{it}, \Gamma, \varepsilon_{cit}) - D_Y(Y_t, z_t, \delta, \varepsilon_{dt})\, Y_t\theta_{it}$.

Since $P_t + D_Y Y$ is monopoly marginal revenue (MR), (2.4) has the interpretation of marginal cost (MC) = "perceived" MR for oligopoly models. The parameters θ_{it} index the competitiveness of oligopoly conduct. As θ_{it}, a positive unknown parameter, moves farther from 0 to 1, the conduct of firm i moves farther from that of a perfect competitor and closer to monopoly. Marginal cost in (2.4) appears as a function of unknown parameters, not as an accounting datum. Only after Γ has been estimated can MC be calculated. If (2.1) and (2.4) are solved simultaneously for all firms, they yield the reduced forms for price and each firm's quantity:

(2.5) $P_t = P^*(W_t, R_t, z_t, \Omega, \varepsilon_t)$,

(2.5') $y_{it} = y_i^*(W_t, R_t, z_t, \Omega, \varepsilon_t)$,

where $\Omega = (\delta, \Gamma, \theta)$ is the vector of all parameters, ε_t is the vector of all structural error terms, and W_t and R_t incorporate all of the W_{it} and R_{it} respectively.

The advantages of the model in (2.1) and (2.4) are three-fold. First, the econometric approach is structural so that each parameter has an economic interpretation. Second, since conventional oligopoly solution concepts (e.g., price taking equilibrium, Cournot-Nash, joint-profit maximization) imply specific values for the θs, estimates can be directly linked to theoretical notions of firm and industry conduct. Third, given the structural nature of the econometrics, the reason why the data identify the conduct parameters can be made clear.

As shown above, in a departure from the SCP traditions, NEIO has been firmly grounded on the neoclassical non-competitive theory to construct explicit structural models, and, it uses the latest econometric techniques to estimate structural parameters and to test structural hypotheses. Empirically, they have been explored within both static and intertemporal frameworks.

2.2 Static models

The basic approach of the static models discussed in this dissertation is to treat a given vector of observed industry prices and outputs as the outcomes of static optimizing behavior and to evaluate what type of non-competitive behaviors among firms would have occurred to generate those prices and output as an equilibrium outcome. Most of them involve parameterizing the marginal revenue function of a firm in an industry, and measuring the extent to which observed price exceeds marginal revenue at observed outputs.

In what follows, three broad approaches to the static models of market structure are summarized. One method is to test whether firms are price takers or not by way of estimating a marginal cost function and then detecting differences between marginal costs and prices at observed outputs. Using relatively easily accessible data; for example, input and output prices and quantities; one can jointly estimate the parameters of a production or cost function and a marginal revenue curve, and then test to see whether the latter is flat. Starting with Rosse (1970), earlier studies rejected price-taking behavior: Appelbaum (1979) for the U.S. petroleum and natural gas industry; Baker and Bresnahan (1985) and (1986) for two leading firms in the U.S. beer industry. On the other hand, some other empirical works attempted to investigate pricing conduct of firms without imposing a priori structure on the data in the form of assumptions on functional forms. For example, Hall (1988) showed that with an assumption of constant returns to scale in an industry, shifts in cost are sufficient to identify market power. Shapiro (1987) and Domowitz et al. (1986. 1988) and others used methods similar to Hall's and found significant markups for U.S. manufacturing industries.

For more detailed analysis of industry conduct. conjectural variation (the expected change in rival's output consequent upon a change in the output of firm i) methods have focused on parameterizing various oligopoly solution concepts. The implication is that if one were to estimate an arbitrary set of conjectures, then one can compare them to values suggested by the different oligopoly models which are computable given knowledge of costs and demands. Starting with Iwata (1974) for the Japanese flat glass industry. more elaborate work has been done by Gollop and Roberts (1979), who attempted to estimate a pattern of conjectural variations[2] across rival firms for the U.S. coffee roasting industry. and followed by others (Roberts, 1984; Spiller and Favaro, 1984; Slade, 1987). However. in a sense. those studies are descriptions of the consequences of pricing conduct rather than descriptions of conduct itself. These kinds of concerns have led to development of models allowing for systematic conduct over time. This last group of works[3] is involved in not only testing whether the conduct is stable, but also developing models capable of explaining price wars, cartel formation, pricing behavior over the business cycle, and so on. For example, research on the Joint Executive Committee, a cartel controlling railroad freight shipments from the

[2] An alternative way to get the same goal is to estimate "conjectural variation elasticity" as in Appelbaum (1982) and Geroski (1983).

[3] This group is sometimes classified as "multi-period models of collusive behavior" because it deals with describing variation of behavior over several time periods. We include this type among the static models in this literature review because it does not model any explicitly dynamic optimization problem.

east coast of the U.S. in the 1880s, showed a systematic pattern of alternating cooperative and non-cooperative pricing behavior (e.g., Porter, 1983, 1985; and Lee and Porter, 1984). Simiarly, Spiller and Favaro (1984) observed major changes in behavior of the Uruguayan banking sector following the relaxation of legal entry barriers.

Table 1 reports the estimated price-cost margins, expressed as the price-cost gap as a proportion of price, from several different NEIO studies for various industries.

Table 1
Some results of published works on measuring market power

Author	Industry	The estimated price-cost margin
Bresnahan (1981)	Autos (1970s)	0.1-0.34[a]
Appelbaum (1982)	Rubber	0.049[b]
	Textile	0.072[b]
	Electrical machinery	0.198[b]
	Tobacco	0.648[b]
Porter (1983)	Railroads	0.40[c]
Lopez (1984)	Food processing	0.50
Roberts (1984)	Coffee roasting	0.055/0.025[d]
Spiller and Favaro (1984)	Banks "before"[e]	0.88/0.21[f]
	Banks "after"[e]	0.40/0.16[f]
Suslow (1986)	Aluminum (interwar)	0.59
Slade (1987)	Retail gasoline	0.10
Karp and Perloff (1989)	Rice exports	0.11

[a] Varies by type of car; larger in standard, luxury segment.
[b] At sample midpoint.
[c] When cartel was succeeding: 0 in reversionary periods.
[d] Largest and second largest firm, respectively.
[e] Uruguayan banks before and after entry deregulation.
[f] Large firm group / small firm group.
Source: Articles cited and Bresnahan (1989).

2.3 Intertemporal models

It can be argued that the NEIO models introduced so far have tried to capture in a static world what is really a dynamic problem of firms. An intertemporal model is suggested when one takes account of planning by firms over many periods. For example, when there are large adjustment costs in accumulating capital, actions in one period would be expected to affect the costs and profits in later periods. The typical model is characterized by maximizing the discounted flow of funds over a finite or infinite horizon when decisions are made intertemporally.

In the intertemporal model, firms may take into account more strategies and expectations over rivals' decisions during the time periods and, hence, behavior may involve more than just a current period reaction to current changes of rivals' decisions. Thus the implications associated with dynamic decision-making in an oligopoly model can have a significant effect on market performance.

Pindyck (1985) noted that intertemporal constraints on production and price, in such cases as learning curves, exhaustible resources, and dynamic demand functions, would affect the extent of market power. Roberts and Samuelson (1988) developed a dynamic model of advertising competition in an oligopolistic industry,[4] incorporating dynamic conjectural variations to account for the intertemporal links created by the durability of advertising. They rejected the hypothesis that the U.S. cigarette market is competitive, and suggested that

[4] Friedman (1983) and Fershtman (1984) provided dynamic model of oligopolistic advertising competition with an intertemporal dependence structure.

firms in the industry act as if their choices would alter the future choices of rival firms. Karp and Perloff (1989, 1993) used a dynamic oligopoly model with costly adjustment of production or inventories to estimate the degree of competition for the international coffee and the international rice export markets. Bernstein (1994) developed a dynamic model with multiple products incorporating price-cost margins in domestic and export markets for the Canadian softwood lumber industry. He suggested that competitive behavior occurred in both markets by testing the estimates of price-cost margins. The intertemporal nature of the model arises from the existence of adjustment costs associated with the capital input.

To this point, all of the specifications in the empirical dynamic NEIO models have represented the capital investment decision of firms as being undertaken, either implicitly or explicitly, from a naive perspective; i.e., overlooking the incentives for strategic behavior arising when firms engage in a capital investment game over time. As extensively noted in theoretical literature on oligopoly behavior, inclusion of capital stocks not only gives a firm control over its cost function intertemporally,[5] but also opens up the possibility of its strategic use of capital stocks to its favor by influencing the market environment in future time periods. Hence, the firm will be able to influence the market outcome through its choice of capital stock. Therefore, it is reasonably argued that mistakenly omitting strategic effects of capital investment from empirical oligopoly models would make the measures of the degree of market power misleading or biased.

[5] Friedman (1982) presented several formulations that relate a firm's marginal cost to its capital stock, and suggested that in any of those cases, capital decisions provide a structural link between time periods, as would be the case, for example, when a large adjustment cost is incurred with capital stock changes.

In the next two chapters, we will construct an illustrative theoretical model emphasizing the strategic role of capital investment in an oligopoly market (Chapter 3), and then set up the theoretical foundation for a comprehensive empirical analysis of market power within the context of a dynamic model (Chapter 4).

CHAPTER 3. AN ILLUSTRATIVE TWO-PERIOD DUOPOLY MODEL

3.1 Introduction

The purpose of this chapter is to present and examine a two-period duopoly model of strategic investment behavior by imperfectly competitive firms. Although the model of this chapter is very simple, it will yield insights about the strategic role of capital investment that will help in the formulation of the dynamic cost of adjustment model in the chapters to follow.

Industrial organization deals with strategic interactions of firms. One broad category of I.O. studies examines firm behavior in dynamic games in which an irreversible commitment in an early stage of the game enables a firm to favorably influence the market outcome in a subsequent stage. Examples of these works (and the nature of the commitment variable in each) include Schmalensee (1978, brand introduction), Gilbert and Newbery (1982, investment in R&D), and Schmalensee (1983, investment in advertising). Beginning with Spence (1977, 1979) and Dixit (1979, 1980), a long series of papers has explored the strategic use of irreversible investment in capital stock.

One such strategic investment model is due to Brander and Spencer (1983). It explains the role of capital in an imperfectly competitive market in which firms' equilibrium outputs depend on their own and their rivals' marginal costs. If firms recognize this dependence of market share on marginal cost, and capital investment expenditures occur before the output is produced, firms might be tempted to shift additional resources to the overhead or "sunk" category so as to reduce marginal costs and gain a strategic advantage in the imperfectly competitive output game. In other words, when business firms can commit to cost-reducing investments before production and sales take place, they may use these capital investments strategically rather than simply to minimize cost. Brander and Spencer use a simple, symmetric, two-stage Nash duopoly model to show that such strategic use of capital will increase total investment, and total output, and lower industry profit.[6]

In the Brander and Spencer model, all investment is made, irreversibly, prior to the realization of output. In our study, we generalize Brander and Spencer's results slightly by allowing for investment over time. Some investment is made contemporaneously with the output decision in our model's second period. But an assumption of convex adjustment costs creates an incentive to spread investment across periods. In particular, firms will want to gradually build toward their ultimate capital stock with capital acquisition in the model's first period as well as the second. As in Brander and Spencer, the strategic role of first period investment stems from two features: investment is irreversible and first period investment has an influence on firms' objective functions in the second stage. Thus, firms' decisions about first period investment will affect the Nash equilibrium in the second stage choose-quantity-and-capital game.

Section 3.2 briefly reviews the assumptions and results of the Brander and Spencer model. Section 3.3 presents our extension of their model and derives same analytical results preliminary to the paper's main findings. In section 3.4, our model's extensions of Brander

[6] In the Brander and Spencer model, firms affect marginal costs of production with expenditures on cost-reducing R&D. But, as they note, there is nothing that formally distinguishes this case from investment in capital stock.

and Spencer's results are presented in the form of four propositions. Section 3.5 provides a brief summary and conclusion.

3.2. Overview of the Brander and Spencer model

The model with strategic capital investment involves a two-stage game. In the first stage, firms choose capital investment levels. These are made known then, in the second stage, output levels are determined. It is assumed that for any given capital investment levels, firms correctly anticipate the output equilibrium, which is resolved as a Nash quantity game. The solution concept in the first stage game in capital investment levels is also Nash, with the overall result being a "subgame perfect equilibrium" in the two stage game.

Firm i, for i = 1 and 2, has output q_i, revenue R^i and cost C^i. Expenditure on capital investment is denoted K_i, and this initial expenditure is converted to a flow by an implicit "rental" rate v_i. Thus the profit flow of firm i is given by

(3.1) $\pi^i(q_1, q_2; K_i) = R^i(q_1, q_2) - C^i(q_i; K_i) - v_iK_i$,

The outputs q_1 and q_2 are substitutes in the sense that increasing the output of good j decreases the total and marginal revenue of firm i. Using subscripts to denote derivatives, these conditions are expressed as

(3.2) $R^i_{q_j} \equiv \dfrac{\partial R^i(q_1, q_2)}{\partial q_j} < 0; \quad R^i_{q_iq_j}(q_1, q_2) \equiv \dfrac{\partial^2 R^i(q_1, q_2)}{\partial q_i \partial q_j} < 0;$

The variable cost (C^i) includes all costs except capital investment. The effect of having undertaken more variable cost-reducing capital investment is to reduce C^i, given q_i.

However, the rate of decrease is assumed to decline (in absolute value) as K_i increases. Marginal cost is strictly positive and decreasing in K_i:

(3.3) $C^i_{Ki}(q_i, K_i) < 0$; $C^i_{KiKi}(q_i, K_i) > 0$; $C^i_{qi}(q_i, K_i) > 0$; $C^i_{qiKi}(q_i, K_i) < 0$.

Given capital investment levels K_1 and K_2, chosen by firms in stage 1, output levels, q_1 and q_2, are determined in stage 2 as the solution to a Nash quantity game. The solutions to the second-stage game can be represented as

(3.4) $q^1 = q^1(K_1, K_2)$ and $q^2 = q^2(K_1, K_2)$.

Using the second order conditions for the firms' profit maximization problems in stage 2, and using conditions that insure stability of equilibrium in the dynamic model that results when a natural adjustment process is appended to the static reaction function model, Brander and Spencer establish the following properties of the $q^i(\bullet)$ functions:

(3.5) $\partial q^i/\partial K_i > 0$ and $\partial q^j/\partial K_i < 0$.

In words, an increase in firm i's capital investment leads to an increase in the second stage equilibrium output for firm i and a decrease in the second stage equilibrium output for firm j. The intuition of this result is illustrated in Figure 1. By increasing its capital, firm 1 reduces its marginal cost. This increases its profit maximizing output response to any given output on the part of firm 2; that is, it shifts firm 1's reaction function outward. The result can be seen in Figure 1 as an increase in equilibrium q_1 and a decrease in equilibrium q_2.

Solution of the first stage of the game proceeds by substituting the $q^1(\bullet)$ and $q^2(\bullet)$ functions into firms' profit functions and then solving for a Nash equilibrium in capital investment levels. Brander and Spencer show that the equilibrium investment levels in the

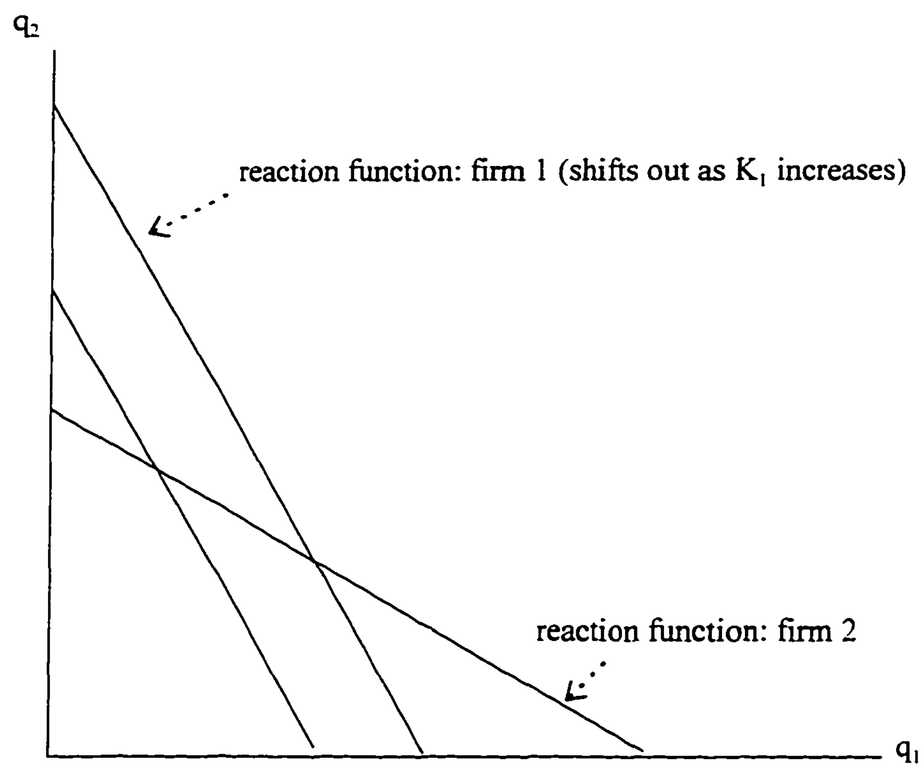

Figure 1. Effect of an increase in capital investment on output equilibrium in the Brander and Spencer model

subgame perfect Nash equilibrium are larger than the investment levels that would minimize the total cost of production for the equilibrium output levels. The intuition of this result is that the "strategic role of capital" (that is, the ability of firms to use capital investment to influence the second-stage equilibrium of the game in a manner that is favorable to the investing firm) provides each firm with an incentive to "overinvest" in capital.

