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DYNAMIC OLIGOPOLY MODELS OF INVESTMENT BEHAVIOR

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Abstract

This thesis consists of three chapters on dynamic oligopoly models. In the first chapter, I emphasize the importance of strategic behavior by entrants. I provide a model of endogenous entry in which potential entrants can influence their product quality in the entry stage by varying the level of sunk investments they make at the time of entry. If the entrants are allowed to influence the distribution of quality in their favor, I demonstrate that they act strategically and their decisions depend on the market structure, i.e., the state vector of the incumbents. Whenever the industry consists of firms with low quality goods, entrants invest substantially and vice versa.

In the second chapter, I focus on the effects of import competition on the investment incentives and the productivity of domestic firms. Firm-and plant-level empirical studies typically find that trade liberalization squeezes price-cost margins among import-competing firms, that this heightened competitive pressure induces productivity gains among these same firms, and that further efficiency gains come from market share re-allocations. Using a computable industrial evolution model to simulate the dynamic effects of import competition, we explore what types of managerial behavior, long-term transition paths and welfare effects are consistent with this set of stylized facts.

In the third chapter, I analyze the linkages between entry costs, firms' investment incentives in oligopolistic markets and welfare. Policy makers argue that high entry costs create significant economic inefficiencies in perfectly competitive markets. Hence, it is argued that policies that promote entry can improve welfare. However, the response in an oligopolistic market is not clear. Increased entry can potentially discourage investments and lead to a welfare loss in the long run. In this study, I analyze empirically how policies that lower entry costs affect welfare and find evidence that such policies might lead to a welfare loss. To do this analysis, first, I develop a structural industrial evolution model with strategic interactions in which firms choose prices in the static game and enter, exit, and invest in the dynamic game, subject to uncertainty and idiosyncratic shocks. Then, I estimate the parameters of both the static and the dynamic game for the Colombian engines and turbines industry. The estimation recovers the demand and cost parameters as well as the investment costs and scrap value and sunk entry cost distributions. I then simulate the model to analyze the effects of sunk entry costs on the investment behavior and the strategic use of investments. I find that lower sunk entry costs lead to a decrease in welfare by reducing incentives to invest. The industry is dominated by high-cost firms which charge higher prices. Firms also find it optimal to accommodate entry rather than spend resources on entry deterrence.

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Chapter 1

Strategic Investment and Endogenous Entry

1.1 Introduction

Over the last decade, economists have made substantial progress in quantifying and explaining the patterns of firm entry, exit, investment, and growth in real world markets. These markets often contain elements of oligopoly competition and enormous heterogeneity in the characteristics and performance of firms. The theoretical literature in industrial organization has provided several models of industry dynamics that are able to explain some of the empirical regularities. In this paper I extend one of these models by Pakes and McGuire [62] and Ericson and Pakes [29] (PEM) and use it to simulate patterns of industrial evolution.

PEM develop the foundations of dynamic Markov-Perfect Nash Equilibria and provide an algorithm for computing such equilibria. PEM focuses on explaining how firms make entry, exit, and investment decisions in order to maximize the expected discounted value of future profits in an oligopolistic market. Its main focus is on the heterogeneity of firms and the uncertainty in returns caused by the randomness in the outcome of investment process. At any given period, a firm's market share, price, and profit depend on the number of currently active firms, their quality levels, and the quality of an exogenous outside option. Firms must invest to improve their position against their competitors, including the outside option. However, investment has a random component to its outcomes and is not sufficient to improve one's own quality. If a potential entrant finds it profitable to enter, it draws an entry cost from a distribution and becomes an incumbent next period with a pre-determined quality level.

One unappealing part of the Pakes-Mcguire-Ericson algorithm is their assumption about entry. They assume that all firms enter with an identical known quality level. In actual industries we observe that firms not only enter with different qualities, but may also choose their quality levels by the type of investments they make.[1] In this paper, I extend the PEM algorithm by introducing endogenous quality choice in which a potential entrant can choose to have a higher (lower) quality level by spending a higher (lower) entry cost. Specifically, a potential entrant draws its quality level from a distribution that is conditional on the amount of investment made by the entrant. Higher investment levels present the entrant a more favorable distribution of quality levels.

In Section 1.2, I review the PEM model in more detail. Then in Section 1.3, I describe my extension in which entrants can influence their quality draws. Section 1.4 lays out the model using two different density functions. Then, in section 1.5, I present results with the adjusted algorithm. Finally, I conclude in section 1.6.

1.2 Pakes-McGuire-Ericson Model

There are many specific oligopoly models that can be covered by their framework. I will concentrate on a specific oligopoly model where firms have differentiated products and simultaneously choose output prices. The current-period pay-off to an active firm with product quality level i is determined by a profit function $\pi(i, s)$, where $i \in Z^+$, the

[1] One can think of advertisement as a tool to affect the perceived quality by the consumers.

set of positive integers, and $s = [s_k; k \in Z^+]$ is a vector whose k^{th} element gives the number of active firms at quality level k. That is, profit functions are static in the sense that they are determined purely by the state variables i and s. The derivation of profit functions is as follows: Let the utility consumer r gets from consuming good f be given by

$$U_{rf} = i_f - \tilde{p}_f + e_{rf} \tag{1.1}$$

where i_f is the quality of good f, $\tilde{p}_f$ is the price of good f, and e_{rf} is the unobservable differences among consumers. Then, consumer r chooses good f if for g = 0,1,$\cdots$,N

$$\begin{aligned} e_{rf} - e_{rg} &\geqslant (i_g - i_f) + (\tilde{p}_f - \tilde{p}_g) \\ &= (i_g - i_0) - (i_f - i_0) + (\tilde{p}_f - p_0) - (\tilde{p}_g - p_0) \\ &= \omega(i_g) - \omega(i_f) + p_f - p_g \end{aligned} \tag{1.2}$$

where $\omega(i_f) = i_f - i_0$, $p_f = \tilde{p}_f - p_0$. Note that both the quality and price of the goods are measured relative to the quality and price of the outside option. If the e_{rf} are assumed to be drawn from an independent (across consumers and across goods) extreme value distribution,[2] then the probability that a randomly chosen consumer will choose good f is

$$\sigma[i_f; p, s] = \frac{exp[\omega(i_f) - p_f]}{1 + \sum_g exp[\omega(i_g) - p_g]} \tag{1.3}$$

[2]The cumulative density function of an extreme value distribution is given by $F(e \leq e^*) = exp[-exp(-e^*)]$.

where p is the vector of prices that satisfy (1.2) and s is as defined before. With N firms, no fixed costs of production, and constant marginal cost equal to mc, a unique Nash equilibrium is given by N equations given by[3]

$$-[p_f - mc]\sigma_f[1-\sigma_f] + \sigma_f = 0 \tag{1.4}$$

Then profits are simply

$$\pi(i,s) = (p(i,s) - mc)M\sigma(i,s) \tag{1.5}$$

where M is the measure of market size, and p and σ are the equilibrium price and the market share implied by (1.3) and (1.4).[4]

Given the market structure, incumbents with product quality i decide whether to remain active or exit and sell their firm for a scrap value ϕ. Those that remain active then choose an investment level x, which affects their future product quality. It costs $c(x)$ and shifts the probability distribution for their next-period realization on i, which is stochastically increasing in x. Investing x increases a firm's product quality by υ, where υ takes a value one with probability $\frac{ax}{1+ax}$ and zero with probability $\frac{1}{1+ax}$, where $a > 0$ is a constant. Note that the model assumes that product quality i is integer valued. So investment might increase a product's quality to the next integer. Note also that investment is necessary for improvement in quality. That is, if a firm chooses not to invest, then quality of his product will not improve. Further, every firm faces industry-wide competition from the outside alternative, which also evolves over time.

[3]See Caplin and Nalebuff [18] for details.

[4]See Berry [11] and Berry, Levinsohn, and Pakes [12] for more information about discrete choice models.

The improvement in the quality of the outside alternative is denoted by ς and has a probability distribution $\mu(.)$. Specifically, we have $\mu(1) = \delta$ and $\mu(0) = 1 - \delta$. So, the increment τ to a firm's quality is denoted by $\tau = \upsilon - \varsigma$. Thus each firm's quality is measured relative to the quality of the outside option, and will drift downward by δ per period, on average, if $\upsilon = 0$.

Before making optimal decisions about exit and investment, an incumbent has to have a belief system on the future states of the industry. Let $\hat{s}_{t+1}$ be the vector that has the number of active competitors at each quality level as its elements. That is,

$$\hat{s}_{t+1} = s_{t+1} - e[i_{t+1}] \tag{1.6}$$

where $e[i_{t+1}]$ is a vector that puts one in the i_{t+1} spot and zero elsewhere. Since $\hat{s}_{t+1}$ is the vector of qualities of an incumbent's competitors, we subtract one from the number of firms with quality i_{t+1}. Then for a firm currently at quality i, investing x, and operating in a market with structure s, the value function is given by

$$\begin{aligned} V(i,s) = \max\{\phi, sup_x[\pi(i,s) - c(x) + \\ \beta \sum V(i+\tau, \hat{s} + e[i+\tau])q^i(\hat{s}|s,\varsigma)p(\tau|x,\varsigma)\mu(\varsigma)]\} \end{aligned} \tag{1.7}$$

where β is the discount factor, $e[i+\tau]$ is a vector that puts one in the $i+\tau$ spot and zero elsewhere, and $q^i(\hat{s}|s,\varsigma)$ is the firm's perceived distribution of future competitors' qualities including beliefs about entry and exit. Note that $e[i+\tau]$ vector has $i+\tau$ as its argument simply because the incumbent's future quality is current quality plus the increment in the quality. If the max operator returns ϕ, it is optimal for the entrepreneur to sell the firm for scrap, otherwise it chooses the investment level x that maximizes the term in square brackets and proceeds to compete in the product market.

Entry is assumed to be sequential from a pool of potential entrants. If the expected discounted cash flow of the m^{th} potential entrant exceeds the entry cost, $x_e(m)$, then entry occurs. In this case, the entrant pays $x_e(m)$ and draws an entry quality i^e from $p^e(.)$. Thus, if $q_{m-1}(\hat{s}|s,\varsigma)$ denotes the m^{th} entrant's beliefs about future quality structure, then the Bellman equation is

$$V^e(s,m) = \beta \sum V(i^e, \hat{s} + e[i^e]) q_{m-1}(\hat{s}|s,\varsigma) p^e(i^e|\varsigma)\mu(\varsigma) \tag{1.8}$$

The algorithm, on the other hand, is different from the theoretical model in two ways: First, the maximum number of entrants is fixed at one by setting $x_e(1) = x_e < \infty$ and $x_e(2) = \infty$. Second, the entry quality of an entrant is fixed at i^{e*} instead of a random draw from $p^e(.)$. Specifically, the algorithm utilizes $p^e(i^e = i^{e*} - 1) = \delta$ and $p^e(i^e = i^{e*}) = 1 - \delta$. That is, a firm enters with quality $i^e = i^{e*}$, which might stay $i^e = i^{e*}$ with probability $1-\delta$, or drop to $i^e = i^{e*} - 1$ next period depending on whether the quality of the outside option stays the same or goes up by one.[5,6]

[5] In the publicly available version of the algorithm, the entrants actually draw their entry cost x_e from a uniform distribution $U[x_L, x_H]$. This is done to deal with the possible discontinuity in the incumbents' value functions.