The subgame perfect equilibrium in the two-stage game described above is referred to by Brander and Spencer as the model's "strategic equilibrium." They compare it to a "non-strategic equilibrium" in which firms make no use of capital's strategic role. This is best thought of as a Nash equilibrium in a one-stage game in which capital and output are simultaneously chosen. Brander and Spencer derive the following results for the symmetric firm case:

In the strategic equilibrium:

i. total investment is greater than in the non-strategic equilibrium.

ii. output is greater than in the non-strategic equilibrium.

iii. each firm earns less profit than in the non-strategic equilibrium.

Result iii. shows a similarity between the Brander and Spencer model, and the classic Prisoner's Dilemma. A firm that unilaterally ignores capital's strategic role will be victimized by a rival who strategically "overinvests" in capital in order to influence the outcome in the second stage Nash quantity game. But when both firms invest strategically, both experience lower profits than they would have in the naive, non-strategic equilibrium of the model.

Because the Nash-in-quantities duopoly equilibrium of stage two is imperfectly competitive (involving price above marginal cost), result ii shows that the strategic use of capital has the potential for being welfare-improving. If result iii's impact on profits is not too great, overall welfare could be greater in the strategic equilibrium than in the non-strategic equilibrium. Brander and Spencer also establish conditions on cost and revenue functions which insure that capital's strategic use will increase welfare.

3.3. The model of strategic capital investment with adjustment costs

In this section, we present our extension of the Brander and Spencer model. As in Brander and Spencer, two firms choose capital investment and output in a two-period model. Each firm chooses some level of irreversible capital investment in period 1. The first period's decisions are observed before the second period in which both output and additional capital investment are simultaneously chosen. Capital investment is subject to convex adjustment costs which, along with capital acquisition costs, are incurred in each period. Variable cost is incurred and revenue is realized in period 2. Note that production and sales are assumed to occur only in the second period. This assumption is made only to simplify the analysis: Qualitatively similar results would probably emerge from a model with first period production, too. However, even our simple model does incorporate the essential feature of convex adjustment costs: Firms have an incentive to build toward a target capital stock gradually over time.

The two firms are denoted 1 and 2 (or, if i denotes 1, then j represents 2 and *vice versa*). Each firm i produces output q^i at variable cost C^i, which includes all costs except capital acquisition and adjustment costs, and earns revenue R^i. Capital investment in period 1 is denoted $\tilde{K}_i$ and K_i denotes the ultimate capital stock. The purchase price of one unit of capital is w_K. In period 1, firm i incurs acquisition cost $w_K \tilde{K}_i$, and adjustment cost which is assumed to be quadratic in net investment, $\frac{d}{2}\tilde{K}_i^2$, where d is an adjustment cost parameter satisfying $d > 0$. In period 2, firms choose output q_i, and final capital stock, $K_i \geq \tilde{K}_i$ incurring additional capital acquisition costs, $w_K\left(K_i - \tilde{K}_i\right)$ and additional adjustment costs, $\frac{d}{2}(K_i - \tilde{K}_i)^2$. Total capital acquisition cost for both periods is $w_K K_i$.

The variable production cost function is $C^i(q_i, K_i)$. Marginal cost of output is increasing in output and decreasing in capital investment. The effect of an increase in cost-reducing capital investment is to reduce variable cost, given output, with the rate of decrease declining (in absolute value) as capital investment increases. Using subscripts to denote derivatives, these conditions are summarized as:

$C^i_{q_i}(q_i, K_i) > 0$, $C^i_{q_i q_i}(q_i, K_i) > 0$, $C^i_{K_i}(q_i, K_i) < 0$, $C^i_{K_i K_i}(q_i, K_i) > 0$,

$C^i_{q_i K_i}(q_i, K_i) < 0$, for $i = 1, 2$.

The revenues are assumed to depend on a firm's output and its rival's output. We assume that marginal revenues are decreasing in own outputs. Increases in the output of one good decrease the total and marginal revenue of the other. These conditions imply the following properties:

$R^i_{q_i q_i}(q_1, q_2) < 0$, $R^i_{q_j}(q_1, q_2) < 0$, $R^i_{q_i q_j}(q_1, q_2) < 0$, for $i = 1, 2$ and $i \neq j$.

Profit π^i of firm i is then given by

$$(3.6)\ \pi^i(q_1, q_2, K_i, \widetilde{K}_i) = R^i(q_1, q_2) - w_K K_i - C^i(q_i, K_i) - \frac{d}{2}(K_i - \widetilde{K}_i)^2 - \frac{d}{2}\widetilde{K}_i^2$$

Looking for a subgame perfect equilibrium[7] leads one to solve the stages by backward induction. Given the first period capital investment levels, $\widetilde{K}_1$ and $\widetilde{K}_2$, the ith firm will choose q_i and $K_i \geq \widetilde{K}_i$ to maximize $\pi^i(q_1, q_2, K_i, \widetilde{K}_i)$ taking q_j as given. Assuming both firms' solutions are interior solutions in the sense that $K_i > \widetilde{K}_i$ (and $q_i > 0$), the Nash equilibrium values for the second period choices, q_i and K_i, are described by first order conditions:[8]

$$(3.7)\ \pi^i_{q_i} = R^i_{q_i}(q_1, q_2) - C^i_{q_i}(q_i, K_i) = 0, \quad i = 1 \text{ and } 2.$$

$$(3.8)\ \pi^i_{K_i} = -w_K - C^i_{K_i}(q_i, K_i) - d(K_i - \widetilde{K}_i) = 0, \quad i = 1 \text{ and } 2.$$

Condition (3.7) says that, at the profit-maximizing choice of output, marginal revenue must equal marginal cost, given the total capital investment over the two periods. Rearranging the

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[7] The firms in our model are assumed to behave optimally (i.e., maximizing their profits) on the equilibrium path at each stage given rivals' strategies. Therefore firms in the equilibrium do not have the incentives to deviate from their strategies unilaterally.

[8] The assumptions made to this point are not sufficient to insure an interior solution. The intuition is as follows: If d were equal to zero, firms would face no incentive to smooth investment over time so the "strategic effect" (See the discussion accompanying equation (3.21) and Section 3.4's Proposition 1.) would induce firms to undertake all investment in the first period. On the other hand, with significant adjustment costs, firms would have an incentive to postpone a significant potion of their investment until the second period in order to economize on adjustment costs. As positive d approaches zero, the character of the optimum will jump discontinuously, at some point, from a roughly even distribution of investment across periods to a concentration of all investment in period 1. We assume that d is sufficiently large so that the local optimum, characterized by equations (3.7) and (3.8), is also a global optimum. That is, we assume that the optimal pattern of investment involves strictly positive investment in period 2 as well as in period 1.

first order condition for capital investment (3.8) gives

$w_K + d(K_i - \widetilde{K}_i) = -C^i_{K_i}(q_i, K_i)$, which implies that marginal acquisition cost plus marginal adjustment cost of an extra unit of capital equals the marginal savings in variable production cost. Second order sufficient conditions for strict global profit maxima in the second stage decision problems are,

$$(3.9)\ \pi^i_{q_iq_i} = R^i_{q_iq_i} - C^i_{q_iq_i} < 0, \quad \pi^i_{K_iK_i} = -C^i_{K_iK_i} - d < 0, \text{ and}$$

$$\left(\pi^i_{q_iq_i}\pi^i_{K_iK_i} - (\pi^i_{q_iK_i})^2\right) > 0, \ i = 1 \text{ and } 2.$$

The first two conditions are guaranteed by previous assumptions. The third is an additional assumption. The second period Nash equilibrium values for output and capital are obtained by simultaneous solution of (3.7) and (3.8) for i = 1 and 2. These optimal choices of q_i and K_i for firm i depend on the levels of capital investment in period 1, $\widetilde{K}_1$ and $\widetilde{K}_2$, and can be written as

$$(3.10)\ q^i = q^i(\widetilde{K}_1, \widetilde{K}_2);$$

$$K^i = K^i(\widetilde{K}_1, \widetilde{K}_2) \text{ for } i = 1 \text{ and } 2.$$

We seek additional reasonable restrictions for the static model by requiring stability of the dynamic model that results when a natural adjustment mechanism is incorporated (Dixit (1986)). Firms are assumed to adjust their second period decision variables in the direction of greater profit at a rate which is proportional to the magnitude of marginal profit. This leads to the following dynamic system:

$$(3.11)\quad \begin{aligned} \dot{q}^i &= s_i \pi^i_{q_i}\left(q_1, q_2, K_i, \widetilde{K}_i\right); \\ \dot{K}^i &= \theta_i \pi^i_{K_i}\left(q_1, q_2, K_i, \widetilde{K}_i\right), \text{ for } i = 1 \text{ and } 2. \end{aligned}$$

where "•" superscripts denote time derivatives and the parameters s_i and $\theta_i > 0$ are speeds of adjustment. Linearizing the system (3.11) about an equilibrium point, $\left(q_i^*, K_i^*\right)$, for i = 1, 2, we have

$$\begin{pmatrix} \dot{q}_1 \\ \dot{K}_1 \\ \dot{q}_2 \\ \dot{K}_2 \end{pmatrix} = \begin{pmatrix} s_1\pi^1_{q_1q_1} & s_1\pi^1_{q_1K_1} & s_1\pi^1_{q_1q_2} & 0 \\ \theta_1\pi^1_{q_1K_1} & \theta_1\pi^1_{K_1K_1} & 0 & 0 \\ s_2\pi^2_{q_2q_1} & 0 & s_2\pi^2_{q_2q_2} & s_2\pi^2_{q_2K_2} \\ 0 & 0 & \theta_2\pi^2_{q_2K_2} & \theta_2\pi^2_{K_2K_2} \end{pmatrix} \begin{pmatrix} q_1 - q_1^* \\ K_1 - K_1^* \\ q_2 - q_2^* \\ K_2 - K_2^* \end{pmatrix}$$

The necessary condition for stability of the dynamic system is that all of the eigenvalues of the coefficient matrix be negative in a neighborhood of equilibrium. For this to hold for all s_i and $\theta_i > 0$, the matrix A,

$$A \equiv \begin{bmatrix} \pi^1_{q_1q_1} & \pi^1_{q_1K_1} & \pi^1_{q_1q_2} & 0 \\ \pi^1_{q_1K_1} & \pi^1_{K_1K_1} & 0 & 0 \\ \pi^2_{q_2q_1} & 0 & \pi^2_{q_2q_2} & \pi^2_{q_2K_2} \\ 0 & 0 & \pi^2_{q_2K_2} & \pi^2_{K_2K_2} \end{bmatrix}$$

must be negative definite in a neighborhood of equilibrium. Thus the principal minors of order i (i = 1, 2, 3, 4) all have sign $(-1)^i$. In particular, the determinant of A is positive.

The variables $\widetilde{K}_1$, $\widetilde{K}_2$, q_1, q_2, K_1, and K_2 are all jointly determined endogenous variables. But it will be instructive to see how second period Nash equilibrium values for q_1, q_2, K_1, and K_2 change as first period investment levels change.[9] Totally differentiate (3.7),

[9]Imagine $\widetilde{K}_1$ and $\widetilde{K}_2$ being manipulated in an artificial experiment, for example.

and (3.8) with respect to $\tilde{K}_1$ to obtain the 4×4 simultaneous equation system:

$$(3.12)\quad \begin{pmatrix} \pi^1_{q_1q_1} & \pi^1_{q_1K_1} & \pi^1_{q_1q_2} & 0 \\ \pi^1_{q_1K_1} & \pi^1_{K_1K_1} & 0 & 0 \\ \pi^2_{q_2q_1} & 0 & \pi^2_{q_2q_2} & \pi^2_{q_2K_2} \\ 0 & 0 & \pi^2_{q_2K_2} & \pi^2_{K_2K_2} \end{pmatrix} \begin{pmatrix} \frac{\partial q_1}{\partial \tilde{K}_1} \\ \frac{\partial K_1}{\partial \tilde{K}_1} \\ \frac{\partial q_2}{\partial \tilde{K}_1} \\ \frac{\partial K_2}{\partial \tilde{K}_1} \end{pmatrix} = \begin{pmatrix} 0 \\ -d \\ 0 \\ 0 \end{pmatrix}$$

Applying Cramer's rule to (3.12), we get

$$(3.13)\quad \frac{\partial q_1}{\partial \tilde{K}_1} = \frac{d}{\det A}\pi^1_{q_1K_1}\left(\pi^2_{q_2q_2}\pi^2_{K_2K_2} - \left(\pi^2_{q_2K_2}\right)^2\right),$$

which is positive because d, det A, $\pi^1_{q_1K_1} = -C^1_{q_1K_1}$, and $\left(\pi^2_{q_2q_2}\pi^2_{K_2K_2} - \left(\pi^2_{q_2K_2}\right)^2\right)$ are all positive (the last by the second order sufficient condition for profit maximization).

Another application of Cramer's rule to equation (3.12) yields

$$(3.14)\quad \frac{\partial q_2}{\partial \tilde{K}_1} = -\frac{d}{\det A}\pi^2_{K_2K_2}\pi^2_{q_1q_2}\pi^1_{q_1K_1},$$

which is negative because, in addition to signs noted above, we have $\pi^2_{K_2K_2} < 0$ by (3.9) and $\pi^2_{q_1q_2} = R^2_{q_1q_2} < 0$.

Similarly, totally differentiating equation (3.7) and (3.8) with respect to $\tilde{K}_2$ and solving by Cramer's rule yields

$$(3.15)\quad \frac{\partial q_2}{\partial \tilde{K}_2} = \frac{d}{\det A}\pi^2_{q_2K_2}\left(\pi^1_{q_1q_1}\pi^1_{K_1K_1} - \left(\pi^1_{q_1K_1}\right)^2\right) > 0,$$

$$(3.16)\quad \frac{\partial q_1}{\partial \tilde{K}_2} = -\frac{d}{\det A}\pi^1_{K_1K_1}\pi^1_{q_1q_2}\pi^2_{q_2K_2} < 0.$$

Equations (3.13) through (3.16) tell us that firm i's Nash equilibrium level of output is increasing in its own first-period capital investment and decreasing in the rival's first-period capital investment. The effect of one firm's period 1 investment on industry output is given by

$$(3.17)\ \frac{\partial(q_i + q_j)}{\partial \tilde{K}_i} = \frac{d}{\det A}\pi^i_{q_i K_i}\left[\pi^j_{q_j q_j}\pi^j_{K_j K_j} - \left(\pi^j_{q_j K_j}\right)^2 - \pi^j_{K_j K_j}\pi^j_{q_i q_j}\right],$$

whose sign is ambiguous, because the sign of the square bracket term of the equation (3.17) is not determined. But, for the symmetric case, the sign will be shown later to be positive.

Equation (3.12) can also be solved for $\frac{\partial K_1}{\partial \tilde{K}_1}$. Generalizing to i = 1 or 2 we have

$$(3.18)\ \frac{\partial K_i}{\partial \tilde{K}_i} = -\frac{d}{\det A}\left[\pi^i_{q_i q_i}\left(\pi^j_{q_j q_j}\pi^j_{K_j K_j} - \left(\pi^j_{q_j K_j}\right)^2\right) - \pi^i_{q_i q_j}\pi^j_{q_j q_i}\pi^j_{K_j K_j}\right]$$

Since the term in square bracket of the equation (3.18) is a third order principal minor of A, the stability conditions require it to be negative. The sign of (3.18) is therefore positive. Likewise, the effect of $\tilde{K}_i$ on the rival's total capital investment is

$$(3.19)\ \frac{\partial K_j}{\partial \tilde{K}_i} = \frac{d}{\det A}\pi^j_{q_j K_j}\pi^j_{q_i q_j}\pi^i_{q_i K_i} < 0$$

The results in equations (3.18) and (3.19) show that an increase in capital investment for firm i in period 1 increases its total capital investment but reduces its rival's total capital investment for the two periods combined.