[6] See Ericson and Pakes [29] for formal definition and proof of the existence of a rational expectations Markov-perfect Nash Equilibrium.

1.3 A Critique

Even though the PEM algorithm does a good job of reproducing some of the major facts in actual market dynamics, it can be improved so as to provide a better approximation. More specifically, as mentioned in PEM, assumptions on entry formulations could have taken different forms. If heterogeneity of firms is a crucial starting point of PEM, then why do not we allow entrants to be heterogeneous? For example, Aw, Chen, and Roberts [7] find evidence of such heterogeneity in the Taiwanese manufacturing data.[7] The theoretical model of PEM allows heterogeneity of entrants via random draws of qualities. However, this is not implemented in the algorithm.[8] I generalize the latter and extend the PEM framework to allow potential entrants the possibility of affecting their entry level qualities simply by agreeing to a higher entry cost. That is, I allow entrants to have a control on $p^e(i^e)$ which I think is a better representative of some actual entrant choices. This is what I call endogenous entry quality. Hence, this paper provides a modified algorithm, while leaving the theoretical results of PEM untouched. One might easily duplicate the results of PEM algorithm with one set of parameter or obtain slightly differing results with a different one. Next, I go over the parametrization of PEM and then lay out endogenous entry quality setting with two examples.

[7] Even though the measure they use is firm productivity, Pakes-McGuire framework uses productivity, efficiency and quality interchangeably.

[8] See Pakes et al. [61] for more details on how the code is implemented.

1.4 The Model

The parameter values that PEM use for the base is given in Table 1.1. PEM also use a specific functional form for $\exp(\omega(i))$, which appears in the market share equation(s). They specifically choose

$$\exp(\omega(i)) = \begin{cases} \exp(i) & \text{if } \; i \leq i^* \\ \exp(i^*)[2 - \exp(i^* - i)] & \text{if } \; i > i^* \end{cases} \tag{1.9}$$

which provides bounded profit functions for sufficiently large i. In my model, I keep most of these parameter values and most of the structure of the algorithm untouched unless I mention otherwise. I modify the sections which have to do with the entry decisions of the potential entrant and the beliefs of the incumbents about entry. Next, I describe my model with two examples in which entrants can influence their product quality.

1.4.1 Poisson Distribution

In this section, I assume potential entrants draw their qualities from a poisson distribution (PD) with a parameter η. Then, probability of drawing a quality level i^e, given η, can be written as

$$p^e(i^e|\eta) = \frac{\eta^{i^e} exp(-\eta)}{i^e!} \tag{1.10}$$

Entrants can influence their quality draws by choosing the parameter η. This has a cost $c(\eta)$, where $c(.)$ is a continuous and convex function. So, the entrant's Bellman equation is given by

$$\widetilde{V}^e(s,m) = sup_{\eta \geq 0}[V^e(s,m) - c(\eta)] \tag{1.11}$$

where $V^e(s,m)$ is as defined in (1.8). Note that $p^e(i^e|\eta)$ is adjusted for the changes that are implied by (1.10). Having solved for η^* in (1.11), if the entrant finds it profitable, i.e., $\widetilde{V}^e(s,m)$ evaluated at η^* is positive, then the entrant pays $c(\eta^*)$ as the entry cost, and becomes an incumbent next period by drawing a quality level i^e from the probability distribution as defined in (1.10).[9]

Incumbents, on the other hand, solve a different problem than the one in the standard PEM algorithm. Briefly, having observed the current market structure, an incumbent can solve for the potential entrant's problem, and thus, he can deduce the probability distribution $p^e(i^e|\eta^*)$. First, define

$$\hat{V}(i,s) = \sum V(i+\tau, \hat{s}+e[i+\tau])q^i(\hat{s}|s,\varsigma)p(\tau|x,\varsigma)\mu(\varsigma) \tag{1.12}$$

which is the last term in (1.7). Then the incumbent's new problem is given by randomizing over possible values of j:

$$\widetilde{V}(i,s) = \max\{\phi, sup_x[\pi(i,s) - c(x) + \beta \sum_j \hat{V}(i,s)p^e(j|\eta^*)]\} \tag{1.13}$$

Note that, as mentioned in section 1.2, $q^i(\hat{s}|s,\varsigma)$ represents an incumbent's beliefs about future competitors' qualities, including the new entrants. So, one could have kept (1.7) as the incumbent's problem, keeping in mind that $q^i(\hat{s}|s,\varsigma)$ now incorporates $p^e(i^e|\eta^*)$. To be exact, I assume $q^i(\hat{s}|s,\varsigma)$ only includes the belief that if there is an entrant, then its quality is $i^e = i^{e*}$, which is what the PEM algorithm does.

[9]Note that, given η^*, the mean and variance of a poisson distribution are both equal to η^*.

1.4.2 Binomial Distribution

A second way to model the probability distribution of quality levels faced by an entrant is to use a binomial distribution (BD). Now, consider a binomial distribution defined by

$$Pr(j = k) = \begin{pmatrix} n \\ k \end{pmatrix} r^k (1-r)^{n-k} \qquad k = 0, \cdots, n \tag{1.14}$$

where j denotes the total number of successes in n trials, and r denotes the probability of success. In my adaptation of the binomial distribution, n is the maximum quality level, which is fixed exogenously, and k is the draw of quality level. More importantly, I assume the success probability r is an increasing and concave function of the parameter η. Analogous to an incumbent's problem, I utilize $r(\eta) = \frac{b\eta}{1+b\eta}$, where $b > 0$ is a constant. Higher values of b imply a higher probability of success in the context of the binomial distribution. Hence, for a given η, the expected value of the draw of quality level is an increasing function of b. Then (1.10) can be rewritten as

$$p^e(i^e|\eta) = \begin{pmatrix} i^{max} \\ i^e \end{pmatrix} \left(\frac{b\eta}{1+b\eta}\right)^{i^e} \left(\frac{1}{1+b\eta}\right)^{i^{max}-i^e} \qquad i^e = 0, \cdots, i^{max} \tag{1.15}$$

where i^{max} is the highest quality level. To summarize, an entrant chooses η^* just like in section 1.4.1, which positively affects his draw of quality, and costs $c(\eta^*)$. Hence, the entrant's problem is as in (1.11) where the probability distribution is replaced by (1.15).

One difficulty with this setting is that an analytical solution is tedious. In order to get over this problem, I allow the entrant to solve his problem by choosing a η from the set $X \subset Z^{+}$. In particular, I implement $X = \{\eta \in Z^{+} : \eta \leq 10\}$. An entrant evaluates the value function defined in (1.11) for every point in X and chooses η^{*} for which the value function is maximized. Then entry occurs if (1.11) returns a positive value for η^{*}. In that case, the entrant pays the entry cost $c(\eta^{*})$ and draws a quality from $p^{e}(i^{e}|\eta^{*})$. Incumbents, on the other hand, solve (1.13) just like in section 1.4.1.

1.5 Results

For both specifications described in section 1.4, experiments are simulated 10 times for 5000 periods starting with [6 0 0] as the initial market structure. Note that in PEM framework, quality levels are restricted to integers. Hence, a state vector [6 0 0] implies an industry with maximum three firms, where one firm has quality level $i = 6$. The parameter values that are used are provided in Table 1.2. First, I show PD specification can reproduce the results of PEM. Second, using PD, I analyze the effects of higher entry costs on the industry structure. Third, I present the results from BD simulations. I also analyze the effects of a change in the parameter of BD, i.e., the constant b.

1.5.1 Illustrations with Poisson Distribution on Entry Quality

This section has two objectives: First, I demonstrate that with the right choice of parameter values, equivalence between industry structures when there is exogenous entry quality and endogenous entry quality can be obtained. Second, I demonstrate the effects of an increase in the entry costs. Summary statistics are provided in Table 1.3. The first column replicates the findings of PEM using their assumption that entrant quality is exogenous. The second and third columns introduce the endogenous quality choice by the entrants.

The findings from the simulations with PEM algorithm are summarized in the first column of Table 1.3. There exist three firms in the industry for 98.42 percent of the time. This is because the entry quality is set at $i^{e*} = 11$. In an industry, where mean quality is 8.08, entry quality of $i^{e*} = 11$ might not be plausible. However, the reason for this choice of entry quality is explained in the next paragraph. Entry and exit take place 1.58 and 1.54 percent of the time, which corresponds to roughly 75 periods. Incumbents invest 0.75 units on average and realize 30 percent mark-ups. One firm concentration ratio is found to be 38 percent on average indicating evenly distributed market shares among the three firms. Firms live approximately 191 periods and make 18.54 units on average. Finally, consumer surplus is 316.79 units and producer surplus is 66.84 units on average.[10]

Next, I simulate the endogenous entry quality framework. Summary statistics are given in the second column of Table 1.3. The solution to the entrant's problem is found to be $\eta^* = 11.67$ on average. Since the purpose of this subsection is to reproduce the results of the exogenous entry quality framework, I simulate the PEM algorithm by setting entry quality equal to 11. Note that the algorithm only allows for integer quality levels. I also specify the distribution of entry costs in PEM algorithm as a uniform distribution with bounds 11 and 12. Note also that I set $c(\eta^*) = \eta^*$ in the endogenous entry quality framework. Hence in exogenous entry quality case, entrants enter with quality 11, which

[10]Note that calculation of producer surplus includes profits, entry costs, scrap values, and costs of investment.

costs them an amount between 11 and 12. In endogenous entry quality case, entrants enter with quality 11.67 on average, which costs them 11.67 on average. In general, endogenous entry quality with poisson distribution and exogenous entry quality with PEM algorithm return almost identical results. An entry quality of $i^{e*} = 11$ provides a significant incentive to enter, and thus, 98.4 percent of the time we observe 3 firms in the industry.[11] One important result is that mean entry quality has a variance of 0.1 (standard deviation 0.32) in the endogenous entry quality framework. This is because the choice eta^* of an entrant varies depending on the state of the incumbents at the time of entry. In short, potential entrants behave strategically when they are making their investment decisions. I will elaborate on this in section 1.5.2.

Next, I simulate what happens when the cost of entry is increased fourfold. The results are reported in the last column of Table 1.3. Two important consequences are worth emphasizing. First, entrants choose smaller η^* ($\eta^* = 9.22$) on average. Higher sunk entry cost forces the entrants to invest less at the time of entry since entry is less profitable. In fact, the potential entrant chooses not to enter the industry with two incumbents whenever the incumbents have high quality goods. Nonetheless, in the low entry cost case, entry by a third firm is profitable even when both incumbents have the highest quality ($i^{max} = 19$) goods. Second, high entry costs increase the variation in the mean quality of the entrants. The variance increases from 0.1 to 0.435. This is because of the amount of investment η^* the entrants make. In the low entry case, the smallest η^* is 11.81 and the biggest is 12.07. Whereas, in the high cost case, the smallest η^* is

[11]This implies that the maximum number of firms should be increased for a better representation of the industry. Since the emphasis is more on the fact that endogenous entry quality simulation replicates the exogenous entry quality results, this fact will be disregarded.

9.09 and the biggest is 10.27. It can be argued that when entry costs are low, the choice η^* of a potential entrant does not depend much on the state of the industry, i.e., the incumbents' qualities.