Strategic firms are aware of the dependence of output and capital investment decisions in the second period on capital investment in the first period. Now, to solve for the first period Nash equilibrium in the strategic model, we substitute (3.10) into (3.6) and write the profit functions as functions of capital investments in the first period:

(3.20) $g^i(\tilde{K}_1, \tilde{K}_2) \equiv \pi^i\left(q_1(\tilde{K}_1, \tilde{K}_2), q_2(\tilde{K}_1, \tilde{K}_2), K_i(\tilde{K}_1, \tilde{K}_2), \tilde{K}_i\right)$, for i= 1, 2.

From equation (3.20), assuming an interior optimum, the first-order conditions for a profit-maximizing choice of $\tilde{K}_i$, given $\tilde{K}_j$, are

(3.21) $g^i_{\tilde{K}_i}(\tilde{K}_1, \tilde{K}_2) = \pi^i_{q_i}\dfrac{\partial q_i}{\partial \tilde{K}_i} + \pi^i_{q_j}\dfrac{\partial q_j}{\partial \tilde{K}_i} + \pi^i_{K_i}\dfrac{\partial K_i}{\partial \tilde{K}_i} + \pi^i_{\tilde{K}_i} = 0$, for $i = 1, 2$ and $i \neq j$.

This implies $\pi^i_{q_j}\dfrac{\partial q_j}{\partial \tilde{K}_i} + \pi^i_{\tilde{K}_i} = 0$ (because $\pi^i_{q_i} = \pi^i_{K_i} = 0$ by the envelope theorem).

This result can be decomposed into two effects. The direct effect, $\pi^i_{\tilde{K}_i}$, would exist even if firm i's investment in period 1 were not observed by firm j before the choice of q_j, and therefore could not affect q_j. The strategic effect, $\pi^i_{q_j}\dfrac{\partial q_j}{\partial \tilde{K}_i}$, results from the influence of the first period investment on firm j's second period action.

We also have the second-order sufficient conditions for a strict local maximum which take the form:

(3.22) $g^i_{\tilde{K}_i\tilde{K}_i}(\tilde{K}_1, \tilde{K}_2) < 0$, for $i = 1, 2$.

Again adding the standard dynamic adjustment process leads to the following,

(3.23) $\dot{\tilde{K}}_i = s_i g^i_{\tilde{K}_i}(\tilde{K}_1, \tilde{K}_2)$ for $i = 1, 2$ where $s_i > 0$.

Taking linear approximations around an equilibrium point $(\tilde{K}_1^*, \tilde{K}_2^*)$ yields

$$(3.24)\quad \begin{pmatrix} \dot{\tilde{K}}_1 \\ \dot{\tilde{K}}_2 \end{pmatrix} = \begin{pmatrix} s_1 g^1_{\tilde{K}_1\tilde{K}_1} & s_1 g^1_{\tilde{K}_1\tilde{K}_2} \\ s_2 g^2_{\tilde{K}_2\tilde{K}_1} & s_2 g^2_{\tilde{K}_2\tilde{K}_2} \end{pmatrix} \begin{pmatrix} \tilde{K}_1 - \tilde{K}_1^* \\ \tilde{K}_2 - \tilde{K}_2^* \end{pmatrix}$$

As before, the stability condition for the reaction function equilibrium for the model is that the coefficient matrix should have negative eigenvalues. Necessary conditions for this to hold for all positive s_1 and s_2 include the second order sufficient conditions for a strict local maximum, $g^1_{\tilde{K}_1\tilde{K}_1}$ and $g^2_{\tilde{K}_2\tilde{K}_2} < 0$ as well as:

$$(3.25)\quad \left(g^1_{\tilde{K}_1\tilde{K}_1} g^2_{\tilde{K}_2\tilde{K}_2} - g^1_{\tilde{K}_1\tilde{K}_2} g^2_{\tilde{K}_1\tilde{K}_2}\right) > 0.$$

To summarize, the "strategic" equilibrium for the model is determined as follows. Optimal values for $\tilde{K}_1$ and $\tilde{K}_2$ denoted by $\tilde{K}_1^S$ and $\tilde{K}_2^S$, are determined by simultaneous solution of equations (3.21) for i = 1 and 2. Substituting these into the functions (3.10) yields strategic optimal values for q_i, and K_i :

$$(3.26)\quad q_i^S = q_i(\tilde{K}_1^S, \tilde{K}_2^S);$$

$$K_i^S = K_i(\tilde{K}_1^S, \tilde{K}_2^S) \quad \text{for } i = 1 \text{ and } 2.$$

Several results proved in the next section examine capital's strategic role through a comparison of the strategic equilibrium with the model's "non-strategic" equilibrium wherein first-period investment is not used to influence the outcome of the second period Nash quantity and investment game. This equilibrium is best thought of as the solution for a version of the model in which the rival's first period investment is not observed before second period choices are made or, equivalently, in which firm i chooses $\tilde{K}_i$, q_i, and K_i

simultaneously in a Nash game with firm j. Nonstrategic equilibrium values, identified by "N" superscripts are simultaneously determined by the first-order conditions below.

$$(3.27)\quad \pi^1_{q_1}(q_1^N, q_2^N, K_1^N, \tilde{K}_1^N) = 0$$

$$\pi^1_{K_1}(q_1^N, q_2^N, K_1^N, \tilde{K}_1^N) = 0$$

$$\pi^2_{q_2}(q_1^N, q_2^N, K_2^N, \tilde{K}_2^N) = 0$$

$$\pi^2_{K_2}(q_1^N, q_2^N, K_2^N, \tilde{K}_2^N) = 0$$

$$\pi^1_{\tilde{K}_1}(q_1^N, q_2^N, K_1^N, \tilde{K}_1^N) = 0$$

$$\pi^2_{\tilde{K}_2}(q_1^N, q_2^N, K_2^N, \tilde{K}_2^N) = 0$$

Note that the first four of these are the equations determining q_i^S, and K_i^S, for i = 1 and 2, except that $\tilde{K}_i^N$ replaces $\tilde{K}_i^S$. So we also have the results.

$$(3.28)\quad q_i^N = q_i(\tilde{K}_1^N, \tilde{K}_2^N);$$

$$K_i^N = K_i(\tilde{K}_1^N, \tilde{K}_2^N) \text{ for } i = 1 \text{ and } 2,$$

where $q_i(\bullet)$ and $K_i(\bullet)$ are the same functions appearing in (3.10).[10]

3.4. Results

We present our model's extensions of Brander and Spencer's results in this section.

[10]The interpretation of equations (3.28) is slightly different, however, than that of their counterparts for the strategic equilibrium. In that case, they prescribed Nash equilibrium values for q_i and K_i, i = 1 and 2, given $\tilde{K}_1$ and $\tilde{K}_2$ chosen in a previous stage. In the non-strategic equilibrium, all six decision variables are chosen simultaneously. Equations (3.28) merely state some relationships that must be satisfied by equilibrium values.

The first Proposition shows that the strategic use of capital leads to "overinvestment" in a specific sense. Subsequently, Propositions 2, 3, and 4 establish some comparisons between the model's strategic and non-strategic equilibria in the case of symmetric firms.

Proposition 1: For a given total amount of capital investment for firm i, strategic behavior induces the firm to use more capital investment in the first period, $\tilde{K}_i$, than the amount that would minimize adjustment costs.

Proof: Adjustment cost-minimizing capital investment in the first period, $\tilde{K}_i$, for given $K_i = K_i^S$, is the solution to $\pi^i_{\tilde{K}_i} = d(K_i^S - \tilde{K}_i) - d\tilde{K}_i = 0$ yielding $\tilde{K}_i = K_i^S/2$.

Note that $\pi^i_{\tilde{K}_i\tilde{K}_i} = -2d < 0$.

However, strategic capital investment in period 1, $\tilde{K}_i^S$, satisfies (3.21) so that

$\pi^i_{\tilde{K}_i} = -\pi^i_{q_j}\dfrac{\partial q_j}{\partial \tilde{K}_i} < 0$, because $\pi^i_{q_j} = R^i_{q_j} < 0$ by our model's assumption and $\dfrac{\partial q_j}{\partial \tilde{K}_i} < 0$ by (3.14) or (3.16). Because the profit function is locally concave in $\tilde{K}_i$ (i.e., $\pi^i_{\tilde{K}_i\tilde{K}_i} < 0$), this requires $\tilde{K}_i^S > K_i^S/2$, which means that the strategic capital investment level exceeds the adjustment cost minimizing investment level in period 1. *Q.E.D.*

Proposition 2: Assuming symmetry,[11] each firm undertakes more period 1 capital investment in the strategic equilibrium than in the non-strategic equilibrium.

[11]Symmetry means that firms face symmetric revenue and cost functions leading to the result that they have identical equilibrium levels of output and first-period and overall capital investment.

Proof: Applying Taylor's theorem to the marginal profit functions, $g^i_{\tilde{K}_i}(\tilde{K}_1, \tilde{K}_2)$, from (3.21) there exists a point, $(\tilde{K}_1^*, \tilde{K}_2^*)$, on the line segment connecting $(\tilde{K}_1^S, \tilde{K}_2^S)$ and $(\tilde{K}_1^N, \tilde{K}_2^N)$ such that

$$(3.29)\quad \begin{aligned} &g^1_{\tilde{K}_1}(\tilde{K}_1^S, \tilde{K}_2^S) - g^1_{\tilde{K}_1}(\tilde{K}_1^N, \tilde{K}_2^N) = \\ &\quad g^1_{\tilde{K}_1\tilde{K}_1}(\tilde{K}_1^*, \tilde{K}_2^*)(\tilde{K}_1^S - \tilde{K}_1^N) + g^1_{\tilde{K}_1\tilde{K}_2}(\tilde{K}_1^*, \tilde{K}_2^*)(\tilde{K}_2^S - \tilde{K}_2^N). \end{aligned}$$

Likewise,

$$\begin{aligned} &g^2_{\tilde{K}_2}(\tilde{K}_1^S, \tilde{K}_2^S) - g^2_{\tilde{K}_2}(\tilde{K}_1^N, \tilde{K}_2^N) = \\ &\quad g^2_{\tilde{K}_2\tilde{K}_1}(\tilde{K}_1^*, \tilde{K}_2^*)(\tilde{K}_1^S - \tilde{K}_1^N) + g^2_{\tilde{K}_2\tilde{K}_2}(\tilde{K}_1^*, \tilde{K}_2^*)(\tilde{K}_2^S - \tilde{K}_2^N). \end{aligned}$$

Rewrite (3.29) as $\Delta g^i_{\tilde{K}_i} = g^i_{\tilde{K}_i\tilde{K}_1}(*)\Delta\tilde{K}_1 + g^i_{\tilde{K}_i\tilde{K}_j}(*)\Delta\tilde{K}_2$ for i = 1 and 2 where $\Delta g^i_{\tilde{K}_i} = g^i_{\tilde{K}_i}(\tilde{K}_1^S, \tilde{K}_2^S) - g^i_{\tilde{K}_i}(\tilde{K}_1^N, \tilde{K}_2^N)$, $\Delta K_i = \tilde{K}_i^S - \tilde{K}_i^N$ and the "*" denotes evaluation of the function at $(\tilde{K}_1^*, \tilde{K}_2^*)$. Solving (3.29) simultaneously yields

$$(3.30)\quad \Delta\tilde{K}_i = \left(\Delta g^i_{\tilde{K}_i} g^j_{\tilde{K}_j\tilde{K}_j}(*) - \Delta g^j_{\tilde{K}_j} g^i_{\tilde{K}_i\tilde{K}_j}(*)\right) \Big/ D, \text{ for } i = 1, 2.$$

where $D = \left[g^1_{\tilde{K}_1\tilde{K}_1}(*)g^2_{\tilde{K}_2\tilde{K}_2}(*) - g^1_{\tilde{K}_1\tilde{K}_2}(*)g^2_{\tilde{K}_2\tilde{K}_1}(*)\right] > 0$ by (3.25).[12]

Adding up the equation (3.30) for i = 1 and 2, yields

$$(3.31)\quad \Delta\tilde{K}_1 + \Delta\tilde{K}_2 = \left[\left(g^2_{\tilde{K}_2\tilde{K}_2}(*) - g^2_{\tilde{K}_2\tilde{K}_1}(*)\right)\Delta g^1_{\tilde{K}_1} + \left(g^1_{\tilde{K}_1\tilde{K}_1}(*) - g^1_{\tilde{K}_1\tilde{K}_2}(*)\right)\Delta g^2_{\tilde{K}_2}\right] \Big/ D.$$

---

[12] Here, and in similar applications of this technique in Proposition 3 and 4, we are assuming that the stability condition of (3.25) holds in a neighborhood of $(\tilde{K}_1^S, \tilde{K}_2^S)$ sufficiently large to include $(\tilde{K}_1^*, \tilde{K}_2^*)$.

By symmetry, $g^1_{\tilde{K}_1\tilde{K}_2}(*) = g^2_{\tilde{K}_2\tilde{K}_1}(*)$, $g^1_{\tilde{K}_1\tilde{K}_1}(*) = g^2_{\tilde{K}_2\tilde{K}_2}(*) < 0$ where the inequality is due to (3.22). Also, referring to the second-order sufficient conditions in (3.25), we have

$\left|g^i_{\tilde{K}_i\tilde{K}_i}(*)\right| > \left|g^i_{\tilde{K}_i\tilde{K}_j}(*)\right|$ so that

(3.32) $\left(g^i_{\tilde{K}_i\tilde{K}_i}(*) - g^i_{\tilde{K}_i\tilde{K}_j}(*)\right) < 0$ for i = 1 and 2, where $j \neq i$.

Now rearranging the right-hand side of the equation (3.29) reduces to

$\Delta g^i_{\tilde{K}_i} = g^i_{\tilde{K}_i}(\tilde{K}^S_1, \tilde{K}^S_2) - g^i_{\tilde{K}_i}(\tilde{K}^N_1, \tilde{K}^N_2) = -g^i_{\tilde{K}_i}(\tilde{K}^N_1, \tilde{K}^N_2)$, because $g^i_{\tilde{K}_i}(\tilde{K}^S_1, \tilde{K}^S_2) = 0$ by the definition of $\tilde{K}^S_i$. Also

$$
\begin{aligned}
g^i_{\tilde{K}_i}(\tilde{K}^N_1, \tilde{K}^N_2) &= \pi^i_{q_i}(q^N_1, q^N_2, K^N_1, K^N_2)\frac{\partial q_i}{\partial \tilde{K}_i} + \pi^i_{q_j}(q^N_1, q^N_2, K^N_1, K^N_2)\frac{\partial q_j}{\partial \tilde{K}_i} \\
&\quad + \pi^i_{K_i}(q^N_1, q^N_2, K^N_1, K^N_2)\frac{\partial K_i}{\partial \tilde{K}_i} + \pi^i_{\tilde{K}_i}(q^N_1, q^N_2, K^N_1, K^N_2) \qquad (3.33) \\
&= \pi^i_{q_j}(q^N_1, q^N_2, K^N_1, K^N_2)\frac{\partial q_j}{\partial \tilde{K}_i} = R^i_{q_j}\frac{\partial q_j}{\partial \tilde{K}_i} > 0,
\end{aligned}
$$

where the second equality sign follows from the envelop theorem (using the relations in (3.27)) and the inequality uses $R^i_{q_j} < 0$ from our model's assumption and (3.9) or (3.11). As a result, the equation (3.29) turns out to be $\Delta g^i_{\tilde{K}_i} = -g^i_{\tilde{K}_i}(\tilde{K}^N_1, \tilde{K}^N_2) < 0$.

Returning to (3.31) and using the result from (3.32), it follows that $\Delta\tilde{K}_1 + \Delta\tilde{K}_2 > 0$ which implies $\Delta\tilde{K}_1, \Delta\tilde{K}_2 > 0$ by the symmetry condition. Therefore we have

$\tilde{K}^S_i > \tilde{K}^N_i$ for i = 1 and 2. *Q.E.D.*

Proposition 3: Assuming symmetry, firm i's total output and total capital investment (throughout the two periods) are larger in the strategic equilibrium than in the non-strategic equilibrium.