As expected, higher entry costs deter entry, especially by a third firm. Industry consists of two firms for 82.28 percent of the time. Entry and exit are observed less frequently compared to the low cost case. Percentage of periods with exit drops from 1.56 to 0.62 and percentage of periods with entry from 1.60 to 0.64. Firms live longer lives on average (191.43 versus 333.88 periods) but accumulate lower payoffs (18.06 versus 8.23 units). Once there are two firms in the industry, they live until it becomes unprofitable to operate. Without competition from a third firm, this takes longer compared to the low entry cost scenario. One would expect firms to accumulate higher payoffs in an industry which operates with two firms in most periods and which has very little competition. However, the increase in entry costs from 11.67 to 36.88 units, which is four times 9.22, reduces firms' payoffs by approximately 25.21 units on average. Note that mean value drops from 18.06 to 8.23 units, which is approximately 9.83 units on average. This implies that firms are actually making higher periodic profits but those profits are not sufficient to compensate for the increase in sunk entry costs. Higher entry costs also result in a higher one-firm concentration ratio (50% versus 38%) and higher price-cost margins (1.39 versus 1.32), both of which are clear consequences of less competition. Mean total investment for the industry drops to 1.96 units, because there are fewer active firms. However, as returns to investment are higher with fewer firms in the market, individual firms invest more (mean weighted investment is 0.86 units). Less competition in the market leads to higher prices, and this hurts the consumers (265.8 versus 313.69 units).

On the producers' side, increase in the profits through higher prices is matched by a decrease through higher entry costs (67.09 versus 67.11).

1.5.2 Illustrations with Binomial Distribution on Entry Quality

Now I turn to simulations with BD, which is described in section 1.4.2. This section has two objectives: First, I demonstrate that, for a given b as explained on section 1.4.2, the entrants behave strategically while making entry decisions. That is, their choices for η^* depend on the quality levels of the incumbents. Second, I analyze how these findings together with the summary statistics for the industry respond to a higher b. Note that, for a given η, an increase in b increases the probability of success, which implies a stochastically increasing draw of quality level. I start with a cost structure $c(\eta) = 0.5\eta^{2.5}$ and $b = 0.1$. In order to illustrate the strategic behavior of the entrants, I plot the choice of η^* versus the state vector of the incumbents. First, I plot the choices of an entrant versus possible quality levels of an incumbent. This relationship is given in Figure 1.1. A negative correlation between the incumbent's quality level and the choice of η by the entrant is evident. If the incumbent has a quality level $i = 1, \cdots, 5$, the entrant's choice is $\eta^* = 5$, whereas it is $\eta^* = 4$ for $i = 6, \cdots, 11$, and $\eta^* = 3$ for $i = 12, \cdots, 19$. Whenever an incumbent has a high product quality, a potential entrant cannot capture sufficient market share, and thus, makes low static profits. Hence, the return to entry is low and the entrant chooses not to invest substantially. Even though defeating the incumbent by choosing a higher η is an option, it is not profitable because of higher entry costs. Next, I simulate BD with higher values for b. The entrant's decision for $b = 0.125$ versus the incumbent's state is given in Figure 1.2. The set of η's that are chosen by the entrants is 4,5 whereas it is 3,4,5 for $b = 0.1$. (In fact, when the simulation is done with $b = 0.175$, this set shrinks to $\eta^* = 4$.) It is quite interesting to observe a degenerate distribution of η, which actually is the quality of an entrant implemented in PEM, as the parameter b increases. Table 1.4 presents results from the simulations with $b = 0.1$ and $b = 0.125$. A clear implication of a greater b is that, given η, the probability of a higher quality draw is higher. Hence mean entry quality increases from 4.69 to 4.75 units as a result of an increase in b. The variance of mean entry quality decreases from 0.048 (standard deviation 0.22) to 0.012 (standard deviation 0.11). This is because an increase in b implies a smaller set of η^* as presented above. (Simulation with $b = 0.175$ results in zero variance since the decision set shrinks to $\eta^* = 4$). The market, on the other hand, becomes more competitive. Entry and exit are observed more frequently (2.76% versus 1.24% for exit and 2.8% versus 1.26% for entry). The market consists of three firms for approximately 65 percent of the time, but this does not imply a higher average quality (8.11 versus 8.1 units). It simply implies there are more firms with similar quality levels. As expected, more competition leads to smaller mark-ups, smaller average firm values (2.04 versus 4.03 units), and shorter lifespans (93.07 versus 162.88 periods). Consumers are better off with more competition (270.86 versus 243.14 units), whereas producers are worse off (67 versus 78.26 units). Finally, Figure 1.3 and 1.4 summarize the optimal choices of η when the entrant faces two incumbents. Figure 1.3 illustrates the strategic behavior of the entrants for $b = 0.15$. The decision of an entrant is plotted against quality levels of two incumbents. The entrants invest substantially ($\eta^* = 4$) whenever both incumbents have low quality goods, moderately ($\eta^* = 3$) whenever one incumbent has medium to best quality and the other has low quality good, and too little

($\eta^* = 2$) whenever both incumbents have medium to high quality goods. Next, Figure 1.4 illustrates the choices of the entrants for $b = 0.175$.[12, 13] Now, similar to the cases with one incumbent, the set of choices of η shrinks. The entrants invest substantially ($\eta^* = 4$) whenever both incumbents have low quality goods, and moderately whenever both incumbents have medium to high quality goods. To clarify Figures 1.3 and 1.4, consider a market structure with two incumbents both with quality $i = 10$ so that the state vector is simply [10 10 0]. A potential entrant chooses $\eta^* = 2$ when $b = 0.15$, whereas the choice is $\eta^* = 3$ for $b = 0.175$. In fact, a move from $\eta^* = 2$ to $\eta^* = 3$ is evident for a significant number of state vectors.

1.6 Conclusion

In this paper, I make a simple contribution to the Pakes-McGuire algorithm by making entrants' initial quality decisions endogenous. I lay out a model of endogenous entry quality in which potential entrants can influence their product quality in the entry stage by varying the level of sunk investments they make at the time of entry. The algorithm allows the entrants to influence the distribution of quality draw in their favor. Specifically, I allow entrants to choose η, which will determine the conditional distribution $p^e(i^e|\eta)$ of entry qualities, and cost them $c(\eta)$. Numerical illustrations using two distribution functions for $p^e(i^e|\eta)$, the poisson distribution and the binomial

[12] Note that two-dimensional figures, such as Figure 1.1 and 1.2 are not exactly subsets of three-dimensional ones, such as Figure 1.3 and 1.4. This is because former two figures come from simulations with maximum number of firms fixed at two, and later two figures from simulations with maximum number of firms fixed at three.

[13] I use b=0.1 and b=0.125 for two-dimensional presentations, and b=0.15 and b=0.175 for three-dimensional presentations only because the effect of such an increase on the entrant's problem is more clearcut.

distribution, show the importance of strategic behavior by the entrants at the stage of entry. It is demonstrated that the entrants' decisions depend on the market structure, i.e., the vector of qualities of the incumbents. Whenever the industry consists of firms with low quality goods, entrants invest substantially. However, they invest too little if the incumbents have fairly high quality goods. I also provide illustrations in which I analyze the reaction of the market variables to changes in entry costs and changes in parametrization of probability distributions. In fact, in real market dynamics, entrants suffer from "brand recognition" which strongly restricts their market shares. It usually takes a few years for a new firm to build up a consumer base and increase its market share. If one associates the variable quality in this model with consumers' perceived quality (or recognition), then the finding that the entrants invest little matches with the empirical findings. There is one point that is worth reminding. Note that all the decisions, both incumbents' and entrants', are based on the discounted sum of future profits given the beliefs on others' strategies. Behavioral factors, such as managerial incentives (agency problems) (Hart [39]) and threat of exit (Schmidt [**?**] and Aghion, Dewatripont and Rey [4]) are not allowed within the PEM model. These issues cannot be captured within this framework. Thus, they are not addressed in this thesis and are left for future studies.

Table 1.1.
Parameter Values for the Base Case

Marginal cost of production (mc)	5
Market Size (M)	5
Discount factor (β)	0.925
Scrap Value (ϕ)	0.1
Sunk Entry Cost (x_e)	0.2
Max number of active firms	6
Max Quality (i^{max})	21
Investment efficiency (a)	3
Probability of Innovation in the outside good (δ)	0.7
Entry Quality (j^*)	4
Cost of Investment ($c(x)$)	x

Table 1.2.
Parameter Values

	PEM	PD and BD
Marginal costs of production (mc)	5	5
Market Size (M)	5	5
Discount factor (β)	0.925	0.925
Scrap Value (ϕ)	0.1	0.1
Sunk Entry Cost (Bounds of uniform distribution)	11-12	NA
Entry Quality (i^{e*})	11	NA
Max Quality (i^{max})	19	19
Investment efficiency (a)	3	3
Probability of Innovation in the outside good (δ)	0.7	0.7
Cost of Investment (c)	1	1

Table 1.3.
Summary Statistics (Poisson Distribution)

		Exogenous Entry Quality	Endogenous Entry Quality
		$c(\eta^*) = \eta^*$	$c(\eta^*) = 4\eta^*$
Periods with 0 firms	0.00%	0.00%	0.00%
Periods with 1 firms	0.02%	0.02%	0.02%
Periods with 2 firms	1.56%	1.58%	82.28%
Periods with 3 firms	98.42%	98.40%	17.70%
Periods with exit	1.54%	1.56%	0.62%
Periods with entry	1.58%	1.60%	0.64%
Periods with entry and exit	1.54%	1.56%	0.05%
Mean investment	2.25 (0.05)	2.24 (0.07)	1.93 (0.09)
Mean weighted investment	0.75 (0.01)	0.75 (0.03)	0.86 (0.03)
Mean price-cost margin	1.32 (0.01)	1.32 (0.01)	1.39 (0.09)
Mean one-firm concentration ratio	0.38 (0.01)	0.38 (0.01)	0.5 (0.01)
Mean quality	8.08 (0.08)	8.14 (0.1)	8.21 (0.09)
Mean domestic share	0.99 (0.01)	0.99 (0.01)	0.98 (0.01)
Mean entry quality	11 (NA)	11.67 (0.32)	9.22 (0.66)
Mean value	18.54 (0.77)	18.06 (1.48)	8.23 (3.54)
Mean lifespan	191.21 (19.52)	191.43 (22.57)	333.88 (52.84)
Mean consumer surplus	316.79 (10.79)	313.69 (13.30)	265.8 (13.56)
Mean producer surplus	66.84 (4.49)	67.11 (5.52)	67.09 (13.4)

Table 1.4.
Summary Statistics (Binomial Distribution)

	Endogenous Entry Quality	
$c(\eta^*) = 0.5\eta^{2.5}$	$b = 0.1$	$b = 0.125$
Periods with 0 firms	0.00%	0.00%
Periods with 1 firms	0.04%	0.04%
Periods with 2 firms	79.36%	35.12%
Periods with 3 firms	20.60%	64.84%
Periods with exit	1.24%	2.76%
Periods with entry	1.26%	2.80%
Periods with entry and exit	0.58%	1.86%
Mean investment	2.04 (0.09)	2.29 (0.05)
Mean weighted investment	0.91 (0.03)	0.87 (0.02)
Mean price-cost margin	1.4 (0.01)	1.35 (0.01)
Mean one-firm concentration ratio	0.5 (0.01)	0.43 (0.01)
Mean quality	8.1 (0.10)	8.11 (0.06)
Mean domestic share	0.98 (0.01)	0.99 (0.01)
Mean entry quality	4.69 (0.22)	4.75 (0.11)
Mean value	4.03 (1.42)	2.04 (0.95)
Mean lifespan	162.88 (25.96)	93.07 (14.84)
Mean consumer surplus	243.04 (30.87)	270.86 (32.12)
Mean producer surplus	78.26 (18.27)	67 (17.25)

Fig. 1.1. Entrant's Investment Decision (η^*) when $b = 0.1$

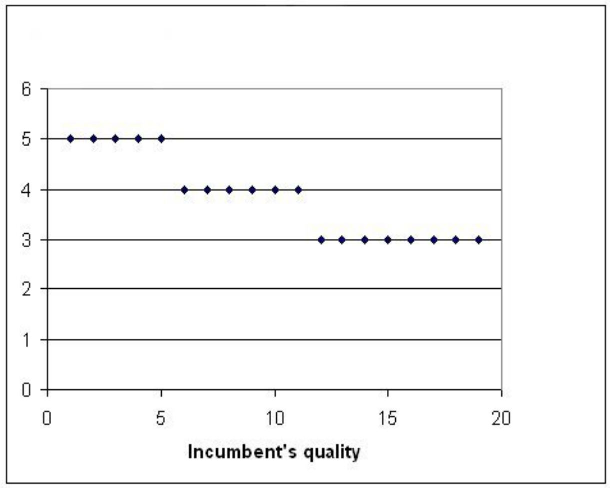


Fig. 1.2. Entrant's Investment Decision (η^*) when $b = 0.125$

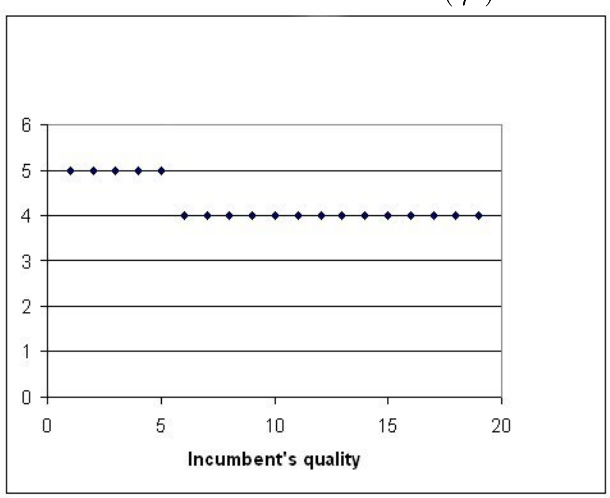


Fig. 1.3. Entrant's Investment Decision (η^*) when $b = 0.15$

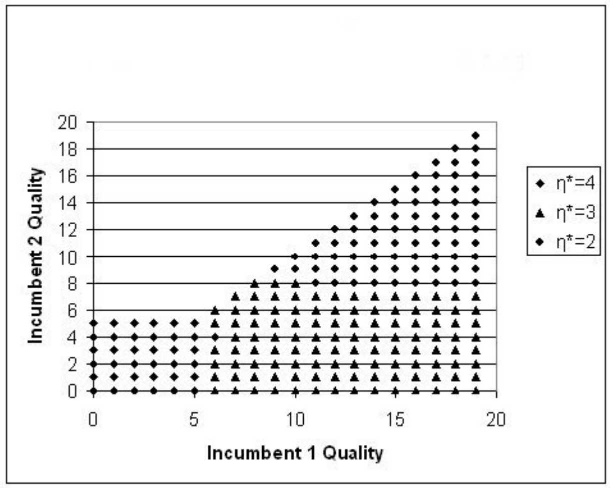
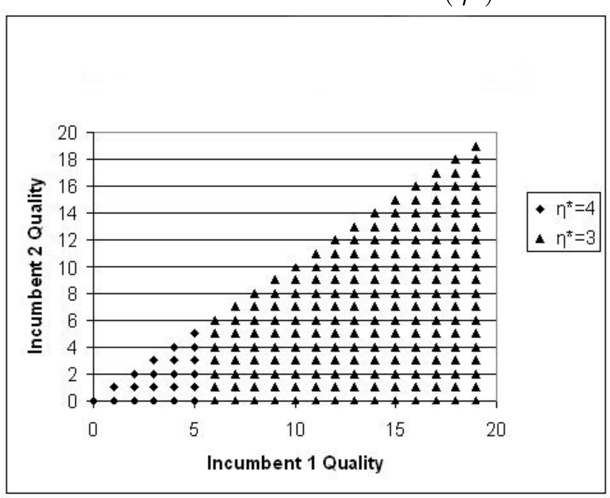


Fig. 1.4. Entrant's Investment Decision (η^*) when $b = 0.175$



Chapter 2

Trade Policy and Industrial Sector Responses in the Developing World: Interpreting the Evidence

2.1 Overview

Most students of economic development feel that liberal trade regimes are a good thing, and that the costs of protection can be substantial. In significant part, this belief traces to the notion that foreign competition disciplines domestic firms, forcing them to eliminate waste, accelerate their innovation rates, or shut down. This "import discipline" notion traces, in turn, to numerous firm- and plant-level empirical studies of liberalization episodes. These conclude that the manufacturing sectors of developing countries have become more efficient after trade liberalization episodes, that this has been accomplished partly through producer turnover, and that heightened competitive pressure from imports has been the motivating force. Although the empirical literature that supports the import discipline hypothesis offers some robust findings, it leaves many basic issues unresolved. One source of ambiguity is that it is based on flawed measures of firm performance. But more fundamentally, this literature (a) fails to identify empirically the mechanisms that link import competition to efficiency, (b) only describes the short-run effects of trade liberalization, and (c) doesn't translate firms' performances into welfare measures. Our objective is to address these shortcomings. Using a computable industrial evolution model to simulate the dynamic effects of import competition, we demonstrate what types of managerial behavior, long-term transition paths, and welfare effects are consistent with the findings of previous firm- and plant-level empirical studies. Our analysis is based on a modified version of Pakes and Ericson's [29] and Pakes and McGuire's [62] model - hereafter, the PEM model. It describes an industry populated by a changing set of firms, each producing its own differentiated product. New firms enter the industry when the expected present value of their future earning stream exceeds their entry costs, and incumbent firms exit when the expected value of their future earnings stream falls below the scrap value of their assets. While active, firms can invest an amount of their choosing to increase the likelihood of a quality-improving product innovation. All economic agents make optimal choices, given their current information sets and the idiosyncratic shocks they experience. (Inter alia, these choices reflect accurate perceptions concerning the stochastic processes they optimize against and the behavior of their competitors.) We modify the PEM framework by introducing an imported product variety that competes with the domestically-produced varieties and increases in quality at an exogenous rate. Simulations of our version of the PEM model reproduce the well-known features of short-run adjustment to trade liberalization by import-competing sectors: price-cost margins fall, and efficiency improves, largely because of the elimination of weak product lines and the exit of inefficient plants. But our results also demonstrate that the intra-industry efficiency effects of foreign competition are probably more nuanced than commonly believed. Specifically, we find that productivity gains due to the purging of weak firms are transitory, and likely to dissipate within 10 to 15 years of trade liberalization. As they fade, the cumulative effects of reform-induced changes in the incentive to innovate become more important. These are often negative, so foreign competition can create a longer-term tendency for the quality of domestic goods to deteriorate relative to imports. Depending upon the nature of the trade reforms, this tendency may or may not be offset by quality/efficiency gains due to embodied technological progress in imported capital. In any case, heightened import competition is likely to be accompanied by permanently higher plant or product line turnover cum more rapid job creation and job destruction. Finally, there is a strong possibility of welfare losses on the part of domestic producers, but welfare gains among consumers due to lower prices are likely to be larger.

2.2 The Import Discipline Hypothesis

Let us begin our discussion by recounting the logic behind the import discipline hypothesis, and the firm-level evidence that is often cited in its support.

2.2.1 Micro Foundations for the Trade-Efficiency Linkage

A variety of theoretical arguments provide possible explanations for the import discipline hypothesis. Some of these apply to any policy reform that intensifies competitive pressures. For example, in contexts where ownership is separate from management, heightened competition can reduce agency problems, and thus may induce managers to move toward high-effort contracts (Hart [39]; Vousden and Campbell [79]). This effect is quite sensitive to modeling assumptions, however, and might well go in the other direction (Scharfstein [71]; Stephen [73]). Regardless of whether agency problems are present, competition may heighten incentives to innovate among those firms close to the technological frontier, while inducing the rest to forfeit market share and/or shut down.

Boone [15] defines heightened competitive pressure as a shock that induces this pattern of response, and provides some examples of demand systems and market equilibria that exhibit this property.[1] Of course, competitive pressures may serve mainly to reduce the rents from innovation, as Schumpeter argued, so these laudatory effects need not obtain. Aghion et al [2] demonstrate that the relationship between product market competition and innovation might exhibit an inverted-U shape, reflecting the relative strength of Schumpeterian and Boone-type forces. Other linkages between openness and efficiency are inherently trade-related. For example, Melitz [53] and Bernard et al [10] demonstrate that by liberalizing trade, countries create new markets for their most efficient firms and new competition for the rest. Thus it is possible to generate efficiency enhancing market share reallocations without necessarily involving innovative activity. Trade flows may also act as a conduit for embodied or disembodied knowledge flows, and may (or may not) change the returns to innovation through general equilibrium effects on factor prices and market sizes (Grossman and Helpman [35]).

2.2.2 The existing evidence

Given the widespread appeal of import discipline arguments, and given the many possible forms they might take, the profession has looked to empiricists to document

[1] Aghion, et al [3] develop a simple model with the same features. They posit that firms can improve their efficiency by no more than one unit per period, so firms that lag more than one unit behind the technological frontier have no chance of catching up. With homogeneous products and Bertrand competition, the threat of competition from an efficient foreign supplier induces firms one step behind to invest in innovations, and induces those further back to relinquish their market.

their nature and measure their importance. Two developments during the past quarter-century have made it possible for the empiricists to respond in force. One is that numerous plant and firm-level data sets have accumulated over sufficient time spans to support econometric inference. The other is that many developing countries have dramatically liberalized their trade regimes, generating a number of natural experiments. At least five such natural experiments have attracted attention from empiricists. One of the earliest occurred in Chile, which went from widespread quantitative restrictions and average effective protection rates over 100 percent in 1967 to virtually no quantitative restrictions and average effective protection rates of 15 percent by 1979 (Tybout et al [77]). Next, Mexico went from license coverage ratios of 91 percent and tariff-based effective protection rates of 31 percent in 1984 to license coverage ratios of 11 percent and effective protection rates of 9 percent in 1990 (Tybout and Westbrook [78]). The Cote d'Ivoire also began its liberalization in 1985, removing quantitative restrictions, and reducing average tariffs by 30 percent over the following 2 years (Harrison [38]). More recently, Brazil reduced its exchange rate-adjusted average nominal tariff rate from 80 percent in 1985 to 21 percent in 1995, simultaneously eliminating non-tariff barriers (Muendler [56]). Finally, in 1991 India removed "licensing and other non-tariff barriers on all imports of intermediate and capital goods and [implemented] significant reductions in tariffs on imports" (Krishna and Mitra [48]). Table 2.1-2.3 summarize a subset of the resulting studies, grouped by country-specific liberalization episode. For each episode, we summarize evidence on plant- or firm-level productivity gains and their relation to measures of trade protection (column 4). Further, since productivity gains due to intra-plant innovations are conceptually distinct from those due to market share reallocations (including entry and exit), we cite evidence that isolates reallocation effects when it is available (column 5). Finally, to give some indication of whether competitive pressures intensified with trade liberalization, we cite studies that relate price-cost mark-ups to openness proxies in column 6. The message that emerges from Table 2.1-2.3 is consistently supportive of the import discipline hypothesis. Import-competing sectors generally undergo the biggest productivity gains during and immediately after trade liberalization episodes. These gains are due, in significant part, to reallocation effects. And they are generally accompanied by reductions in price-cost mark-ups, suggesting that heightened competitive pressure is the driving force behind the adjustments.