Proof: By Taylor's theorem, there exists a point $\left(\tilde{K}_1^{*}, \tilde{K}_2^{*}\right)$ on the line segment connecting $\left(\tilde{K}_1^{S}, \tilde{K}_2^{S}\right)$ and $\left(\tilde{K}_1^{N}, \tilde{K}_2^{N}\right)$ such that

$$q_1^S - q_1^N = \frac{\partial q_1}{\partial \tilde{K}_1}\left(\tilde{K}_1^{*}, \tilde{K}_2^{*}\right)\left(\tilde{K}_1^{S} - \tilde{K}_1^{N}\right) + \frac{\partial q_1}{\partial \tilde{K}_2}\left(\tilde{K}_1^{*}, \tilde{K}_2^{*}\right)\left(\tilde{K}_2^{S} - \tilde{K}_2^{N}\right)$$

$$= \left(\tilde{K}_1^{S} - \tilde{K}_1^{N}\right)\left[\frac{\partial q_1}{\partial \tilde{K}_1}\left(\tilde{K}_1^{*}, \tilde{K}_2^{*}\right) + \frac{\partial q_2}{\partial \tilde{K}_1}\left(\tilde{K}_1^{*}, \tilde{K}_2^{*}\right)\right] = q_2^S - q_2^N, \tag{3.34}$$

by the symmetry assumption.

Likewise, there exists a point $\left(\tilde{K}_1^{*}, \tilde{K}_2^{*}\right)$ on the line segment connecting $\left(\tilde{K}_1^{S}, \tilde{K}_2^{S}\right)$ and $\left(\tilde{K}_1^{N}, \tilde{K}_2^{N}\right)$ such that

$$K_1^S - K_1^N = \left(\tilde{K}_1^{S} - \tilde{K}_1^{N}\right)\left[\frac{\partial K_1}{\partial \tilde{K}_1}\left(\tilde{K}_1^{*}, \tilde{K}_2^{*}\right) + \frac{\partial K_2}{\partial \tilde{K}_1}\left(\tilde{K}_1^{*}, \tilde{K}_2^{*}\right)\right] = K_2^S - K_2^N \tag{3.35}$$

By Proposition 2, $\left(\tilde{K}_1^{S} - \tilde{K}_1^{N}\right) > 0$. The remaining problem is to sign the terms in square brackets in (3.34) and (3.35). For simplicity, the A matrix as defined on page 25 can be expressed in the symmetric case as:

$$A = \begin{bmatrix} \pi^1_{q_1q_1} & \pi^1_{q_1K_1} & \pi^1_{q_1q_2} & 0 \\ \pi^1_{q_1K_1} & \pi^1_{K_1K_1} & 0 & 0 \\ \pi^2_{q_2q_1} & 0 & \pi^2_{q_2q_2} & \pi^2_{q_2K_2} \\ 0 & 0 & \pi^2_{q_2K_2} & \pi^2_{K_2K_2} \end{bmatrix} \equiv \begin{bmatrix} \alpha & \beta & \gamma & 0 \\ \beta & \delta & 0 & 0 \\ \gamma & 0 & \alpha & \beta \\ 0 & 0 & \beta & \delta \end{bmatrix}$$

where α, β, γ, and δ are defined in the obvious way.

By recalling (3.17), (3.18) and (3.19) with symmetry, we have

$$(3.36)\quad \frac{\partial(q_1+q_2)}{\partial\tilde{K}_1}=\frac{d}{\det A}\beta(\alpha\delta-\beta^2-\delta\gamma)$$

$$(3.37)\quad \frac{\partial(K_1+K_2)}{\partial\tilde{K}_1}=\frac{d}{\det A}(-(\alpha+\gamma))(\alpha\delta-\beta^2-\delta\gamma)$$

To determine the signs of (3.36) and (3.37), we rely on the stability condition discussed on page 25. In particular, the determinant of A must be positive. Thus it follows that

$$(3.38)\quad (\alpha\delta-\beta^2)^2-\gamma^2\delta^2=(\alpha\delta-\beta^2-\gamma\delta)(\alpha\delta-\beta^2+\gamma\delta)>0.$$

Now $\alpha\delta-\beta^2>0$ and $\delta<0$ by (3.9), and $\gamma=R^i_{q_1q_i}<0$ as assumed in our model, so we have $(\alpha\delta-\beta^2+\gamma\delta)>0$. But then (3.38) implies that

$$(3.39)\quad (\alpha\delta-\beta^2-\gamma\delta)>0.$$

The stability condition in page 25 also requires that the second order principal minor of A involving that the first and third columns and rows be positive: $(\alpha^2-\gamma^2)>0$. So $|\alpha|>|\gamma|$. But we know $\alpha=\pi^i_{qiqi}<0$ by (3.9), hence

$$(3.40)\quad (\alpha+\gamma)<0$$

Combining (3.39) and (3.40) with $d>0$, $\det A>0$, and $\beta=-C^i_{q_iK_i}>0$, we can determine the signs of square brackets in (3.34) and (3.35) to be positive, therefore, the equation, (3.34) and (3.35), are positive respectively. *Q.E.D.*

Because the second stage of the game involves two decision variables for each of the two firms, visualizing the geometry of the reaction function equilibrium is difficult. One kind of graphical interpretation of Proposition 3 can be achieved using "conditional" best response functions denoted, for firm i, by $r^i(q_j, K_i)$ and defined as firm i's optimal output conditional on capital stock K_i, and given that firm j produces q_j. These conditional best response functions are implicitly defined by[13]

(3.41) $\pi^1_{q_1}\left(r^1(q_2, K_1), q_2, K_1\right) \equiv 0$ and

(3.42) $\pi^2_{q_2}\left(q_1, r^2(q_1, K_2), K_2\right) \equiv 0.$

q_1^S and q_2^S are determined by the intersection in the (q_1, q_2) plane, of $r^1(q_2, K_1^S)$ and $r^2(q_1, K_1^S)$. Similarly, q_1^N and q_2^N are determined by the intersection of $r^1(q_2, K_1^N)$ and $r^2(q_1, K_2^N)$. Differentiating (3.41) with respect to q_2 and K_1, we have

(3.43) $\dfrac{\partial r^1}{\partial q_2}(q_2, K_1) = -\dfrac{\pi^1_{q_1q_2}}{\pi^1_{q_1q_1}} < 0$ and $\dfrac{\partial r^1}{\partial K_1}(q_2, K_1) = -\dfrac{\pi^1_{q_1K_1}}{\pi^1_{q_1q_1}} > 0.$

Likewise, differentiating (3.42) with respect to q_1 and K_2, we also have:

$$\frac{\partial r^2}{\partial q_1}(q_1, K_2) < 0 \text{ and } \frac{\partial r^2}{\partial K_2}(q_1, K_2) > 0.$$

Conditional best response functions slope downward and shift outward as capital increases (See figure 2). Proposition 3 establishes that $K_i^S > K_i^N$ for i = 1 and 2, in the symmetric case, so the conditional best response functions shift out in going from the non-strategic to strategic equilibrium. This is consistent, as Figure 2 shows (and Proposition 3 proves), with $q_i^S > q_i^N$ for i = 1 and 2.

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[13] Note that $\pi^i_{q_i}$ does not depend on $\tilde{K}_i$ except through K_i.

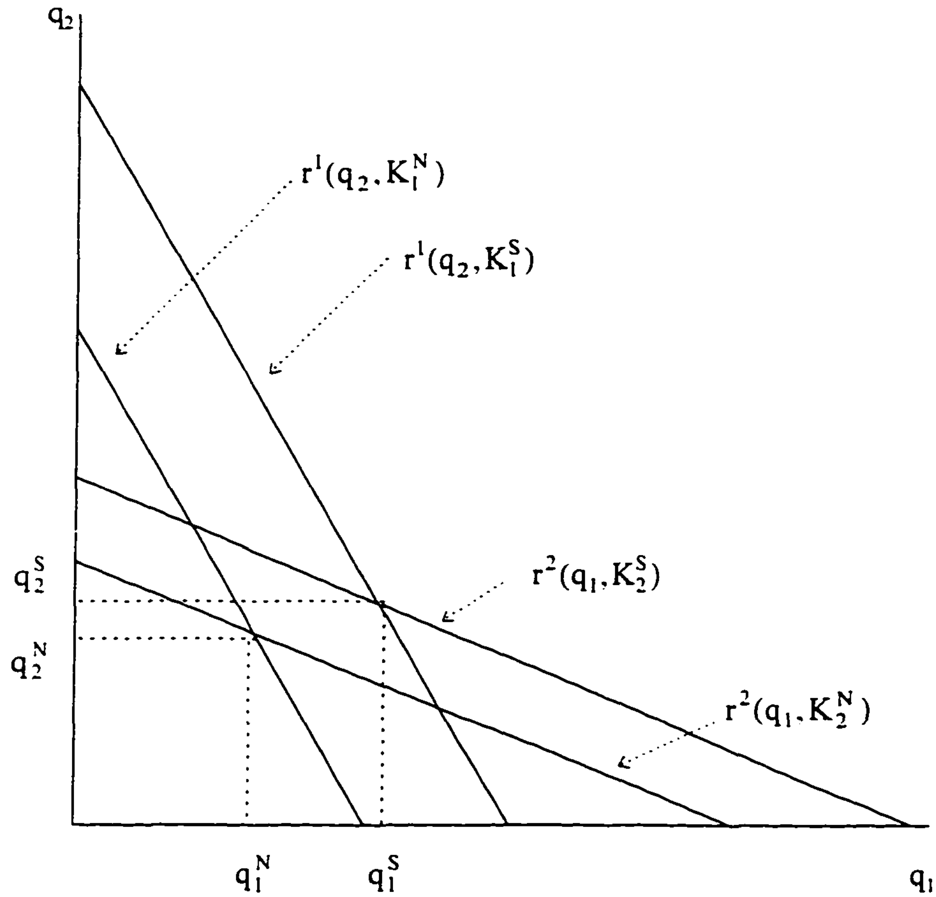

Figure 2. Comparison of the strategic and non-strategic equilibria

Proposition 4: Assuming symmetry, firms earn less profit at the strategic equilibrium than at non-strategic equilibrium.

Proof: Applying Taylor's theorem to the profit function $\pi^i = g^i(\tilde{K}_1, \tilde{K}_2)$, there exists a point $(\tilde{K}_1^*, \tilde{K}_2^*)$ on the line segment connecting $(\tilde{K}_1^S, \tilde{K}_2^S)$ and $(\tilde{K}_1^N, \tilde{K}_2^N)$ such that

$$(3.44)\quad \begin{aligned} & g^i(\tilde{K}_1^S, \tilde{K}_2^S) - g^i(\tilde{K}_1^N, \tilde{K}_2^N) = \\ & g^i_{\tilde{K}_i}(\tilde{K}_1^*, \tilde{K}_2^*)(\tilde{K}_i^S - \tilde{K}_i^N) + g^i_{\tilde{K}_j}(\tilde{K}_1^*, \tilde{K}_2^*)(\tilde{K}_j^S - \tilde{K}_j^N). \end{aligned}$$

Rewriting (3.44) as,

$$(3.45)\quad \Delta g^i = g^i_{\tilde{K}_i}(*)\Delta\tilde{K}_i + g^i_{\tilde{K}_j}(*)\Delta\tilde{K}_j = \left(g^i_{\tilde{K}_i}(*) + g^i_{\tilde{K}_j}(*)\right)\Delta\tilde{K}_1,$$

where the second equality follows because $\Delta\tilde{K}_1 = \Delta\tilde{K}_2$ under symmetry.

Now $g^i_{\tilde{K}_i}(*) = \pi^i_{q_i}(*)\dfrac{\partial q_i}{\partial \tilde{K}_i} + \pi^i_{q_j}(*)\dfrac{\partial q_j}{\partial \tilde{K}_i} + \pi^i_{K_i}(*)\dfrac{\partial K_i}{\partial \tilde{K}_i} + \pi^i_{\tilde{K}_i}(*) = \pi^i_{q_j}(*)\dfrac{\partial q_j}{\partial \tilde{K}_i} + \pi^i_{\tilde{K}_i}(*)$.

where, for example, $\pi^i_{q_i}(*) \equiv \pi^i_{q_i}\left(q_1(\tilde{K}_1^*, \tilde{K}_2^*), q_2(\tilde{K}_1^*, \tilde{K}_2^*), K_1(\tilde{K}_1^*, \tilde{K}_2^*), \tilde{K}_1^*\right)$, and

$\pi^i_{q_i}(*) = \pi^i_{K_i}(*) = 0$ by the envelope theorem.

Likewise, $g^i_{\tilde{K}_j}(*) = \pi^i_{q_i}(*)\dfrac{\partial q_i}{\partial \tilde{K}_j} + \pi^i_{q_j}(*)\dfrac{\partial q_j}{\partial \tilde{K}_j} + \pi^i_{K_i}(*)\dfrac{\partial K_i}{\partial \tilde{K}_j} = \pi^i_{q_j}(*)\dfrac{\partial q_j}{\partial \tilde{K}_j}$ by the envelope theorem. Therefore the equation, (3.45), can be written as

$$(3.46)\quad \Delta g^i = \left[\pi^i_{q_j}(*)\left(\frac{\partial q_j}{\partial \tilde{K}_i} + \frac{\partial q_j}{\partial \tilde{K}_j}\right) + \pi^i_{\tilde{K}_i}(*)\right]\Delta\tilde{K}_1 = \left[\pi^i_{q_j}(*)\frac{\partial(q_i + q_j)}{\partial \tilde{K}_i} + \pi^i_{\tilde{K}_i}(*)\right]\Delta\tilde{K}_1$$

because $\dfrac{\partial q_j}{\partial \tilde{K}_j} = \dfrac{\partial q_i}{\partial \tilde{K}_i}$ by symmetry. Now $\pi^i_{q_j}(*) = R^i_{q_j}(*) < 0$. Also, as shown in the proof of

Proposition 1. $\pi^{i}_{\tilde{K}_i} < 0$ between $\left(\tilde{K}_1^S, \tilde{K}_2^S\right)$ and $\left(\tilde{K}_1^N, \tilde{K}_2^N\right)$ and therefore at $\left(\tilde{K}_1^{\bullet}, \tilde{K}_2^{\bullet}\right)$. From the proof of Proposition 3, $\frac{\partial\left(q_i + q_j\right)}{\partial\tilde{K}_i} > 0$. Finally, by Proposition 2, $\Delta\tilde{K}_1$ is positive. Using these results in (3.46) leads to $\Delta g^i < 0$, which implies $\pi_i^S < \pi_i^N$. *Q.E.D.*

3.5. Conclusion

This chapter generalizes Brander and Spencer's (1983) model of firms' strategic investment behavior by allowing for investment over time subject to convex adjustment costs. In the symmetric duopoly case, several features of the strategic equilibrium contrast with results for the naive equilibrium in which firms fail to exploit capitals' strategic role: i) Strategic firms "overinvest" in the first period in the sense that the initial investment in capital is larger than necessary to minimize adjustment costs. ii) In the strategic equilibrium, output and overall capital investment (for both periods combined) is larger than in the non-strategic equilibrium. Because the output market equilibrium is imperfectly competitive, this raises the possibility that welfare might be higher in the strategic equilibrium than in the non-strategic equilibrium. iii) Strategic firms face a situation reminiscent, in one respect, of the familiar "Prisoner's Dilemma" game. A firm can benefit by unilaterally "overinvesting" in order to influence the market outcome in a subsequent stage. But when both pursue these incentives, profits fall for both.

Beyond these modest generalizations of Brander and Spencer's results, the model yields an insight which will be useful in formulating the dynamic cost of adjustment model to be developed in subsequent chapters. That insight is captured by equation (3.21), which we reproduce here for convenience.

$$(3.21)\quad g^i_{\tilde{K}_i}\left(\tilde{K}_1, \tilde{K}_2\right) = \pi^i_{q_j}\frac{\partial q_j}{\partial \tilde{K}_i} + \pi^i_{\tilde{K}_i} = 0.$$

Again, firm i's first-order condition for optimal first period investment involves two effects. The direct effect (represented by $\pi^i_{\tilde{K}_i}$) accounts for the firm's incentive to economize on adjustment costs. The indirect, or "strategic," effect (represented by $\pi^i_{q_j}\frac{\partial q_j}{\partial \tilde{K}_i}$) anticipates firm j's future reaction to today's investment decision by firm i and recognizes that that reaction may have an independent effect on firm i's profit.

Our dynamic cost of adjustment model will involve a multi-firm, multi-stage generalization of the model of this chapter. We will not explicitly solve for the subgame perfect Nash equilibrium for this model. But, drawing upon lessons learned from the simple model, we will incorporate a strategic effect, similar to that in equation (3.21), in the dynamic adjustment cost model's first order condition for optimal investment.[14]

[14] Investment by firm i in one period will be allowed to trigger arbitrary rivals' quantity responses in the next period which, in turn, affect firm i through their effect on next period's price.