2.2.3 Limitations of the existing evidence

Taken together, the studies in Table 2.1-2.3 constitute a valuable set of stylized facts concerning the effects of trade policy on industrial sector performance. Nonetheless, our ability to draw policy implications from this evidence is limited by problems with the performance measures that have been used, and by problems linking these measures to the policy regime. We now consider each in turn.

2.2.3.1 Problems measuring performance

One measurement problem derives from data limitations. It is infeasible to collect detailed information on the quantities of each of the different product varieties that firms produce. Thus all of the productivity studies in Table 2.1-2.3 measure output as deflated revenues. Similarly, although most of these studies measure labor inputs in terms of number of workers or hours worked, data limitations force them to measure intermediate inputs as deflated expenditures, and capital stocks as depreciated and depreciated expenditures. The resulting productivity measures therefore fall somewhere between revenue per unit cost, and revenue per unit input bundle. This feature of productivity measures would be a non-issue if outputs and intermediate input bundles were homogeneous across producers. But manufactured products are quite differentiated, even within narrowly defined industries, and price-cost mark-ups exhibit considerable variation across producers with product-specific demand conditions. In this setting, Katayama, et al [45] (hereafter KLT) note that firms with high mark-ups tend to generate lots of revenue per unit input bundle, and thus tend to appear relatively productive. Similarly, high ratios of revenues to measured input usage tend to occur at firms that pay dearly for their workers, since these firms pass some of their labor costs forward to consumers. In contrast, when demand elasticities are common across firms, cross sectional variation in true productive efficiency has little to do with cross sectional variation in revenue per unit input bundle. The reason is that productivity shocks cause input usage and revenue to move up or down roughly in proportion to one another.[2] This spurious cross-sectional variation in measured productivity matters especially in studies where the effects of

[2]KLT show that if the production technology is constant returns and Cobb-Douglas, measured productivity for the i^{th} producer takes the form: $\widetilde{\phi}_{it} = \mu_{it} + ln(\overline{W}_t/\overline{P}_t) + \alpha ln(W^p_{it}/\overline{W}^p_t)$, where μ_{it} is the firm's optimal mark-up (determined by demand elasticities), $\overline{W}_t$ is the industry-wide price deflator used for factor inputs, $\overline{P}_t$ is the industry-wide deflator used for sales revenues, $\overline{W}^p_t$ is the appropriate industry-wide price index for factors measured in physical terms (most importantly, labor), W^p_{it} is the unobservable firm-specific unit price for these same factors , and α is the share of total cost attribute to labor. Thus $\widetilde{\phi}$ reflects mark-ups and relative labor costs but it is independent of true productivity unless productivity affects mark-ups or the prices of factors measured in physical units. Even if the workers are paid more because they are more productive, the standard performance measures tell us nothing about economic efficiency because firms that use valuable inputs to produce valuable outputs need not be more efficient than firms that use cheap inputs to produce cheap output.

reallocation-based productivity gains are calculated because big firms tend to pay their workers more, and to face relatively low demand elasticities.[3] Thus they tend to look relatively efficient, even if their true productivity is mediocre, and measured efficiency gains will be overstated when market shares shift in favor of these firms. Nonetheless, to the extent that big firms get big by being efficient, one can expect some cross-sectional correlation between measured efficiency and true efficiency, so measures of reallocation-based productivity gains are not entirely spurious. Time series variation in measured productivity is also likely to have a spurious component, albeit here again it should at least be correlated with true productivity growth. More precisely, if the cross-firm distribution of factor prices were time invariant, if the price deflators used were representative of the prices faced by the sample of producers being analyzed, and if firms could change their input usage without incurring adjustment costs, the average productivity measure would be a good proxy for average true productivity.[4] But mark-ups clearly tend fall with trade liberalization and this effect is particularly marked among large producers (Table 2.1-2.3, column 6). Thus, to the extent that this margin squeeze is most dramatic among import-competing firms, these studies may tend to understate efficiency gains in the import-competing industries during liberalization episodes. Measured productivity

[3] Although it is somewhat tangential to our discussion, it is worth noting that this property of standard productivity measures probably also creates large biases in studies that compare productivity indices across multinationals, exporters and domestic producers.

[4] Under the assumptions in footnote 2 of this chapter, this follows because profit maximization implies that the optimal mark-up (μ_{it}) is related to the firm's true productivity (ϕ_{it}) by $\mu_{it} = \phi_{it} - ln(W_{it}/P_{it})$, where lnW_{it} is the log of the unobservable firm-specific deflator for a unit bundle of all inputs, regardless of whether they are measured in physical or expenditure terms. Substituting this expression into the expression for measured productivity in footnote 2 and averaging across firms yields the result that cross-firm mean values of measured productivities should be close to mean values of true productivity if the price deflators used are representative of the sample of firms.

growth may also be understated in these industries because adjustment costs induce them to retain excess labor and capital during periods of slack demand. Both effects may help explain why the measured efficiency gains during the Brazilian, Chilean and the Mexico trade liberalizations were quite modest, despite major policy shocks and, at least in Chile, evidence of widespread labor shedding. The fact that manufactured products are differentiated across firms and through time creates another basic measurement problem for the studies in Table 2.1-2.3. Product innovations generally affect social welfare, but productivity studies only pick up temporal variation in process innovation. Thus, for example, firms that save on input usage by producing less appealing products are likely to look better than firms that keep their marginal costs constant but improve their products. With variation in both product quality and productive efficiency, firms' performances should be measured in terms of their contributions to social surplus. Like the first problem, this one may be more important for cross-plant analyses than for time series, although changes in the set of available products probably matter over medium to long-term horizons. A final measurement problem is that the Table 2.1-2.3 studies tend to miss some costs that firms incur in order to become more productive. Because the data are usually unavailable, analysts are usually unable to include investments in R&D, worker training and other types of overhead in their studies. Similarly, when efficiency gains are accomplished through labor shedding, severance costs and the costs borne by displaced workers are generally not part of the calculations. By understating the costs of innovation and workforce downsizing, the typical study tends to treat productivity gains as unequivocally desirable, and may overstate the gains from import competition.

2.2.3.2 Problems linking performance to the policy regime

Even if firms' performances had been appropriately measured, they would still leave some basic policy issues unresolved. One reason is that they are not very informative about the underlying behavior that generated the observed patterns of association between performance measures and openness proxies. For example, although we can be fairly confident that intra-firm efficiency is correlated through time with openness, we don't know whether it reflects the changing nature of an agency problem, a shift in the return to innovation at owner-managed firms, or greater incentives to shed non-essential labor. Nor do we know whether trade liberalization increases the incentives to absorb new embodied technologies through capital investments.[5] Answers to these questions determine whether the observed correlations are due to domestic market failures - in which case trade policy may not be the best way to address them - or are inherently trade-related. Related issues arise in studies that measure reallocation-based productivity gains. Most simply report the amount of sectoral productivity growth that is not attributable to intra-plant productivity gains (Pavcnik [65]; Liu [51]; Tybout and Westbrook [78]; Tybout [75]). But without a dynamic structural model to interpret these figures, it is impossible to say how things might have differed under a more protectionist regime.[6] Do reallocation-based gains reflect an improvement in the efficiency of the weeding out process, or are they present because liberalization creates more plants

[5] Muendler (2003) does provide some evidence on the role of imported technologies in Brazil.

[6] Muendler [56] goes one step further by estimating exit probabilities for incumbent plants before versus after the Brazilian trade liberalization of the early 1990s. But this exercise does not explain entry or market share reallocations, and it fails to identify the deep parameters needed for counter-factual analysis.

that need weeding out - perhaps by reducing the incentives to innovate? Finally, because the time periods covered by the studies in Table 2.1-2.3 are relatively brief, it is not clear whether this body of evidence describes transitory changes or long-run adjustments. They might reflect a one-time shakedown, or they might reflect a lasting change in industry dynamics. They might even describe short-run effects that are more than reversed over the medium to long term.

2.3 Interpreting the evidence with structural models

Thus far we have argued that the existing empirical evidence on import discipline effects is noisy and biased, but three basic findings are probably qualitatively correct. Specifically, among import-competing firms, trade liberalization squeezes price-cost margins, induces some intra-plant efficiency gains, and induces additional efficiency gains due to the shutting down of weak plants. We have also argued that, measurement issues aside, these findings are of limited use for policy analysis. They do not tell us anything about the managerial behavior behind the intra-plant productivity gains, they do not go beyond short-run effects, and they do not link adjustment patterns to welfare. The remainder of this paper presents a calibrated model that does all of these things in a way that is consistent with the empirical evidence.

2.3.1 An Industrial Evolution Model with Import Discipline Effects

If we are to interpret the existing evidence and draw policy implications, we require a structural model that captures several basic features. First, if we are to study intra-firm productivity change, the model should include the micro foundations for at least one form of induced innovation. Second, given that we believe the trade regime affects competitive pressures and mark-ups, the model should allow for imperfect competition. Third, if we are to study adjustment paths, the model should be explicitly dynamic, with forward-looking heterogeneous agents who foresee the future imperfectly. Fourth, given that we believe turnover-based productivity growth is significant, the model should allow for endogenous entry and market share reallocations. And finally, if we are to study the net welfare effects of changes in behavior, the model should assign some costs to entry and innovation. Needless to say, the modeling exercise we have described above is a difficult one. But if we forego econometric analysis and content ourselves with calibration, it is possible to construct a computable model with all of these features, and thereby to develop a broad sense for some of the dynamic structural relationships that are consistent with the stylized facts of Table 2.1-2.3. In the remainder of this section we demonstrate how this might be done, and we use the results to inform our interpretation of the econometric evidence. To keep the analysis tractable we study a hypothetical industry populated by a handful of firms that differ only in terms of the quality of their products.

2.3.2 The Ericson-Pakes-McGuire Model

We base our analysis closely on the industrial evolution model developed by Ericson and Pakes [29] and simulated by Pakes and McGuire [62] and [63]. The basic assumptions behind the simulated version of this model are concisely summarized in Pakes and McGuire [62] and [63], which we now paraphrase.

The PEM model describes the evolution of an industry populated by a changing set of firms, each producing a single differentiated product. Factor prices and the price of an outside good - for present purposes, a composite imported good - are exogenous. Product quality varies across firms and through time. The current-period pay-off to an active firm with product quality level i is determined by a profit function $\pi(i, s)$, where $i \in Z^{+}$, the set of positive integers, and $s = [s_j; j \in Z^{+}]$ is a vector whose j^{th} element gives the number of active firms at quality level j.[7] Given s, incumbents with product quality i decide whether to remain active or exit and sell their firm for a scrap value ϕ. Those that remain active also choose an investment level x, which costs them cx and shifts the probability distribution for their next-period quality realization. Larger x investments lead to more favorable shifts.

For a firm currently at quality i, investing x in product development, and operating in a market with structure s, let $p(i', s'|x, i, s)$ be the perceived probability distribution for next period's market structure. Then, given a discount factor of β, such a firm perceives its current value to be

$$V(i, s) = max\{\phi, \quad \pi(i, s) + sup_{x \geq 0}[-cx + \beta \sum_{i', s'} V(i', s')p(i', s'|x, i, s)]\} \tag{2.1}$$

If the max operator returns ϕ, it is optimal for the entrepreneur to sell the firm for scrap, otherwise it chooses the investment level x that maximizes the term in square brackets and proceeds to compete in the product market.

[7] Given investment decisions, future realizations on (i, s) are presumed not to depend upon firms' current pricing or output decisions. Thus the profit function reflects a simple "spot market" equilibrium in the goods markets and, for example, punishment strategies are disallowed.

It is convenient to treat the quality index i as normalized relative to current quality of the imported good. Then if i grows through time, firms at this quality level must be investing more than enough in innovation to keep up with the quality of the imported good. More precisely, let the Bernoulli random variables ν_t and ς_t represent increments to own and foreign quality, respectively, and assume that i_t evolves according to: $i_{t+1} - i_t = \nu_t - \varsigma_t$. Shocks to the quality of the imported good, ς_t, are exogenous draws that take on the value one with probability $\mu(1) = \delta$, where $0 < \delta < 1$ is a constant. Shocks to the quality of a domestic good depend upon the firm's investment current investment: $P[\nu_t = 1|x_t] = \frac{ax_t}{1+ax_t}$, where $a > 0$ is a constant. Thus for a firm investing x_t, the expected gain in quality relative to the imported good is $E(i_{t+1} - i_t) = \frac{ax_t}{1+ax_t} - \delta$.

To further characterize the transition kernel, $p(i', s'|x, i, s)$, let $\widehat{s_i}$ describe the states of the competitors of a firm at state i when the industry structure is s, and let $q(\widehat{s_i}|i, s, \varsigma)$ describe this firm's beliefs about the probability of landing at market structure $\widehat{s_i}$ next period, given the current state and ς_t. Then the transition probabilities that enter (2.1) are:

$$p(i' = i^*, s' = s^*|x, i, s) = \sum_{\varsigma} p(\nu = i^* - i - \varsigma|x) q(\widehat{s_i}' = s^* - e(i^*)|i, s, \varsigma)\mu(\varsigma) \qquad (2.2)$$

where $e(i)$ is a compatible vector with zeros everywhere except in the i^{th} position, which holds a one. Note that $q(\widehat{s_i}|i, s, \varsigma)$ embodies firm i's beliefs about entry behavior and the value functions of all competing incumbents.

Finally, there is at most one entrant per period, and this entrepreneur creates a firm if doing so generates an expected discounted cash flow that exceeds the entry cost,

x_e. Any potential entrant for whom this condition holds pays x_e (drawn from a uniform distribution), and after a set-up period becomes an incumbent with an initial relative quality i^e. Note that i^e measures quality relative to imported good, so this specification means that entrants always jump into the market the same expected distance from the foreign best practice frontier, so it amounts to the assumption that foreign technological innovations are always embodied in the capital stocks of new firms, up to a constant gap.

Equilibria obtain when all firms' beliefs, $q(\widehat{s_i}|i, s, \varsigma)$, are consistent with the objective distribution of industry structures based on the investment, entry and exit rules described above. Pakes and Erikson [29] show that Markov-perfect equilibria exist, although uniqueness is not ensured. Also, although the industry exhibits ongoing entry and exit, the number of firms is bounded by some integer $\bar{n}$, and each active firm is limited to a finite integer set of states, $\Omega = \{1, ..., K\}$. Thus one need only compute equilibria for tuples $(i, s) \in \Omega \times S$ where $S = \{s = [s_1, ..., s_k] : \Sigma_j s_j \leq \overline{n} < \infty\}$.

2.3.3 Our Adaptation of the Model

We base firms' profit functions on pure Bertrand competition in product markets characterized by a nested-logit demand system (McFadden [52]). Nest 0 contains only the composite imported variety, and nest 1 contains all of the domestic varieties. More precisely, we define the net utility that the j^{th} consumer derives from consuming a unit of product i at price P_{it} in period t to be:

$$U_{ijt} = \begin{cases} \omega_{0t} + \omega_{it} - \theta P_{it} + \xi_{j,1t} + (1-\varphi)\varepsilon_{ijt} & \text{if } \ i = 1, \cdots, N_t \\ \omega_{0t} - \theta P_{0t} + \xi_{j,0t} + (1-\varphi)\varepsilon_{0jt} & \text{if } \ i = 0 \end{cases} \tag{2.3}$$

Here P_{0t} is the price of the imported good, $\omega_{0t} = g(\sum_{k=1}^{t} \varsigma_k)$, $g'(.) \geqslant 0$, $g''(.) < 0$, measures the mean gross utility delivered by a unit of the current generation imported variety, and $\omega_{it} = f(i_t)$ measures the mean extra utility delivered by a unit of any domestic good at quality level i_t.[8] Also, $\theta > 0$ measures price sensitivity, and φ measures the degree of substitution between domestic varieties and the imported good ($0 < \varphi < 1$). The latter follows because $\xi_{j,dt}$ varies only across individuals and across nests ($d = 1$ for domestic varieties and 0 for imports), while ε_{ijt} varies across individuals and across all varieties. (Both $\xi_{j,dt} + (1 - \varphi)\varepsilon_{ijt}$ and ε_{ij} have extreme value distributions across individuals.) This allows us to control the degree of substitution between imports and the domestic varieties.[9]

Given our utility function, improvements in the quality of the imported good and reductions in its price have very similar effects from the perspective of consumers. Thus ongoing quality improvements abroad can also be viewed as ongoing price reductions, perhaps due to exchange rate appreciation. Similar comments apply concerning the domestic goods. Marginal cost reductions always lead to price reductions in our characterization of the spot market equilibrium. So, although we assume that the domestic firms have identical, flat marginal cost schedules, roughly speaking we may view the effects of product innovations as similar to the effects of process innovation.

[8] We use $f(i) = \frac{15i}{i+1} - 5$. (We do not need to make specific assumptions about $g(.)$ to solve the model, since it only affects the level of consumer surplus.) Note that our specification for $f(i)$ implies diminishing marginal utility from quality premiums. Also, it ensures that the return to quality improvements (relative to the imported good) approaches zero as $i \to \infty$, and thus eliminates the incentive for firms to drive i above the maximum value considered, K.

[9] Berry [11] provides further details on the product market equilibria that obtain with nested logit demands and pure Bertrand pricing rules.

2.3.4 Simulation Exercises

Using modified versions of the Gauss and C programs written by Ariel Pakes, Paul McGuire and Gautam Gowrisankaran, we study the effects of import competition on industrial structure using two policy experiments. The first is to permanently reduce the price of the composite imported good, P_0 (hereafter, the "RPM experiment"). It is meant to approximate a reduction in trade barriers. The second is to permanently accelerate the rate of innovation for imported goods, δ (hereafter, the AIM experiment). It is meant to describe the effects of trading with a country where technological progress is rapid, as opposed to modest.

Both sets of exercises begin from a parametrization in which imports have a very small market share. Also, we assume that no more than six domestic firms are simultaneously active in the domestic market. (This bound is rarely hit under the parameterizations we use - three to five firms are typically active.) Thus we caution that the results may overstate the importance of oligopolistic interactions for most manufacturing industries.

To eliminate any role for starting values, we begin each simulation with 5,000 periods under the pre-reform parametrization, then we shock the parameter of interest and track the industry's adjustment. The shock is always presumed to surprise entrepreneurs, but once in place the new parameter values are presumed to be common knowledge. Each experiment is repeated 100 times, and the average trajectories are graphed. Our graphs are normalized so that the regime change takes place in period 50, and thereafter they show both the simulated responses and the mean trajectory that would have emerged in the absence of the regime switch. The parameter values we use for these simulations are presented in Table 2.4.

It is not possible to be precise about the length of time that corresponds to a single period. But the typical life span of a firm in our simulations is 4 to 6 periods, so an average life span of 10 years implies that one period amounts to roughly 2 years. Similarly, we note that the average entry/exit rate in our base case simulations is 23 percent, which is roughly twice the annual rate observed among manufacturing plants in semi-industrialized countries (Roberts and Tybout [67]).

2.3.4.1 Reduced Price for Imports (RPM)

Our results for a permanent reduction in the price of imports - the RPM experiment - are summarized by figures 2.1 through 2.8 and the first two columns of Table 2.5. Consider first the domestic market share trajectories presented in figure 2.1. When the price of the imported good drops from 1.5 to 0, the share of output supplied by domestic firms immediately drops as consumers shift toward the import variety. The price-cost mark-ups of domestic varieties also drop as domestic entrepreneurs react to the new environment (figure 2.5).

The net exit rate is roughly 10 percent in the first post-reform period, and all of the disappearing firms come from the low end of the product quality distribution. Thus the unweighted average quality of domestic goods rises sharply in the immediate aftermath of the reform (figure 2.2). (The weighted average relative quality of domestic goods doesn't change much initially because exiting firms are small - see figure 2.3.) But incentives to innovate are clearly less at the lower imported price, reflecting a simple

Schumpeterian mechanism: firms with the most market power gain the most from R&D (figure 2.4).[10] Consequently, average quality/efficiency begins a sustained downward trend after 4 or 5 periods. One implication is that short-run analyses of the efficiency effects of trade liberalization may be quite misleading.

Workers are unlikely to like the new regime because it discourages investments in product improvements, thereby reducing firms' average live spans (Table 2.5) and increasing rates of job turnover. On the other hand, consumers are clearly better off, especially during the early periods (figure 2.8). This is because the prices of domestic and foreign goods are lower after the reform (figure 2.5), the decline in the relative quality of domestic goods hasn't really gotten started (figures 2.2 and 2.3), and the domestic varieties that exit weren't contributing much to their welfare. Consumers' enthusiasm for the new regime fades as the relative quality of domestic products declines, and the prices of these goods come back up a bit. But overall, the reform generates a 22 percent increase in the present value of their surplus (Table 2.5).[11]

Finally, domestic producers suffer capital losses when the regime hits, and they remain worse off under the new regime because their mark-ups are smaller (figure 2.7). Overall, the present value of their surplus is reduced by 11 percent. Nonetheless, social welfare is dominated by consumer surplus, which increases in present value by 21 percent (Table 2.5).

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[10] Rodrik [68] flags this effect as a possible reaction to heightened import competition. In our model it is conceivable that a small reduction in the price of imports might drive a marginal firm from the market, thereby increasing the return to innovation for the remaining producers. However, this phenomenon is clearly not typical of our simulations.

[11] Given that we have held the rate of innovation among imported goods fixed, consumer preferences for the open regime don't depend upon what functional form we choose for $g(.)$.

Of course, other assumptions might have led to different patterns of response, and we could certainly refine our calibration, but it is noteworthy that our simulations match up well to most of the econometric evidence. That is, import competition induces smaller firms, lower mark-ups, and a cleansing effect that helps to sustain efficiency. The only seeming incongruity is that efficiency gains in the RPM experiment come exclusively from firm turnover and market share reallocations in our simulations, while the studies in Table 2.1-2.3 find significant intra-firm productivity gains. However, one can reconcile this experiment with the evidence by simply thinking of entry and exit as corresponding to product lines rather than plants. Then the same plant might continue to exist as it retools for a new product, and thus might exhibit short run intra-plant efficiency gains. This interpretation is consistent with evidence on the Chilean experience, where plants improved their efficiency by shedding labor rather than expanding output with a given labor force (e.g., Tybout [76]). It is also consistent with the common finding that, while manufacturing productivity improves after trade liberalization, unemployment increases economy-wide, and therefore aggregate productivity growth is modest.