CHAPTER 4. EMPIRICAL MODEL I: THEORETICAL FOUNDATIONS

In this chapter we will lay out the theoretical foundations of our empirical models for the measurement of market power. Particularly, we analyze the intertemporal nature of the capital investment decision arising from both capital adjustment cost and strategic interactions among firms. In establishing a comprehensive framework, we will be aware of how modeling dynamic behavior of capital investment away from standard static models can lead to both different results and interpretations and how inferences of market power differ across models.

Let us assume a representative firm produces a single output y^j using two variable inputs: labor (L^j), and materials (M^j) at prices, w_L, and w_M; and the services of stocks of quasi-fixed capital (K^j), where j =1, 2,..., n indexes firms. The quantities of the variable factors employed can be costlessly changed without delay, whereas the stock of the quasi-fixed input is costly to adjust.

The production technology is represented by a variable cost function which specifies the minimum expenditure on variable factors needed to produce $y^j(s)$, given the amount of the quasi-fixed factor $K^j(s)$:

(4.1) $c^j_v = C^j_v(w_L(s), w_M(s), K^j(s), y^j(s), s) = w(s) L^j(s) + w_M(s) M^j(s)$

where $w_L(s)$, and $w_M(s)$ are period s prices for labor, and materials, respectively. Note that the dependence of $C^j_v(\bullet)$ on s allows for technological change. $K^j(s)$ is the capital input used in period s. $y^j(s)$ is the output in period s. $L^j(s)$, and $M^j(s)$ are optimal variable factor employment levels in period s. The properties of the variable cost function are

i. $\partial C^j_v / \partial w_i \geq 0$, $i = L, M$ (nondecreasing in variable input prices)

ii. C^j_v is concave in w_L and w_M.

iii. $\partial C^j_v / \partial K^j \leq 0$ (nonincreasing in the quasi-fixed factor)

iv. $\partial^2 C^j_v / \partial K^{j2} > 0$ (convexity in the quasi-fixed factor)

v. $C^j_v(\theta w_L, \theta w_M, K^j, y^j, s) = \theta C_v(w_L, w_M, K^j, y^j, s)$ for any scalar θ (linear homogeneity in variable factor prices)

vi. $\partial C^j_v / \partial y^j \geq 0$ (nondecreasing in output)

Shepherd's lemma can be applied to equation (4.1) to obtain conditional factor demands for the variable inputs.

(4.2) $$\frac{\partial C^j_v}{\partial w_L} = L^j(s)$$

(4.3) $$\frac{\partial C^j_v}{\partial w_M} = M^j(s)$$

We assume that the flow of capital services in any period is proportional to the stock of the capital asset, and the stock evolves according to a perpetual inventory process. Thus, capital accumulation is governed by the following equation.

(4.4) $I^j(s) = K^j(s) - (1-\delta)K^j(s-1)$,

where $I^j(s)$ is gross investment in period s and δ is a fixed depreciation rate, such that $0 \leq \delta \leq 1$.

Quasi-fixed capital is subject to an adjustment cost that is internal to the firm. We assume that adjustment costs are written as

(4.5) $c^j_a = C^j_a(K^j(s) - (1-\delta)K^j(s-1))$, where C^j_a is an increasing and convex function of gross investment: $C^{j\prime}_a(\bullet) > 0$, and $C^{j\prime\prime}_a(\bullet) > 0$. Thus, the firm might not wish to close the gap between the steady state level and the actual level of capital stock entirely within one time period and instead might find it desirable to economize on current adjustment costs at the expense of having a less efficient capital stock, thereby optimally spreading the adjustment process out over time. Note that in period s, the decision maker chooses $I^j(s)$ given $K^j(s-1)$, or equivalently chooses $K^j(s)$ given $K^j(s-1)$. Note also that $K^j(s)$ enters production in period s.

Output price is given by an inverse output demand function:

(4.6) $P(s) = D(Y(s), z(s))$

where $D(\bullet)$ is twice continuously differentiable and nonincreasing in output, $Y(s) = \sum_{j=1}^{n} y^j(s)$ is aggregate industry output, and z(s) is a vector of exogenous demand shifters.

The jth firm's problem is to maximize, at each date t, the expected present value of the flow of funds. Thus

$$(4.7)\ E_t \sum_{s=t}^{\infty} \alpha(t,s)\ [D(Y(s), z(s))\, y^j(s) - C^j_v(w_L(s), w_M(s), K^j(s), y^j(s), s)$$
$$- C^j_a (K^j(s) - (1-\delta)K^j(s-1)) - w_K(s)\, K^j(s)]$$

where E_t represents expectation conditional on information available at time t (later denoted Ω_t), and w_K is the rental price of one unit of capital. $\alpha(t, s)$ is the factor for discounting period s funds to period t.[15]

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[15] In particular, $\alpha(t, t) = 1$ and, with nominal interest rate r, $\alpha(t, s) = 1/(1+r)^{s-t}$.

In the maximization of the objective function above, $z(s)$, $w_L(s)$, $w_M(s)$, and $w_K(s)$ are exogenous stochastic processes, and $K^j(t-1)$ is given at time t. The decision maker chooses $y^j(t)$ and, $K^j(t)$ at time t, and decision rules for choosing

$y^j(t+1)$, $y^j(t+2)$, $y^j(t+3)$, ... and $K^j(t+1)$, $K^j(t+2)$, $K^j(t+3)$, ...

as functions of the information that will be available when these variables have to be chosen. We can denote these decision rules:

$\tilde{y}^j_{t+1}(\Omega_{t+1})$, $\tilde{y}^j_{t+2}(\Omega_{t+2})$,...... and $\tilde{K}^j_{t+1}(\Omega_{t+1})$, $\tilde{K}^j_{t+1}(\Omega_{t+2})$,......

Note that our regression equations will be derived from the first order conditions for optimal choice of $y^j(t)$ and $K^j(t)$.

Now, to solve the optimization problem, the objective function in (4.7) can be rewritten as

$$D(Y(t), z(t))\, y^j(t) - C^j_v\,(w_L(t), w_M(t), K^j(t), y^j(t), t)$$

$$- C^j_a(K^j(t) - (1-\delta)K^j(t-1)) - w_K(t)\, K^j(t)$$

$$+ E_t \sum_{s=t+1}^{\infty} \text{(terms that do not involve } y^j(t))$$

Differentiating the above with respect to $y^j(t)$ yields the following first order condition.

(4.8)

$$D(Y(t),z(t)) + y^j(t)\frac{\partial D(Y(t),z(t))}{\partial Y(t)}\frac{\partial Y(t)}{\partial y^j(t)} - \frac{\partial C^j_v}{\partial y^j(t)}(w_L(t), w_M(t), K^j(t), y^j(t), t) = 0$$

Rewriting equation (4.8) yields

$$(4.9)\quad P(t)\left(1+\frac{\lambda^j(t)}{\varepsilon(t)}\right)=\frac{\partial C_v^j}{\partial y^j(t)}(\, w_L(t),\ w_M(t),\ K^j(t),\ y^j(t),\ t)$$

where P(t) is output price in period t; $\lambda^j(t) = \dfrac{\partial Y(t)}{\partial y^j(t)}\dfrac{y^j(t)}{Y(t)}$ is the conjectural elasticity of aggregate output with respect to the jth firm's output, an index of oligopoly conduct; and $\varepsilon(t) = \left(\dfrac{\partial D}{\partial Y}\right)^{-1}\dfrac{D(Y(t), z(t))}{Y(t)}$ is the output market demand elasticity. This equation, (4.9), expresses equality between the firm's short-run marginal cost and its perceived marginal revenue.

Rearranging equation (4.9) yields a Lerner index of performance:

$L_I^j = \dfrac{(P - MC^j)}{P} = -\dfrac{\lambda^j}{\varepsilon}$ If $\lambda^j(t) = 0$ (i.e., $L^j_I = 0$), then the jth firm behaves competitively, setting price equal to marginal cost, and if $\lambda^j(t) = 1$ (i.e., $L^j_I = -1/\varepsilon$), then jth firm operates with the pure monopoly markup of price over marginal cost.

To analyze firm j's choice of capital in period t, let us return to expression (4.7) again and rewrite it as

$$\begin{aligned}
&D(Y(t), z(t))\, y^j(t) - C^j_v\, (\, w_L(t), w_M(t), K^j(t), y^j(t), t)\\
&\qquad - C^j_a\, (K^j(t) - (1-\delta)K^j(t-1)) - w_K(t)K^j(t)\\
&\qquad + E_t\, \alpha(t, t+1)\, [\, D(Y(t+1), z(t+1))\, y^j(t+1)\\
&\qquad - C^j_v\, (w_L(t+1), w_M(t+1), K^j(t+1), y^j(t+1), t+1)\\
&\qquad - C^j_a\, (K^j(t+1) - (1-\delta)K^j(t)) - w_K(t+1)K^j(t+1)]\\
&\qquad + E_t \sum_{s=t+2}^{\infty} \text{(terms that do not involve } K^j(t))
\end{aligned}$$

For the moment, we ignore any impact of a choice of $K^j(t)$ on rival's decisions in future periods. Under this naive assumption, differentiating the objective function with respect to $K^j(t)$ would yield the following Euler equation.

(4.10)

$$-\frac{\partial C_v^j}{\partial K^j(t)}(w_L(t), w_M(t), K^j(t), y^j(t), t) - C_a^{j\prime}(K^j(t)-(1-\delta)K^j(t-1)) - w_K(t)$$
$$+ E_t\alpha(t, t+1)(1-\delta)C_a^{j\prime}(K^j(t+1)-(1-\delta)K^j(t)) = 0$$

Rearranging this yields

(4.11)

$$w_K(t) + C_a^{j\prime}(K^j(t)-(1-\delta)K^j(t-1)) = -\frac{\partial C_v^j}{\partial K^j(t)}(w_L(t), w_M(t), K^j(t), y^j(t), t)$$
$$+ E_t\alpha(t, t+1)(1-\delta)C_a^{j\prime}(K^j(t+1)-(1-\delta)K^j(t))$$

Note, however, that in the version of condition (4.11) for period t+1, the second term on the left-hand side is $C_a^{j\prime}(K^j(t+1)-(1-\delta)K^j(t))$. As long as marginal adjustment costs are not constant (so that period t+1 adjustment cost depends on $K^j(t)$), the jth firm's choice of $K^j(t)$ will affect its choices of capital in subsequent periods. As long as $\frac{\partial^2 C_v^j}{\partial y^j \partial K^j}$ is not zero, these impacts on future capital will affect firm j's marginal costs in future periods. This, in turn, will alter the future output market equilibria. Thus, here, as in the illustrative two-period model of Chapter 3, investment decisions have a strategic effect stemming from the impact of current investment on rivals' output and, ultimately, price in future periods. Firm j's marginal condition (4.11) does not incorporate this strategic effect, however. (4.11) could be said to characterize a "naive" equilibrium, in which firms do not anticipate the effects that their investment decisions have on rival's actions.

In reality, the dynamic cost of adjustment model is a complicated dynamic game in which players' period t strategies have impacts on rivals' objective functions in subsequent periods. In her survey of empirical applications of oligopoly games, Slade (1995) notes that characterization of the equilibria of such models can be intractable unless simplifying assumptions are made. For the purposes at hand, we assume that rivals' future responses to the jth firm's choice of capital in period t are confined to period t+1. From the perspective of firm j, the meaningful part of this reaction is the impact it will have on market output in period t+1. Furthermore, we assume that the jth firm's perception of this impact is captured by a "dynamic conjectural variation," $\partial Y^{-j}(t+1)/\partial K^j(t)$, which we assume to be a constant, γ^j, where $Y^{-j} = \sum_{i \neq j} y^i$. With these assumptions, the jth firm's decision problem is a dynamic optimization problem that can be treated in isolation; that is, without reference to rivals' problems. Yet, the jth firm's problem does incorporate a strategic effect of capital investment, at least in one *ad hoc* way, and enables us to characterize a more "sophisticated" equilibrium than the one represented by equation (4.11).[16]

The derivation leading to equation (4.11) now yields:

[16] The approach taken here is essentially the same as that used by Roberts and Samuelson (1988) in their analysis of the strategic effects of advertising expenditure in the cigarette industry. They also use the terms "naive" and "sophisticated" equilibria in the way we have here.

(4.12)

$$w_K(t)+C_a^{j'}(K^j(t)-(1-\delta)K^j(t-1))=-\frac{\partial C_v^j}{\partial K^j(t)}(w_L(t), w_M(t), K^j(t), y^j(t), t)$$

$$+E_t\alpha(t,t+1)\left[(1-\delta)C_a^{j'}(K^j(t+1)-(1-\delta)K^j(t))+\frac{\partial D}{\partial Y}(Y(t+1), z(t+1))\frac{\partial Y^{-j}(t+1)}{\partial K^j(t)}y^j(t+1)\right]$$

or

$$w_K(t)+C_a^{j'}(K^j(t)-(1-\delta)K^j(t-1))=-\frac{\partial C_v^j}{\partial K^j(t)}(w_L(t), w_M(t), K^j(t), y^j(t), t)$$

$$+E_t\alpha(t,t+1)\left[(1-\delta)C_a^{j'}(K^j(t+1)-(1-\delta)K^j(t))+\frac{P(t+1)}{\varepsilon(t+1)}\gamma^j\frac{y^j(t+1)}{Y(t+1)}\right]$$

where $\varepsilon(t+1)\equiv\left[\frac{\partial D}{\partial Y}(Y(t+1), z(t+1))\right]^{-1}\frac{P(t+1)}{Y(t+1)}$ is the market demand elasticity in period t+1 and $\gamma^j=\frac{\partial Y^{-j}(t+1)}{\partial K^j(t)}$ is firm j's dynamic conjectural variation of next period's rivals' output with respect to this period's own capital.[17] Equation (4.12) says that, when capital is optimally employed, the rental price plus the adjustment cost attributable to the last unit installed in period t is just offset by the resulting savings in period t variable cost plus the expected present value of period t+1 adjustment cost savings (due to installation of the unit of capital in t rather than t+1) minus the expected marginal loss of future revenue due to the price decrease resulting from rivals' increased production.

[17] In the derivation of equation (4.12), the envelope theorem allows us to ignore the effects of firm j's choice of $K^j(t)$ on its own future actions. Also in Chapter 3's model, the counterpart of the γ^j introduced here is $\partial q^i/\partial\tilde{K}_j$. To the extent that the results of Chapter 3's model are generalizable to the present case, the expected sign for γ^j is negative.

In sum, the "short-run model" consists of equations (4.2), (4.3), and (4.9). This model does not explain the determination of capital, but merely treats it as exogenous. The "dynamic cost of adjustment model" consists of equations (4.2), (4.3), and (4.9), and (4.12). The "long-run model" is obtained from the present formulation by assuming that capital adjustment costs are identically zero, so that capital is chosen in each period to minimize the total cost of producing the optimal output level and there are no intertemporal strategic investment effects. That is, for given $y^j(t)$, $K^j(t)$ is chosen to minimize

$C^j_v\,(\,w_L(t), w_M(t), K^j(t), y^j(t), t\,) + w_K(t)K^j(t)$.

The first order condition for this problem is

$$(4.13)\quad -\frac{\partial C_v^j}{\partial K^j}(\,w_L(t), w_M(t), K^j(t),\ y^j(t),\ t) = w_K(t).$$

The long-run model, then consists of equations (4.2), (4.3), (4.9), and (4.13).

In this chapter, we have developed two types of theory-consistent empirical models for measuring firm market power. One type (consisting of the short-run and long-run equilibrium models) is derived from a static optimization problem for the firm and the other (i.e., the dynamic cost of adjustment model) is based on the intertemporal nature of firms' optimizing behavior with the emphasis on the strategic role of capital investment. All of these theoretical models will be used as a basis for economic interpretation of the data in the next chapter. Furthermore, since all the models that we have developed in this chapter have been grounded at the firm-level, we will develop industry-level counterparts that use aggregate data collected from industry sources.

CHAPTER 5. EMPIRICAL MODEL II: FUNCTIONAL FORMS AND AGGREGATION ISSUES

This chapter translates our theoretical models developed in Chapters 3 and 4 into implementable models and introduces the hypotheses to be tested. The specification of the empirical models begins with the selection of a flexible functional form for the cost function. Then the equations of the models are reinterpreted in terms of this cost function. Finally we discuss the issue of checking the cost function properties.

One of the most important reasons why flexible functional forms have been used in econometric applications is that they have sufficient parameters to reproduce comparative static effects without imposing many prior restrictions on the economic phenomena being measured. Thus, cost functions with a flexible form, which can be interpreted as second order approximations to arbitrary cost functions, have been widely used in the empirical literature. In our analysis, we follow Denny, Fuss, and Waverman (1981) in the use of a quadratic cost function, as one of the flexible functional forms, since this choice permits the measurement of market power without losing aggregation consistency.