2.3.4.2 Accelerated Innovation Among Imports (AIM)

An alternative form of opening occurs when domestic firms are faced with accelerated innovation among the imported goods. We think of this type of shock as approximating policies that bring dynamic new trading partners into play and/or policies that remove non-tariff barriers on products that are subject to relatively rapid technological change. It might also approximate policies that lead to extended periods of real exchange rate appreciation, although it is difficult to imagine this occurring indefinitely without macro crises emerging. The simulated responses to such a regime change are graphed in figures 2.9 through 2.16, which contrast behavior when $\delta = 0.6$ with behavior when $\delta = 0.8$. (Recall that δ is the exogenous probability of an improvement in the quality of imported goods.)

Figure 2.9 shows that domestic firms lose no market share in the face of this type of competitive pressure. The reason is that they reduce their prices enough to compensate for the reduction in their relative quality once new regime begins to take hold (figure 2.13). They do, however, gradually lose relative quality (figures 2.10 and 2.11, lower line) as improvements among imported goods cumulate and they increasingly scale back their own investments (figure 2.12). The gradual decline in domestic investment mirrors the gradual fall in domestic mark-ups, once again reflecting a Schumpeterian reduction in the incentive to innovate.

Our post-reform series on relative efficiency are a bit misleading because, when the rate of innovation among imported goods increases, the yardstick for performance of the domestic varieties increases too. Thereafter domestic producers must improve their quality index by 0.8 per period rather than 0.6 per period simply in order to keep up. So although relative quality trends downward for 40 periods after the AIM regime is implemented, the per-period change in the level of domestic quality actually increases. We demonstrate this with an extra trajectory in figures 2.10 and 2.11 (top line) that shows the quality of the domestic goods relative to a hypothetical reference good that continues to improve by 0.6 per period after the reform is implemented. This scenario is therefore consistent with the stylized fact that intra-firm efficiency gains accelerate after liberalization episodes.

That domestic producers are able to increase the rate of improvement in their goods reflects two forces. First, the mean life span of firms drops 23 percent when δ increases from 0.6 to 0.8 (Table 2.5). Second, after the regime switch, new firms are able to embody rapidly improving global best practice technologies in their plants at no additional expense. Thus, although firms invest less in keeping up with import innovations, each is more quickly replaced by an entrant near the technology frontier.[12] This type of induced innovation provides some micro foundations for the common finding that countries with high-tech trading partners enjoy relatively rapid growth (Coe and Helpman [19]).

The AIM shock immediately improves producer surplus because domestic firms don't lose much relative quality initially, and they spend less of their gross revenue on investment (figure 2.15). However, the cost savings from reduced investments are gradually swamped by the revenue losses induced by persistently higher rates of quality improvements among imports.

How do consumers fare? Figure 2.16 suggests that they to do worse than they did under the RPM experiment because the relative quality of imported goods has fallen. However, this figure is drawn under the extreme assumption that consumers only care about the variety of goods available and their *relative* quality, and not about the average *level* of quality. (That is, $g'(\omega_{0t}) = 0$.) If we had allowed $g(\omega_{0t})$ to grow with improvements in the quality of imports, we could easily have demonstrated large consumer gains

[12] If new firms were allowed to endogenously invest in order to influence their initial product quality, the AIM shock would increase entrants' initial investments and thus increase their relative size. That is, given the choice, entrepreneurs adjust by shifting their investments away from post-entry expenditures toward pre-entry expenditures. Experiments that demonstrate this reaction are available from the authors upon request.

due to the more rapid rate of quality improvement among both domestic and imported goods. The interested reader may choose his favorite g(.) specification and perform this exercise for himself.

2.4 Summary and Conclusions

The existing literature on industrial responses to trade liberalization documents consistent patterns of correlation between openness proxies and several measures of performance: price-cost mark-ups, intra-plant productivity gains, and reallocation-based productivity gains. These stylized facts are useful, but they don't tell us much about the underlying behavior of producers, nor do they link firms' performances to welfare measures, so they are of limited use for policy analysis. We have sketched an alternative approach to the analysis of trade liberalization that does both, and we have demonstrated this approach using fabricated data.

2.4.1 Lessons from the Simulation Exercises

Although our simulations are not calibrated to actual data, they make several basic points. First, when outward-oriented trade reforms reduce price-cost mark-ups, the less successful producers are likely to shut down or eliminate some product lines. This one-time adjustment in the set of firms and products is a quick source of efficiency gains, particularly when the new policy regime involves a sudden, significant departure from the previous environment. But it dissipates after 5 or 6 periods (10 to 12 years). Thus panel-based econometric studies of liberalization-based productivity gains - which typically span a decade, or less - are probably not representative of longer term effects.

Second, the same forces that induce exit tend to discourage innovation, so after liberalization, the quality of domestic products may well decline relative to imports. This effect is gradual, but in our simulations it eventually swamps the efficiency-enhancing effects of the initial wave of exits. In principle, other characterizations of market equilibria might have led to different conclusions concerning the effects of foreign competition on domestic innovation - Boone [15] and Aghion et al [2] provide some examples. But we found it difficult to identify plausible specifications that reverse this finding.

Third, falling behind in relative quality need not lead to deceleration in the absolute rate of innovation. Deceleration is less likely if trade liberalization increases the rate at which embodied technologies become available through capital goods imports. The more rapid these arrivals, the better new entrants are positioned to produce near the technological frontier.

Fourth, plant and job turnover rates are likely to be permanently higher after liberalization. This effect is particularly marked when the reforms allow new, embodied technologies arrive to arrive relatively rapidly through capital goods imports. Such an environment creates ongoing incentives to introduce new plants or assembly lines, rather than continually to upgrade existing facilities. The resultant higher turnover works to the detriment of labor, which is more frequently displaced.[13]

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[13] Heightened foreign competition may have had this effect in India. A recent study of India's post-liberalization period finds that "firms subject to external exposure . . . face higher earnings variability and job insecurity. At the same time, though, the employees of foreign owned and import-competing firms are more frequently involved in training programs than firms not subject to foreign competition." (Daveri et al [24]).. Similarly, Levinsohn [49] finds that tradeable goods sectors exhibited relatively high job turnover rates in post-liberalization Chile.

Fifth, although all of our figures represent averages over 100 trajectories, they still reflect a large role for idiosyncratic shocks. Thus the consequences of policy reforms may remain obscured by noise for substantial periods of time, particularly when one is studying variables that respond to expectations like investment, entry and exit.

2.4.2 Future Directions

There are at least two important limitations to the strategy we have demonstrated in this paper. The first is that it involves many modeling assumptions. We would naturally prefer to avoid using so much structure, but we do not believe it is possible to perform welfare-based policy analysis without it. Our view is: if the calibrated models generate patterns of turnover, pricing and efficiency gains that match observed patterns, they simply provide a coherent interpretation for observed experiences. One of our objectives is develop enough experience with computable industrial evolution models that we have a good sense for the practical importance of the various modeling assumptions.

The second limitation of our approach to analysis is that it is computationally intensive. The solution algorithms currently available for PEM models handle about a dozen firms, at most, and can take hours to solve for value functions at a given set of parameter values. Thus they can be calibrated to small industries using actual data on market shares, turnover patterns, prices and efficiency gains, but they are unlikely to serve as a basis for econometric estimation of all parameters. (Entry costs and scrap values are particularly difficult to identify.) We are currently exploring alternative solution algorithms that will allow us to handle more firms, and we are attempting to calibrate PEM-type models more tightly to actual liberalization experiences.

Table 2.1.
Openness, Mark-ups and Productivity Growth I

Country and liberalization episode	Performance Measure	Performance Determinant	Intra-plant productivity growth	Entry, Exit and Market Share Reallocation	Mark-up Effects
Chile, 1973-79					
DeMelo and Urata (1986)	Price-cost margin	Import penetration rate			Post-reform penetration of imports reduced mark-ups most in highly concentrated sectors
Tybout et al (1991)	Econometrically estimated TFP residuals	Effective protection rates	Sectors undergoing large reductions in protection exhibit the largest gains		
Tybout* (1996)	Price-cost margin	Import penetration rate			Margins are negatively affected by import penetration, especially among large plants
Liu* (1993)	Econometrically estimated TFP residuals			Entry/exit a significant determinant of productivity growth	
Pavcnik* (2002)	Olley-Pakes (1996) estimates of TFP residuals	Tariff rates	Productivity grew faster in import-competing sectors with trade liberalization	Most of the post-liberalization productivity gains came from market share reallocations and entry/exit	

* Based on data from post-reform years only (1979-1986)

Table 2.2.
Openness, Mark-ups and Productivity Growth II

Country and liberalization episode	Performance Measure	Performance Determinant	Intra-plant productivity growth	Entry, Exit and Market Share Reallocation	Mark-up Effects
Brazil, 1991-94					
Muendler (2003)	Olley-Pakes (1996) estimates of TFP residuals	Tariff rates, market penetration rates penetration rates	Import competition substantially increases productivity	Exit significantly contributed to efficiency gains; other forms of market share reallocation not studied	
Hay (2001)	Econometrically estimated TFP residuals, operating profits	Tariff rates, effective rates of protection, exchange rate	Import competition increases productivity		Operating profits are positively associated with nominal protection rates
Mexico, 1984-89					
Tybout and Westbrook (1995)	Production function-based TFP residuals	Effective protection, import penetration, license coverage ratios	Sectors with most exposure to import competition showed the most gain		
Grether (1996)	Price cost margin	Effective protection, official protection, and license coverage rates			Big firms undergoing the most reduction in protection show the biggest reduction in margins

Table 2.3.
Openness, Mark-ups and Productivity Growth III

Country and liberalization episode	Performance Measure	Performance Determinant	Intra-plant productivity growth	Entry, Exit and Market Share Reallocation	Mark-up Effects
India, 1991-97					
Krishna and Mitra (1998)	Hall (1988)-type estimates of TFP residuals and mark-ups	Trade liberalization dummy	Productivity gains with trade liberalization		Significant reductions in mark-ups after trade liberalization
Cote d'Ivoire					
Harrison (1994)	Hall (1988)-type estimates of TFP residuals and mark-ups		Productivity growth tripled after trade liberalization		Weak evidence that price-cost margins fell with trade liberalization
Harrison (1996)	Production function-based TFP residuals; price-cost margins	Tariff rates, controlling for FDI in plants, sector	High tariffs are negatively associated with productivity, controlling for FDI		High tariffs are associated with high margins and low productivity

Table 2.4.
Parameter Values for Policy Experiments

Parameters	Reduced Price for Imports (RPM)	Accelerated Innovation for Imports (AIM)
Marginal costs of production (domestic firms)	1	1
Market Size (M)	10	10
Discount factor (β)	0.925	0.925
Scrap Value (ϕ)	0.1	0.1
Max Efficiency (i^{max})	21	21
Investment efficiency (a)	2	2
Price sensitivity of consumers (θ)	5	5
Degree of substitution between nests (σ)	0.5	0.5
Price of the imported good (P_0)	1.5 to 0	1.5
Probability of Innovation in the Imported good (δ)	0.6	0.6 to 0.8