As with many applied econometric studies, firm-level data are not accessible; only industry data can be obtained. Since the theoretical model is posed in terms of firm-level optimization problems involving firm-level cost functions, an industry-level model must first be derived from it before using industry-level data in the econometric analysis. In what follows, we carry out aggregation of firm-level relations to industry-level counterparts.

Assume that the jth firm's variable cost function, C_v^j takes the following quadratic form:

$$
\begin{aligned}
(5.1)\ C_v^j = {} & b_0 + b_L w_L + b_M w_M + b_y y^j + b_K K^j + b_T T \\
& + 0.5\{b_{LL}(w_L)^2 + b_{MM}(w_M)^2 + b_{yy}(y^j)^2 + b_{KK}(K^j)^2 + b_{TT}(T)^2\} \\
& + b_{LM} w_L w_M \\
& + b_{KL} K^j w_L + b_{KM} K^j w_M + b_{Ky} K^j y^j \\
& + b_{Ly} w_L y^j + b_{My} w_M y^j + b_{yT} y^j T \\
& + b_{LT} w_L T + b_{MT} w_M T + b_{KT} K^j T
\end{aligned}
$$

where j = 1, 2, ..., n indexes firms.

Given this specification for C_v^j, equations (4.2), and (4.3) become:

$$(5.2)\ L^j = b_L + b_{LL} w_L + b_{LM} w_M + b_{KL} K^j + b_{Ly} y^j + b_{LT} T$$

$$(5.3)\ M^j = b_M + b_{MM} w_M + b_{LM} w_L + b_{KM} K^j + b_{My} y^j + b_{MT} T$$

Summing across all n firms we have industry-level factor demands:

$$(5.4)\ L = B_L + B_{LL} w_L + B_{LM} w_M + b_{KL} K + b_{Ly} Y + B_{LT} T$$

$$(5.5)\ M = B_M + B_{MM} w_M + B_{LM} w_L + b_{KM} K + b_{My} Y + B_{MT} T$$

where $B_L = nb_L$, $B_M = nb_M$, $B_{LL} = nb_{LL}$, $B_{MM} = nb_{MM}$, $B_{LM} = nb_{LM}$, $B_{LT} = nb_{LT}$, $B_{MT} = nb_{MT}$; and $K = \sum_{j=1}^{n} K^j$ and $Y = \sum_{j=1}^{n} y^j$ are industry aggregate capital stock and output respectively.

Assume that market demand for the industry's product takes the following constant elasticity form:

(5.6) $\ln Y = a + \varepsilon \ln(P/S) + \mu \ln (Z/S)$

where S = the implicit GDP price deflator, Z = GDP in current dollars, ε = output market demand elasticity. ε, a, and μ are unknown parameters. Equation (4.9) then becomes

$$(5.7)\ P(1+\frac{\lambda^j}{\varepsilon}) = b_y + b_{Ly}\, w_L + b_{My}\, w_M + b_{Ky}\, K^j + b_{yy}\, y^j + b_{LT}\, T$$

$$\text{where } \varepsilon = \left(\frac{\partial D}{\partial Y}\right)^{-1} \frac{D(Y, Z)}{Y}.$$

Multiplying by 1/n and summing across firms, we have

$$(5.8)\ P(1+\frac{\lambda}{\varepsilon}) = \frac{1}{n}\sum_{j=1}^{n}\frac{\partial C_v^j}{\partial y^j}$$

$$= b_y + b_{Ly}\, w_L + b_{My}\, w_M + \tilde{b}_{Ky}\, K + \tilde{b}_{yy}\, Y + b_{LT}\, T$$

where $\tilde{b}_{Ky} = b_{Ky}/n$, $\tilde{b}_{yy} = b_{yy}/n$, and $\lambda = \frac{1}{n}\sum_{j=1}^{n}\lambda^j$, the simple average of the individual firms' conduct parameters.

The equations, (5.4), (5.5), (5.6), and (5.8) make up the short-run equilibrium model for the industry. The output supply relation of equation (5.8) is the basis for estimating an index of market power at the industry level, and a corresponding industry level performance index. Rearranging (5.8) we have: $L_I = \dfrac{P - \frac{1}{n}\sum_j \frac{\partial C_v^j}{\partial y^j}}{P} = -\dfrac{\lambda}{\varepsilon}$. Thus, the industry's "average" Lerner index is given by $-\lambda/\varepsilon$.

The adjustment cost function is assumed quadratic in order to limit the number of parameters to be estimated; that is,

(5.9) $C_a(I(t)) = 0.5\ b_{II}\,[I(t)]^2$

Then, equation (4.12) in the dynamic cost-of-adjustment model averaged over n firms becomes

$$(5.10)\ -w_K = b_K + b_{LK}\,w_L + b_{KM}\,w_M + \tilde{b}_{KK}\ K + \tilde{b}_{Ky}\ Y + b_{KT}\,T$$

$$+\ \tilde{b}_{II}\ (K(t) - (1-\delta)\,K(t-1))$$

$$-\ E_t\,\alpha(t, t+1)\left[(1-\delta)\tilde{b}_{II}\,(K(t+1)\ -\ (1-\delta)\ K(t))\ + \tilde{\gamma}\frac{P(t+1)}{\varepsilon}\right]$$

where $\tilde{b}_{KK} = b_{KK} / n$, $\tilde{b}_{II} = b_{II} / n$, $\tilde{\gamma} \equiv \frac{1}{n}\gamma$, and $\gamma = \sum_{j=1}^{n} \gamma^j \frac{y^j(t+1)}{Y(t+1)}$, which is the market-share weighted average of firms' dynamic conjectural variations with respect to capital.[18] Thus, the dynamic cost of adjustment model consists of equations, (5.4), (5.5), (5.6), (5.8), and (5.10). The parameter $\tilde{\gamma}$ can be used to formulate tests of firm's strategic conduct in capital investment.

To get the long-run equilibrium model, equation (4.13), an equilibrium condition for capital when capital adjustment costs are zero, is added:

$$(5.11)\ \ -w_K = \frac{\partial C_v^j}{\partial K^j} = b_K + b_{KL}\,w_L + b_{KM}\,w_M + b_{KK}\,K^j + b_{Ky}\,y^j + b_{KT}\,T$$

Taking a simple average of equation (5.11) over n firms yields

$$(5.12)\ -w_K = b_K + b_{KL}\,w_L + b_{KM}\,w_M + \tilde{b}_{KK}\ K + \tilde{b}_{Ky}\ Y + b_{KT}\,T$$

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[18] Note that we have used (5.6) in writing the elasticity of demand as a constant.

The long-run model consists of equations, (5.4), (5.5), (5.6), (5.8), and (5.12).

Because n, the "number of firms in the industry," is not known, not all of the parameters of the firm-level cost function (equation (5.1)) can be recovered through estimation of industry level relations. In what follows, we discuss the extent to which we can check the properties of the variable cost function given in Chapter 4.

i) Nondecreasing in variable input prices

$$\frac{\partial C_v^j}{\partial w_L} = b_L + b_{LL}\, w_L + b_{LM}\, w_M + b_{KL}\, K^j + b_{Ly}\, y^j + b_{LT}\, T$$

should be nonnegative for all j. But we only can check this condition at the industry level. Summing over all firms, j = 1, 2, ..., n, yields

$$B_L + B_{LL}\, w_L + B_{LM}\, w_M + b_{KL}\, K + b_{Ly}\, Y + B_{LT}\, T \geq 0,$$

which should be satisfied at all sample points. Likewise, nondecreasing in material price "at the industry level" requires

$B_M + B_{MM}\, w_M + B_{LM}\, w_L + b_{KM}\, K + b_{My}\, Y + B_{MT}\, T \geq 0$ at all sample points.

ii) Concave in factor prices

For the variable cost function to be concave in factor prices, the Hessian matrix must be negative definite.

$$\left[\frac{\partial^2 C_v^j}{\partial w_h\, \partial w_i}\right]_{h,i=L,M} = \begin{bmatrix} b_{LL} & b_{LM} \\ b_{LM} & b_{MM} \end{bmatrix}$$ is negative definite if and only if

$$\begin{bmatrix} B_{LL} & B_{LM} \\ B_{LM} & B_{MM} \end{bmatrix}$$ is negative definite.

In other words, the model must satisfy B_{LL}, $B_{MM} < 0$, and $(B_{LL}B_{MM} - B_{LM}^2) > 0$.

iii) Nonincreasing in the quasi-fixed factor

The cost function is nonincreasing in the quasi-fixed factor

if $\frac{\partial C_v^j}{\partial K^j} = b_K + b_{KL}\, w_L + b_{KM}\, w_M + b_{KK}\, K^j + b_{Ky}\, y^j + b_{KT}\, T \leq 0$. But we only can check this

condition at the industry level. Averaging over all firms, j = 1, 2, ..., n, yields

$b_K + b_{KL}\, w_L + b_{KM}\, w_M + \tilde{b}_{KK}\, K + \tilde{b}_{KY}\, Y + b_{KT}\, T \leq 0$ at all sample points.

iv) Convexity in the quasi-fixed factor

The cost function is convex in the quasi-fixed factor if $\frac{\partial^2 C_v^j}{\partial K^{j^2}} = b_{KK} > 0$, which is satisfied if

and only if $\tilde{b}_{KK} > 0$. Note that checking properties (iii) and (iv) requires estimates from the

long-run or dynamic cost of adjustment models.

v) Linear homogeniety in variable factor prices

One drawback of the quadratic functional form is that there is no way to impose linear

homogeneity through parametric restrictions.

vi) Nondecreasing in output

The cost function is nondecreasing in output if

$\frac{\partial C_v^j}{\partial y^j} = b_y + b_{Ly}\, w_L + b_{My}\, w_M + b_{Ky}\, K^j + b_{yy}\, y^j + b_{LT}\, T \geq 0$. But we only can check this

condition at the industry level. Averaging over all firms, j = 1, 2, ..., n, yields

$b_y + b_{Ly}\, w_L + b_{My}\, w_M + \tilde{b}_{KY}\, K + \tilde{b}_{YY}\, Y + b_{LT}\, T \geq 0$ at all sample points.

We will check these theoretical properties of the variable cost function using the estimation

results that will be provided in next chapters. Before proceeding with this, however, using the industry-level model systems we have derived, we will analyze data from the U.S. transformer industry for the 1958-1991 period, hoping that we have taken into consideration the most important components of firms' decision-making behavior.

The next chapter discusses estimation methods and their validity for each of the three systems of equations, and also deals with some issues about model specification tests.

CHAPTER 6. ESTIMATION STRATEGIES

Once the system of estimating equations is specified, the question becomes what sort of econometric procedures might be used. In this chapter, we start with the descriptions of some parameter restrictions implied by the short-run, long-run, and dynamic cost of adjustment model structures. Then, we address the estimation procedures to be used for the three simultaneous equation systems. Finally, we explain a model specification test method to be used to assess the comparative performance of the models.

Equations (5.4), (5.5), (5.6), (5.8), (5.10), and (5.12) are the basis for our empirical models. For convenience, we rewrite them here as equations. (6.1), (6.2), (6.3), (6.4), (6.5), and (6.6). Subscripts are used to denote observations, the expectation operator in equation (5.10) has been dropped, and random error terms have been added.

$$(6.1)\ L(t) = B_L + B_{LL}\, w_L(t) + B_{LM}\, w_M(t) + b_{KL}\, K(t) + b_{Ly}\, Y(t) + B_{LT}\, T(t) + u_L(t)$$

$$(6.2)\ M(t) = B_M + B_{MM}\, w_M(t) + B_{LM}\, w_L(t) + b_{KM}\, K(t) + b_{My}\, Y(t) + B_{MT}\, T(t) + u_M(t)$$

$$(6.3)\ \ln Y(t) = a + \varepsilon \ln(P(t)/S(t)) + \mu \ln(Z(t)/S(t)) + u_Y(t)$$

$$(6.4)\ P(t)\left(1 + \frac{\lambda}{\varepsilon}\right) = b_y + b_{Ly}\, w_L(t) + b_{My}\, w_M(t) + \tilde{b}_{Ky}\, K(t) + \tilde{b}_{yy}\, Y(t) + b_{LT}\, T(t) + u_P(t)$$

$$(6.5)\ -w_K(t) = b_K + b_{KL}\, w_L(t) + b_{KM}\, w_M(t) + \tilde{b}_{KK}\, K(t) + \tilde{b}_{Ky}\, Y(t) + b_{KT}\, T(t)$$
$$+\ \tilde{b}_{II}\, (K(t) - (1-\delta(t))\, K(t-1))$$

$$- \alpha(t, t+1)\left[(1-\delta(t))\tilde{b}_{II}(K(t+1) - (1-\delta(t))\, K(t)) + \tilde{\gamma}\frac{P(t+1)}{\varepsilon}\right] + u_K(t)$$

$$(6.6)\; - w_K = b_K + b_{KL}\, w_L\,(t) + b_{KM}\, w_M\,(t) + \tilde{b}_{KK}\;\; K(t) \; + \; \tilde{b}_{Ky}\;\; Y(t) \; + b_{KT}\, T(t) + u_K(t)$$

where u_L, u_M, u_Y, u_P, and u_K are the random errors in each equation.

The short-run model, consisting of equations (6.1), (6.2), (6.3), and (6.4), embodies structure imposed by the theory of the profit maximizing firm in the form of over-identifying cross-equation restrictions on parameters B_{LM}, b_{Ly}, and b_{My}. The long-run model adds an equation, (6.6), and additional cross-equation restrictions on b_{KL}, b_{KM}, and $\tilde{b}_{Ky}$. Thus, the test of the long-run model against alternative theories of the determination of capital stock turns out to be a test of these restrictions. Further, the test of the cost-of-adjustment model against the long-run model is a test of $\tilde{b}_{II} = \tilde{\gamma} = 0$ in the context of (6.1), (6.2), (6.3), (6.4), and (6.5).

The error terms in the equation sets of the short-run and long-run models are assumed to have zero expected values, and positive definite, constant, contemporaneous covariance matrix. The equation sets characterizing the short-run and long-run models are estimated as a complete system using the nonlinear iterative three stage least squares estimator. Although full information maximum likelihood (FIML) is theoretically favorable, since non-linear three stage least squares (NL3SLS) does not require a normality assumption, it is a frequently used method for relatively small samples as in our data.

It is natural to ask which equilibrium specification is more appropriate to explain the structure of production and factor demands given the information from the data. One approach to testing the long-run model would be to estimate the equation system by full information maximum likelihood and then test the restrictions using a likelihood ratio procedure, or estimate them by three stage least squares and test the restrictions using some appropriate counterpart to the likelihood ratio test. However, the problem with this approach is that it requires that equations of the form (6.1), (6.2), (6.3), (6.4), and (6.6) remain the true specification even when the restrictions are not imposed. But if the capital stock is not at the long-run equilibrium level, it is unlikely that the correct specification for capital stock would be of the form of equation (6.6). An alternative approach follows the test method developed by Schankerman and Nadiri (1986). With short-run equilibrium as a maintained hypothesis, the Schankerman and Nadiri procedure enables us to test the null hypothesis H_0: Capital is at its full static equilibrium level (i.e., the long-run equilibrium model) versus an alternative hypothesis H_1: The stock of capital is determined by some other unspecified method.

Let $\beta = \left(b_{KL}, b_{KM}, \tilde{b}_{Ky}\right)'$ be the vector of parameters in the capital demand equation (5.12) of the long-run equilibrium model which also appear in the short-run equilibrium model. The long-run model implies cross-equation restrictions involving these parameters, while estimating short-run equilibrium model does not impose any of these restrictions on β. Let $\hat{\beta}$ be a consistent and asymptotically efficient estimator of β on H_0. We can take $\hat{\beta}$ to be the 3SLS estimator of β from the long-run model. $\hat{V}$ is the asymptotic covariance matrix of this estimator. Let $\tilde{\beta}$ be an estimator of β that is consistent on H_0 or H_1. We can take $\tilde{\beta}$ to be the 3SLS estimator of β from the short-run model. $\tilde{V}$ is the asymptotic covariance matrix of $\tilde{\beta}$ obtained from 3SLS estimation of short-run equilibrium. The test statistic is

$M=(\tilde{\beta}-\hat{\beta})' W^{-1}(\tilde{\beta}-\hat{\beta})$, where W is a consistent estimator of $\tilde{V}-\hat{V}$. On H_0, M is distributed χ^2_q, where q (=3) is the number of parameter restrictions being tested.

The dynamic cost of adjustment model consists of equations (6.1), (6.2), (6.3), (6.4), and (6.5). The error terms in the first four equations represent optimizing errors (equations (6.1), (6.2), and (6.4)) or the effect of omitted variables (equation (6.3)), but the error term in equation (6.5) is an expectation error which arises when the conditional expectations of the future values of variables in (6.5) are replaced by their actual values. The estimator used for this model is the GMM (generalized method of moments) estimator proposed by Hansen and Singleton (1982). Intuitively, the GMM estimator chooses parameter estimates so as to minimize the correlation between the model's error terms and a set of instrumental variables. The instrumental variables are chosen from the elements of the information set available to agents. In the case of equation (6.5), imposing orthogonality between the error term and the instruments amounts to an assumption of rational expectations.

The Schankerman and Nadiri procedure can also be used to test the validity of the dynamic cost of adjustment model. With short-run equilibrium as a maintained hypothesis, the test is: H_o: Capital is determined in a manner consistent with the dynamic cost of adjustment model versus H_1: The stock of capital is determined by some other unspecified method. As in the test of the long-run model, the test involves a comparison of two estimates of a vector of parameters which are subject to additional cross-equation restrictions when H_o is true: $\beta=(b_{KL}, b_{KM}, \tilde{b}_{Ky}, \varepsilon)'$. $\hat{\beta}$, the estimator of β that is consistent and asymptotically efficient on H_o, is taken to be the GMM estimator from the dynamic cost of adjustment model. $\tilde{\beta}$, the estimator of β that is consistent on H_0 or H_1, is taken to be the 3SLS estimator from the short-run model. The test proceeds as described above using the M statistic.

CHAPTER 7. THE TRANSFORMER INDUSTRY

For empirical implementation of the models, we use industry time-series data on the U.S. transformer industry, 1958-1991. The following section (7.1) reviews some previous studies on the oligopolisitic nature of the industry. Then section (7.2) presents data construction details for each of the variables along with some discussion of the conceptual issue of the user cost of capital.

7.1 The transformer industry

We analyze the transformer industry (SIC 3612) over the 1958-1991 period.[19] It is one component of the electrical machinery industry (SIC 36) that Appelbaum used in his 1982 study of market power. Appelbaum found that the electrical machinery industry was characterized by significant oligopoly power with an industry average Lerner's index value of 0.19 for the 1947-1971 time period. Hazilla (1991) estimated the Lerner's index to be 0.17 based on an average of three different econometric estimates of the conjectural elasticity during the 1958-1974 time period. Hall's (1988) work also suggested that the electrical machinery industry had significant market power during the 1949-1985 time period. On the

[19] The industry definition, "transformers, except electronic," that used in the 1987 Standard Industrial Classification (SIC) system. This industry is made up of establishments engaged in manufacturing power, distribution, instrument, and specialty transformers.

other hand, referring to SCP-type studies,[20] the transformer industry was classified within a group of industries with four-firm concentration ratios of 75 per cent or higher during the 1935-1972 time period. Shepherd (1970) made approximate ratings of barriers to entry for U.S. manufacturing industries and suggested that the transformer industry had very high barriers to entry during the early 1950s and 1960s. According to the 1987 Census of Manufactures report, the transformer industry was producing 1.9 % of SIC 36 output.[21] There were 239 firms, the largest 4 firms producing 46% of industry output and its Herfindahl index[22] was 706 in the transformer industry (SIC 3612) while it was 129 in the electrical machinery industry (SIC 36) in 1987.

The industry has a history of collusive behavior.[23] A well-known price-fixing conspiracy among the companies making electrical equipment was in effect during the 1950s and 1960s. For example, Fuller (1962) described, "The conspiracies in the industry covered such equipment as circuit breakers, power transformers, and turbine generators, which are sold in large extent to power and light companies and government installations. Relatively little product differentiation can be developed among these informed buyers. As a result, a firm's sales depend on offering the best price. Although "book prices" are established for various products, sales are frequently "off book," and price competition has come to take the

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[20] See, Kamerschen (1968) and Brozen (1982).

[21] The SIC 36 industry has 37 SIC four-digit industries in it.

[22] The Herfindahl index is calculated by squaring the market share (in percent) of each of the top 50 companies.

[23] See also Sultan (1974).

form of competing percentages off book price. The cartel agreements were specially designed to prevent the instigation of price competition. which in some instances had forced prices down to 60 percent of book." And Caves (1986) pointed out "Like many cartel arrangements, the electrical manufacturers' agreements began because of the desire to maintain prices in the face of strong competitive pressures, but it was precisely these pressures which caused breaks to occur. Periodically, some firm with excess capacity would offer a discount to get a large order. Others would retaliate, and the cartel would lapse. Prices would fall to lower and lower levels, until something had to be done. The cry would go up to stabilize prices, and the meetings would start again."

7.2 Data

The data used in this research consist of annual time series of industry-level variables relating to the transformer industry (SIC 3612). The variables are mostly obtained from the NBER manufacturing productivity database which contains annual information on U.S. manufacturing industries from 1958 to 1991. The data themselves originally came from various government data sources, with many of the variables taken directly from the Census Bureau's Annual Survey of Manufactures and Census of Manufactures.

A price deflator for the industry's value of shipments is used as a measure of the model's output price. Real output quantity is taken to be the value of shipments (adjusted for inventory changes) divided by the price deflator. Material input price and quantity are similarly derived from series on a price deflator and nominal expenditures on the input. Labor input is measured by total production worker hours and labor price by average production worker wages. A real capital stock series is available as a measure of the industry's capital input.

The calculation of capital service price is based on the work of Christensen and Jorgenson (1969) and is slightly modified for availability of the data. Let the price for one unit of a capital asset in period t be J(t), and let the one period rate of return available to the firm on an alternative investment from t-1 to t be r(t). Define $w_K(t)$ as the implicit one period rental rate of the capital asset. Let us consider an agent with J(t-1) dollars in cash at period t-1. Then he has two options: He can invest it at rate of interest r(t) or purchase one capital asset and rent it to a firm for one period at rental rate $w_K(t)$. Under the first option, he will own, at time t, a financial asset worth (1+ r(t)) J(t-1) dollars. Under the second option, he will own, at time t, a real asset and cash with value totaling $(1 - u_c(t))\,(w_K(t) - c(t)J(t-1)) + (1 - \delta)\,J(t)$, where $u_c(t)$ is the effective corporate income tax rate, c(t) is the property tax rate in period t, and δ is the physical depreciation rate for capital. The first term in this equation is the amount of rental income after tax and the second term is the market value of the undepreciated portion of the capital asset at date t. Now the value of the implicit rental rate on capital is the value of $w_K(t)$ that equalizes the two expressions:[24]

$$w_K(t) = \frac{1}{1-u_c(t)}\left[r(t)J(t-1) + \delta J(t) - (J(t) - J(t-1))\right] + c(t)J(t-1)$$

[24] In fact, $1/(1 - u_c(t))$ is a simple version of the "effective" rate of taxation on capital income which is usually given by $(1 - v(t) - u_c(t)\rho)/(1 - u_c(t))$ where ρ is the present value of depreciation deductions for tax purposes on a dollar's investment over the lifetime of the asset, and v(t) is the effective rate of the investment tax credit. But, it is very hard to get the available data for all variables in this tax formula.

where $u_c(t)$ is calculated by the formula used by Christensen and Jorgenson (1969), which is simply taxes paid divided by property income before taxes: $u_c(t)$ = (profit tax liability)/(property income). Note that, consistent with the definition of the Survey of Current Business, "property income" consists of profits from current production and net interest payments. Moreover, as in Berndt's early study (1976), we choose to focus only on the rate of return variable, the capital gain or loss on the value of the asset, and the corporate profits tax rate, ignoring the property tax term:

$$w_K(t) = \frac{1}{1 - u_c(t)}\left[r(t)J(t-1) + \delta J(t) - (J(t) - J(t-1))\right]$$

The NBER database contains, for each industry, a price deflator for new investment which will serve as a measure of J(t). The physical depreciation rate can be deduced from the real capital stock, new capital spending, and the investment price deflator series. A Moody's bond yield on Aaa bonds (Economic Report of the President) was chosen as a proxy variable for the interest rate. Time series data on two additional variables appearing in the output demand equation, the implicit GDP price deflator (S) and GDP in nominal terms (Z) were also obtained from the Economic Report of the President. The tax variables are available in the Survey of Current Business and are reported on the basis of two-digit SIC manufacturing industries.

The next chapter discusses the results obtained from the estimation of the models in Chapter 5.

CHAPTER 8. EMPIRICAL RESULTS

8.1. Estimation of the short-run and long-run models

As presented in the previous chapters, the short-run model consists of two industry input demand functions, the output demand function, and the profit maximization condition, (6.1), (6.2), (6.3), and (6.4) respectively. The long-run model requires one additional equation specifying capital demand (6.6), along with the short-run model equations.

We assume that the disturbance terms in each model are serially independently and identically distributed with mean vector zero and constant, contemporaneous covariance matrix. Estimation of these models was carried out using iterative NL3SLS. NL3SLS is used to take into account the fact that each model system is simultaneous and the disturbance terms are correlated across equations in any given time period. In the short-run model: L(t), M(t), Y(t), and P(t) are endogenous. Factor prices, nominal GDP, the GDP deflator, and the time trend are exogenous variables, and K(t) is predetermined. In the long-run model, K(t) becomes endogenous as well.

The instruments that we used in the estimation of the two models are: a constant, real GDP, the wage rate (w_L), the material price (w_M), a time trend (T), the rental rate of capital stock (w_K), and the once-lagged value of each of these variables. Due to the lags and leads necessary to construct the data required for estimation, the effective part of the sample is 1960-1990, including a total of 31 observations.

The parameter estimates and standard errors are given in Table 2. The conventional

R^2 value and the Durbin-Watson statistics are presented in Table 3.[25] The parameter estimates reported in Table 2 are analyzed to provide specific information on the applicability of the models to the data. First, the majority of parameters in the short-run and the long-run model are significant. However, we need to check parameter estimates for consistency with the theoretical properties of the variable cost function. As explained in Chapter 5, not all of these properties can be verified at the firm level. Monotonicity requirements of the cost function with respect to the prices w_L, w_M, are met at the industry level at all sample points in the short-run model. Concavity of the variable cost function in input prices requires that the Hessian matrix of second order partial derivatives with respect to w_L, w_M be negative definite. Necessary and sufficient conditions for this are given by:

$B_{LL} < 0$, $B_{MM} < 0$, and $(B_{LL} B_{MM} - B_{LM}^2) > 0$.

The parameter estimates for B_{LL} and B_{MM} have the right sign and are significantly different from zero, in the short-run model. The sign condition on the second order principal minor is satisfied with a marginal significance level of 13.8%. In the long-run case, the monotonicity and concavity conditions are satisfied with a good level of statistical significance. Furthermore, the variable cost function is decreasing in the capital stock "at the industry-level" for all sample periods. Also convexity in the capital stock is verified with the positive value of $\tilde{b}_{KK}$, with a marginal significance level of 21.1 %. Lastly, the variable cost function

[25] The values of the D.W. statistics in the empirical results lead one to suspect serial correlation in the error terms of each equation. The equations of the short-run and long-run models were quasi-first-differenced and an effort was made to estimate the auto-regressive parameters and the structural parameters jointly by application of NL3SLS to these transformed models. These efforts were unsuccessful, however, due to convergence problems.

is increasing in output "at the industry-level" for all years in both models. Thus the variable cost function is reasonably well-behaved in the two models.

As given in Table 2, the estimates of the own-price elasticity are significantly negative for both models. The significantly negative estimates of μ in both models, taken at face value, would suggest that transformers are an inferior good. This surprising result raises suspicion that real income is merely serving as a proxy for a time trend and the significantly negative estimate of μ is a reflection of the fact that the industry is outdated, with demand steadily decreasing over time. To test this possibility, we re-estimated the model with a time trend in the demand equation (along with the real income term). The estimates of μ remained negative and the estimate of the time-trend variable were never statistically significant. Other parameter estimates changed by less than 5%.[26]

The measurement of market conduct and market performance is of primary interest in this study. The estimates of conjectural elasticities (λ) are fairly consistent across the two models and highly significant. So, based on either set of results, we can reject the hypothesis of price-taking conduct. Combining the estimates of the demand elasticity (ε) and the conduct parameter (λ) yields an estimate of the index of performance, i.e., the Lerner index of oligopoly power. The Lerner index was computed as $L_I = \dfrac{P - \frac{1}{n}\sum_j \frac{\partial C_v^j}{\partial y^j}}{P} = -\dfrac{\lambda}{\varepsilon}$ in our empirical models. The larger the index, the more oligopoly power the firm is able to

[26] Another possible treatment of the anomaly of negative income elasticity estimates may be to re-specify the demand equation using quality-adjusted price indexes for the products. But, unfortunately, the NBER Database used in this dissertation does not contain any data to handle changes in quality.

Table 2

NL3SLS Estimation results for the short-run and long-run models

Parameter	Short-run model	Long-run model
B_L	32.1861 (12.7924)	49.3588 (8.9324)
B_{LL}	-3.86754 (2.30145)	-8.50522 (1.7727)
B_{LM}	12.5965 (14.868)	30.8315 (2.4759)
b_{KL}	0.0023 (0.0116)	-0.0109 (0.9288E-02)
b_{Ly}	0.0131 (0.3494E-02)	0.0122 (0.3272E-02)
B_{LT}	-0.2323 (0.9395)	0.9294 (1.3147)
B_M	1190.57 (156.281)	1129.6 (122.919)
B_{MM}	-966.475 (194.467)	-1053.38 (192.396)
b_{KM}	-0.5529 (0.1602)	-0.5277 (0.1186)
b_{My}	0.3307 (0.041)	0.3428 (0.0405)
B_{MT}	38.1024 (10.6781)	34.0582 (9.5750)
a	3.1862 (0.9715)	3.5292 (0.9606)
ε	-2.6811 (0.3907)	-2.9207 (0.3758)
μ	-0.6859 (0.2266)	-0.8222 (0.2186)
b_y	0.2890 (0.0584)	0.2655 (0.0558)
$\tilde{b}_{Ky}$	-9.15E-05 (4.02E-05)	-4.11E-05 (0.3145E-04)
$\tilde{b}_{yy}$	-4.18E-05 (0.966E-05)	-5.09E-05 (0.1338E-04)
b_{yT}	0.0072 (0.2809E-02)	6.86E-03 (0.2947E-02)

Table 2 (continued)

λ	0.8381 (0.2498)	0.8773 (0.2876)
L_1	0.3125 (0.0884)	0.3003 (0.1001)
b_K	N.A.	0.0230 (0.1026)
b_{TK}	N.A.	0.01072 (0.6358E-02)
$\tilde{b}_{KK}$	N.A.	1.55E-04 (0.1242E-03)

Note: Estimated standard errors in parentheses. N.A. = not applicable.

Table 3

R^2's and Durbin-Watson statistics from NL3SLS Estimation of the Short-run and Long-run models

	Short-run model		Long-run model	
Equations	R^2	D.W.	R^2	D.W.
(6-1)	0.919	0.641	0.856	0.538
(6-2)	0.934	1.021	0.937	1.057
(6-3)	0.779	0.761	0.764	0.755
(6-4)	0.992	1.104	0.991	1.101
(6-6)	N.A.	N.A.	0.232	0.747

Note: Each equation of each model was solved for one endogenous variable equation ((6.1), L; (6.2), M; (6.3), lnY; (6.4), P; and (6.6), K). Using parameter estimates and observed values for the model's variables, "fitted series" for each endogenous variable were then calculated using, in each case, just one structural equation. The reported R^2s are the squared simple correlation coefficients between these fitted series and the actual series. N.A. = not applicable.

exercise. The estimates of Lerner's measure (L_I), presented in Table 1, are fairly consistent across the two models, and highly significant. This implies that it is not possible to reject the hypothesis that there exist positive price-cost differentials in the output market based on results from either the short-run or the long-run model.

Now turning to the Schankerman and Nadiri test, we conduct the test to see whether the data for the transformer industry conforms with the long-run model of economic behavior. The value of the test statistic (M) for the results reported was 25.43 with a 0.5% critical value of 10.6 for the χ^2 distribution with 2 degrees of freedom.[27] Thus the long-run equilibrium specification was rejected for the industry. This result implies that the services of capital stock in this industry are not employed up to the point at which marginal revenue product equals user cost in every period.

8.2. Estimation of dynamic cost of adjustment model

The rejection of the long-run model leaves open the question of how capital stocks are

[27] As frequently happens in practice, our W matrix (a consistent estimator of $\tilde{V} - \hat{V}$) had one negative element on the diagonal. We follow the precedent set in several studies (Schankerman and Nadiri (1986), Bernstein and Mohnen (1991)) of conducting the tests on the basis of the subvector of β corresponding to the 2×2 positive definite submatrix of W.

determined in this industry. We now turn our attention to the dynamic cost of adjustment model represented by (6.1), (6.2), (6.3), (6.4), and (6.5).[28]

The error terms appended to equations (6.1), (6.2), (6.3), and (6.4) are assumed to represent optimizing errors, but the error term added to equation (6.5) is primarily an expectation error which arises when the conditional expectations of the future values of the variables in (6.5) are replaced by their actual values. The error in the Euler equation ought to reflect expectational errors only, but it is also affected by measurement or optimizing errors, and these, in turn, may be correlated with contemporaneous values of the exogenous variables appearing in the system of equations. This leads to the recommendation (Pindyck and Rotemberg (1982)) that GMM estimation be carried out using a conditioning set of instrumental variables which contains only lagged variables. The instruments we used in the estimation are: a constant, the one period lagged values of the capital stock (K(t-1)), labor (L(t-1)), materials (M(t-1)), output (Y(t-1)), the logarithm of GDP(t-1), a time trend (T(t-1)), output price (P(t-1)) and, the effective tax rate on capital income, and the two-period lagged values of K, M, w_L, w_M, T, GDP, and P.

The empirical results of GMM in the dynamic cost of adjustment model are reported in Table 4. The model actually estimated here differs from the one developed in Chapter 5 in one respect: Adjustment cost is assumed to be a function of net, rather than gross

[28] The discount factor, $\alpha(t, t+1)$, in equation (6.5) is replaced by $1/(1+r_t)$, where r_t is the interest rate used in the calculation of the user cost.

Table 4

GMM Estimation results for the dynamic cost of adjustment model

Parameter	Estimate	Estimated standard error
B_L	46.9363	8.1055
B_{LL}	-6.7227	1.3699
B_{LM}	23.0569	11.9977
b_{KL}	-0.0185	0.8621E-02
b_{Ly}	0.0158	0.2681E-02
B_{LT}	0.5951	0.6183
B_M	1206.17	127.118
B_{MM}	-890.175	178.919
b_{KM}	-0.7418	0.1356
b_{My}	0.3917	0.0412
B_{MT}	32.9768	9.5678
a	2.4243	0.9748
ε	-2.0506	0.2891
b	-0.3409	0.1773
b_y	0.2794	0.0468
$\tilde{b}_{Ky}$	-7.28E-05	0.2930E-04
$\tilde{b}_{yy}$	-4.53E-05	0.9392E-05
b_{yT}	0.0053	0.2212E-02

Table 4. (continued)

λ	0.5601	0.1788
L_I	0.2731	0.0844
b_K	-0.2682	0.2136
b_{TK}	-4.31E-04	0.009
$\tilde{b}_{II}$	9.21E-04	0.0004
$\tilde{b}_{KK}$	4.27E-04	0.0002
$\tilde{\gamma}$	1.3810	0.6529

Table 5

R^2's and Durbin-Watson statistics from GMM estimation of the dynamic cost of adjustment model

Equations	R^2	D.W.
(6-1)	0.873	0.579
(6-2)	0.935	0.999
(6-3)	0.804	0.708
(6-4)	0.992	1.045
(6-5)	0.983	0.673

Note: Table 3's note on the calculation of R^2s applies here as well. The R^2s for equation (6-5) are reflective of the models fit of the capital series.

investment.[29] This change removes the three factors of $1 - \delta(t)$ appearing in equation (6.5). The conventional R^2 values and the Durbin-Watson statistics are presented in Table 5.

Overall the fit is good, as the R^2's are high in all five equations. Note the high R^2 of equation (6.5) is in contrast with the low R^2 in equation (6.6) in the long-run model. The estimates of the model's parameters generally have a good level of significance. Monotonicity requirements of the cost function with respect to the prices w_L, w_M, are met "at the industry level" at all sample points. Concavity of the variable cost function in input prices is well satisfied with a good significance level. The cost function is decreasing in capital stocks "at the industry level" for all years and the positive estimate of $\tilde{b}_{KK}$ indicates convexity in the quasi-fixed factor with a marginal significance level of 3.16%. The cost function is also increasing in output "at the industry level" for all years. Therefore we can say that the estimated industry variable cost function is well behaved.

As given in Table 4, and consistent with results form the short-run and long-run models, the own-price elasticity of output demand is negative and the income elasticity is positive.

Table 4 also presents estimates of the Lerner's index (L_I) and the conjectural elasticity (λ). Both are significantly different from zero but lower than the corresponding estimates obtained from the short-run and long-run models. The performance index is 0.273, which is higher than the 0.2 that was found by Appelbaum (1982) for the U.S. electrical products industry (SIC 36) in 1947-1971. Thus the results of estimation of the dynamic cost of

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[29] The model yielded a generally better fit with adjustment cost a function of net rather than gross investment.

adjustment model permit us to reject the hypothesis of price-taking conduct and competitive performance in the industry's output market.

As an indication of the strategic effect of capital investment, the market-share weighted average of the dynamic conjectural variation parameter, $\tilde{\gamma}$, is different from zero and statistically significant.[30] The significance of this result suggests that we can reject the null hypothesis that there is no strategic effect of investment in this industry. In other words, firms appear to recognize that their choices of capital investment will influence the imperfectly competitive output equilibrium in future periods. The estimate of $\tilde{b}_{II}$ provides evidence on the existence of costs of adjustment. As seen in Table 4, $\tilde{b}_{II}$ is significantly positive with a marginal significance level of 13.9% (in a one-tailed test) suggesting positive and convex adjustment costs. Moreover, the estimates of the adjustment cost and strategic effect parameters are jointly different from zero with a chi-square value of 9.81 against a $\chi^2_{2,0.01}$ critical value of 9.21. This result supports a rejection of the null hypothesis of the long-run model against the dynamic cost of adjustment model as an alternative.

Further, we proceed to assess the validity of the dynamic cost of adjustment model using the Schankerman and Nadiri test. The value of the test statistic (χ^2_4) was

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[30] However, the positive value turns out to be inconsistent with our theoretical result of equation (3.14) in Chapter 3. This inconsistency might be caused by different structures between the theoretical and the empirical models, e.g., in the empirical model, we have n firms and many periods rather than two firms and two periods. Also we may need to specify the empirical model to capture longer repercussions; that is, rivals' responses to an increase in own capital investment may extend beyond the next period.

26.70 with a marginal significance level of 0.002%, so that the dynamic model was also rejected.[31]

[31] The marginal significance level was higher than that in the test of the long-run model, implying a kind of endorsement of the dynamic cost of adjustment model over the long-run model.

CHAPTER 9. SUMMARY

In the past decades, industrial economists have developed a variety of approaches to measuring market power. Due to an increasing awareness of the limitations of the traditional SCP approach in measuring market power, the NEIO approach has been recently developed. The NEIO approach is firmly grounded in the neoclassical non-competitive theory of the firm to construct explicit structural models, and uses the latest econometric techniques to estimate structural parameters and to test structural hypotheses. NEIO studies for measuring market power can be broadly divided into static models and intertemporal models. Mostly specifications in the NEIO models have represented the capital investment decision of firms as being undertaken without recognition of the incentives for strategic behavior arising when firms engage in a capital investment game over time. As extensively noted in the theoretical literature on oligopoly behavior, inclusion of capital stocks not only gives a firm control over its cost function intertemporally, but also opens up the possibility of its strategic use of capital stocks to its benefit by influencing the market environment in future time periods.

The purpose of this dissertation is to measure the degree of market power within the context of each of three models; short-run, and long-run equilibrium models, and a dynamic cost of adjustment model with strategic capital investment; and to see how inferences of market power differ across the three cases.

Chapter 3 examines a two-period duopoly model of strategic investment behavior by imperfectly competitive firms. This chapter also generalizes Brander and Spencer's (1983) model of firms' strategic investment behavior by allowing for investment over time subject to convex adjustment costs. In the symmetric duopoly case, several features of the strategic equilibrium contrast with results for the naive equilibrium in which firms fail to exploit capitals' strategic role: i) Strategic firms "overinvest" in the first period in the sense that the initial investment in capital is larger than necessary to minimize adjustment costs. ii) In the strategic equilibrium, output and overall capital investment (for both periods combined) is larger than in the non-strategic equilibrium. Because the output market equilibrium is imperfectly competitive, this raises the possibility that welfare might be higher in the strategic equilibrium than in the non-strategic equilibrium. iii) Strategic firms face a situation reminiscent, in one respect, of the familiar "Prisoner's Dilemma" game. A firm can benefit by unilaterally "overinvesting" in order to influence the market outcome in a subsequent stage. But when both pursue these incentives, profits fall for both.

Chapters 4 and 5 develop comprehensive models for measuring market power within static and dynamic intertemporal frameworks. We delve into how modeling dynamic behavior of capital investment away from standard static models can lead to both different results and interpretations and how inferences of market power differ across models. Drawing upon lessons learned from the simple theoretical model in Chapter 3, we incorporate a strategic effect in the dynamic adjustment cost model's first order condition for optimal investment. Our dynamic cost of adjustment model involves a multi-firm, multi-stage generalization of the theoretical model. Chapter 4 starts to introduce a quadratic cost function that permits the measurement of market power without losing aggregation consistency, followed by deriving three equilibrium models for the presence of firm market power and finally by some discussion on the cost function properties in terms of industry-level variables.

Chapter 6 discusses the estimation methods. First, the statistical properties of three simultaneous equation systems from Chapter 5 are discussed. NL3SLS (non-linear three stage least squares) is used as an estimation method for two static equilibrium models. In addition, following Schankerman and Nadiri (1986), a specification test is conducted to see whether the long-run equilibrium model is consistent with the data. GMM suggested by Hansen and Singleton (1982) is used for the estimation of the dynamic adjustment cost model. We estimate the models by using data for the transformer industry producers, 1958-1991. The historical evidence indicates that there existed a price-fixing behavior among the companies making electrical equipment during the 1950s and 1960s.

Important results from the estimations are: i) The estimates of Lerner's measure are fairly consistent across the static models, and highly significant. This implies that it is possible to reject the hypothesis of price-taking behavior in the output market based on results from either the short-run or the long-run model. ii) The Schankerman and Nadiri test result shows that the long-run model may be rejected. This implies that the services of capital stock in this industry are not employed up to the point at which marginal revenue product equals user cost in every period. iii) The Lerner's index is lower in the dynamic model than that in the static models. As for the strategic effect of capital investment which is expressed as the market-share weighted average of the dynamic conjectural variation parameter, the statistically significant parameter suggests that we can reject the null hypothesis that there is no strategic effect of investment in this industry. iv) The result of a joint test with the estimates of the adjustment cost and strategic effect parameters supports a rejection of the null hypothesis of the long-run model against the dynamic cost of adjustment model as an alternative. However, the Schankerman and Nadiri test of the dynamic cost of adjustment model also leads to rejection.

APPENDIX. THE DATA FOR THE TRANSFORMER INDUSTRY

Data on price indices and quantities of output, capital, labor, materials, and investment.

U.S. transformer industry, 1960-90

Year	L^a	$w_L{}^b$	M^c	$w_M{}^d$	Q^c	P^d	$GDP(Z)^e$
1960	49.7	2.6539	1089.1986	0.287	1678.3105	0.438	513300
1961	47.4	2.7637	1084.8591	0.284	1720.4326	0.416	531800
1962	50.4	2.7182	1229.1228	0.285	1929.0726	0.399	571600
1963	47.8	2.7573	1199.6479	0.284	1914.7756	0.379	603100
1964	53.3	2.7654	1314.9306	0.288	2221.5424	0.376	648000
1965	57.5	2.8556	1454.7619	0.294	2633.1521	0.368	702700
1966	62.7	2.9681	1568.2120	0.302	2850.1313	0.381	769800
1967	69.7	3.0616	1728.9389	0.311	3053.0710	0.407	814300
1968	74.0	3.1662	1763.5512	0.321	3223.3332	0.420	889300
1969	73.6	3.2866	1793.7125	0.334	3429.8994	0.398	959500
1970	74.9	3.5914	1879.0960	0.354	3557.5307	0.405	1010700
1971	67.5	3.8548	1782.7397	0.365	3510.6870	0.393	1097200
1972	71.3	4.0126	1872.9946	0.374	3776.5625	0.384	1207000
1973	78.4	4.1632	2061.5385	0.390	4342.5688	0.397	1349600
1974	75.3	4.6972	2064.4172	0.489	4323.0932	0.472	1458600
1975	56.2	5.1672	1565.2014	0.546	3120.9675	0.558	1585900
1976	53.2	5.3590	1515.4515	0.576	3170.1569	0.573	1768400
1977	62.5	5.5968	1707.0741	0.622	3737.5205	0.605	1974100
1978	63.9	6.1909	1778.9864	0.671	3914.0158	0.635	2232700
1979	68.0	6.4382	1799.3343	0.751	4143.0698	0.671	2488600
1980	65.7	7.1293	1782.0665	0.842	4008.8552	0.734	2708000
1981	65.5	7.6656	1836.4939	0.907	3934.8193	0.830	3030600
1982	51.3	8.9863	1528.8172	0.930	3328.9919	0.883	3149600
1983	49.8	9.1686	1505.0686	0.947	3142.2863	0.901	3405000
1984	52.7	9.5218	1717.0061	0.982	3534.7873	0.917	3777200
1985	49.5	9.9495	1749.3902	0.984	3444.1860	0.946	4038700
1986	48.4	10.2190	1723.0452	0.972	3426.9875	0.956	4268600
1987	46.7	10.0749	1656.4000	1.000	3249.3000	1.000	4539900
1988	49.5	10.1353	1766.3919	1.092	3805.3481	0.991	4900400
1989	50.3	10.1570	1829.1702	1.145	3699.1579	1.069	5250800
1990	49.2	10.8902	1966.1104	1.139	3616.5502	1.148	5546100

Continued.

Year	K^c	w_K^d	r	J^d	depreciation rate	Tax rate	GDP deflator
1960	820.900	0.0689	0.0441	0.337	0.0621	0.5562	26
1961	852.599	0.1215	0.0435	0.337	0.1088	0.5775	26.3
1962	913.599	0.0280	0.0433	0.341	0.0072	0.5353	26.9
1963	926.700	0.0435	0.0426	0.345	0.0284	0.5321	27.2
1964	924.299	0.0535	0.044	0.351	0.0459	0.5271	27.7
1965	937.099	0.0472	0.0449	0.358	0.0459	0.4661	28.4
1966	990.500	0.0582	0.0513	0.368	0.0627	0.4600	29.4
1967	1096.90	0.0358	0.0551	0.382	0.0342	0.4604	30.3
1968	1187.69	0.0277	0.0618	0.400	0.0197	0.5135	31.8
1969	1261.69	0.0526	0.0703	0.418	0.0325	0.5490	33.4
1970	1322.50	0.0609	0.0804	0.444	0.0482	0.5244	35.2
1971	1359.69	0.0329	0.0739	0.468	0.0166	0.4971	37.1
1972	1357.00	0.0660	0.0721	0.487	0.0424	0.4637	38.8
1973	1373.00	0.0869	0.0744	0.496	0.0422	0.4455	41.3
1974	1396.50	0.0530	0.0857	0.534	0.0472	0.4389	44.9
1975	1382.69	0.0105	0.0883	0.606	0.0514	0.3974	49.2
1976	1381.80	0.0862	0.0843	0.640	0.0374	0.5239	52.3
1977	1393.90	0.0973	0.0802	0.680	0.0627	0.4451	55.9
1978	1427.00	0.0793	0.0873	0.722	0.0388	0.4274	60.3
1979	1451.09	0.0912	0.0963	0.777	0.0485	0.4270	65.5
1980	1470.69	0.1037	0.1194	0.851	0.0541	0.3745	71.7
1981	1484.19	0.1513	0.1417	0.920	0.0503	0.3534	78.9
1982	1484.80	0.2937	0.1379	0.962	0.0531	0.5370	83.8
1983	1469.69	0.3216	0.1204	0.961	0.0544	0.4740	87.2
1984	1463.90	0.3470	0.1271	0.961	0.0625	0.4748	91.0
1985	1463.40	0.3852	0.1137	0.960	0.0566	0.5727	94.4
1986	1460.50	0.2639	0.0902	0.981	0.0480	0.5727	96.9
1987	1420.80	0.2239	0.0938	1.000	0.0723	0.3507	100.0
1988	1395.90	0.2363	0.0971	1.018	0.0637	0.3907	103.9
1989	1374.00	0.2422	0.0926	1.033	0.0697	0.3753	108.5
1990	1364.50	0.2703	0.0932	1.048	0.0826	0.3792	113.3

a. millions of hours.
b. average hourly compensation (current dollars).
c. millions of 1987 dollars.
d. current dollars/1987 dollars.
e. millions of current dollars.

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