Table 2.5.
Summary Statistics for RPM and AIM regimes

	Base case	Reduced Price for Imports (RPM)	Accelerated Import Innovation (AIM)
	$P_0 = 1.5, \quad \delta = 0.6$	$P_0 = 0, \quad \delta = 0.6$	$P_0 = 1.5, \quad \delta = 0.8$
Percentage of periods with entry and exit*	55.8	57.8	72.1
Mean number of firms active*	3.8	3.6	2.9
Mean lifespan*	5.3	5.0	4.2
Mean consumer surplus**	855.3	1045.9	686.5***
Mean producer surplus**	27.9	25.0	30.1
Mean total surplus**	882.8	1072.0	716.6***

* Means taken across 100 trajectories of 5,000 periods each

** Means taken across 100 trajectories of 100 periods each, discounted back to initial year of regime

*** Excludes gains due to more rapid growth in the average quality of goods

Fig. 2.1. Domestic Market Share, RPM Experiment

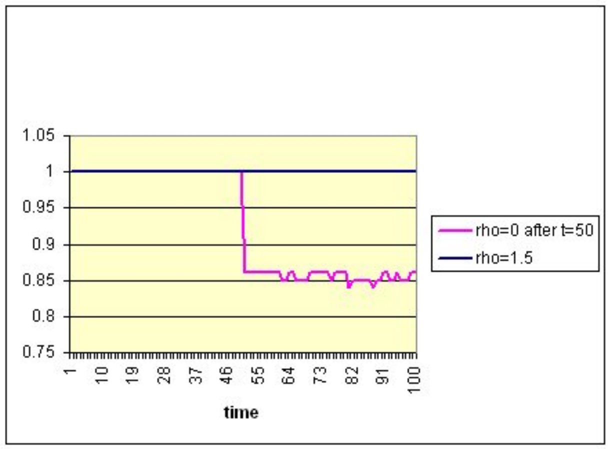


Fig. 2.2. Unweighted Mean Efficiency, RPM Experiment

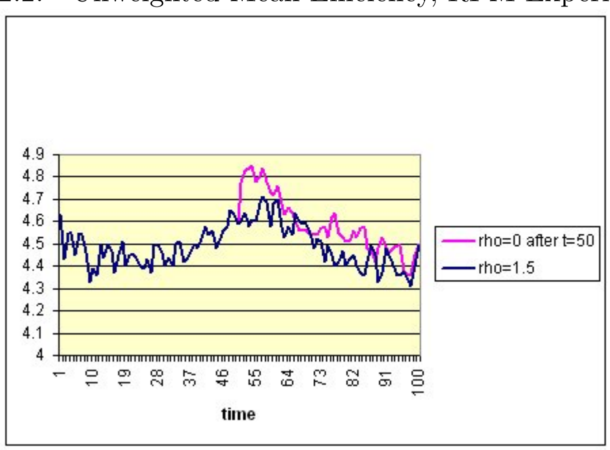


Fig. 2.3. Weighted Mean Efficiency, RPM Experiment

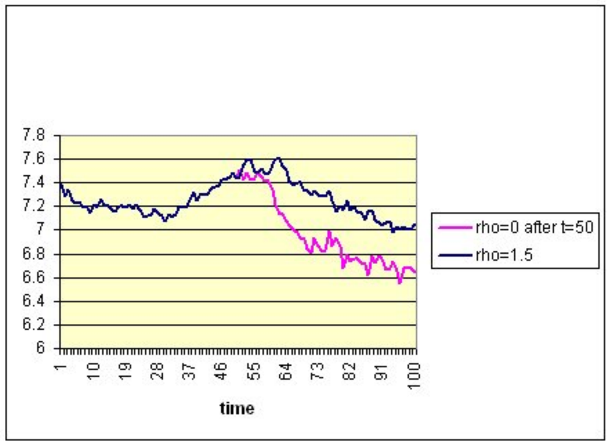


Fig. 2.4. Unweighted Mean Investment, RPM Experiment

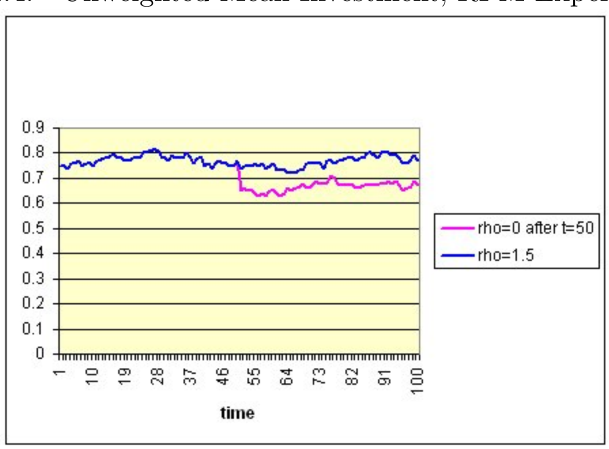


Fig. 2.5. Price-Cost Margin, RPM Experiment

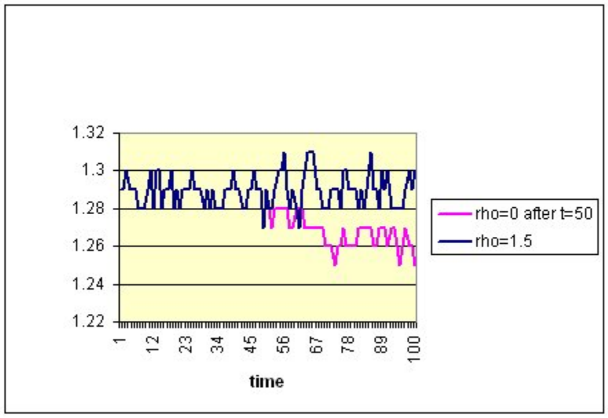


Fig. 2.6. One Firm Concentration, RPM Experiment

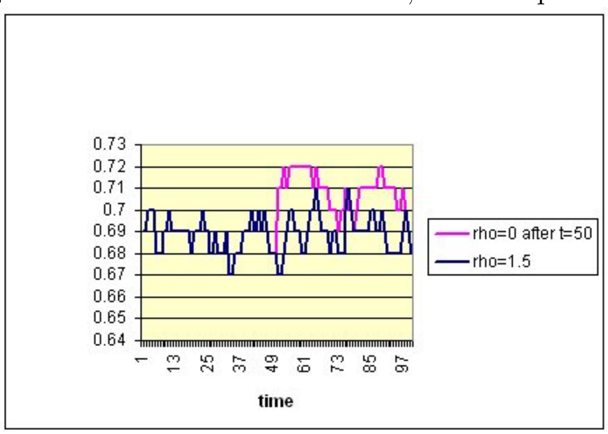


Fig. 2.7. Producer Surplus, RPM Experiment

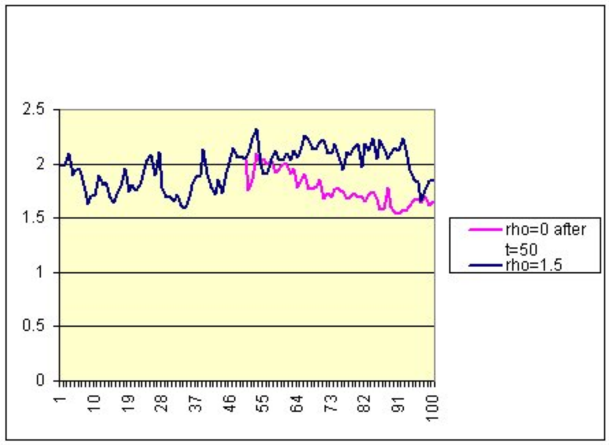


Fig. 2.8. Consumer Surplus, RPM Experiment

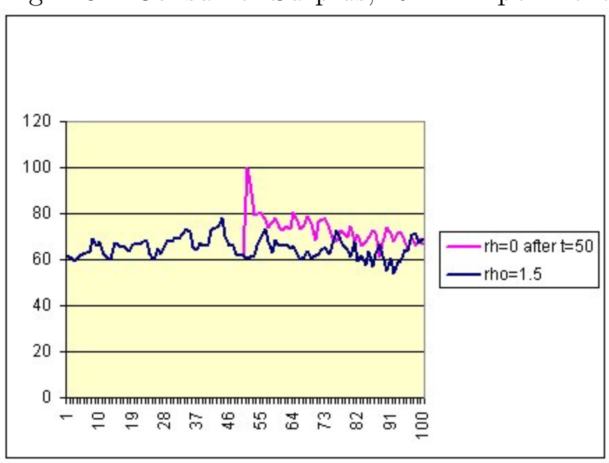


Fig. 2.9. Domestic Market Share, AIM Experiment

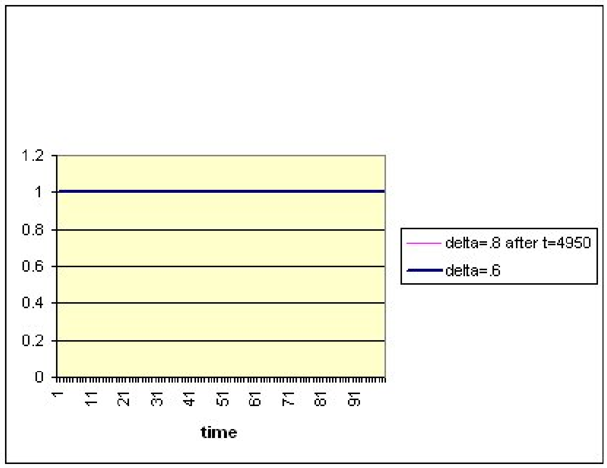


Fig. 2.10. Unweighted Mean Efficiency, AIM Experiment

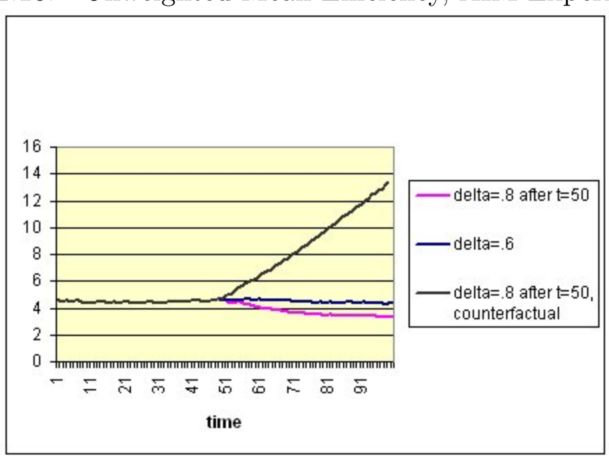


Fig. 2.11. Weighted Mean Efficiency, AIM Experiment

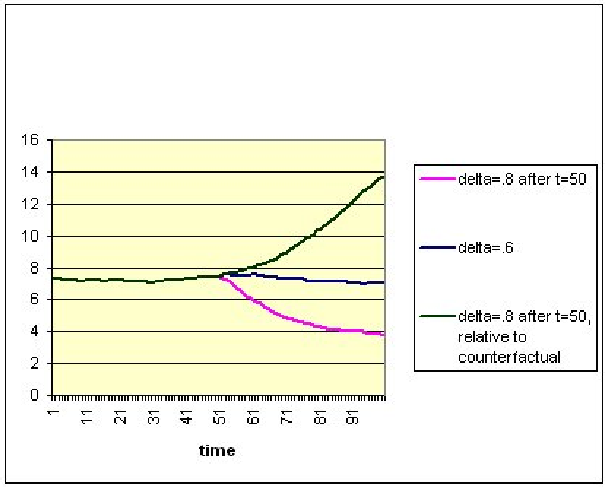


Fig. 2.12. Unweighted Mean Investment, AIM Experiment

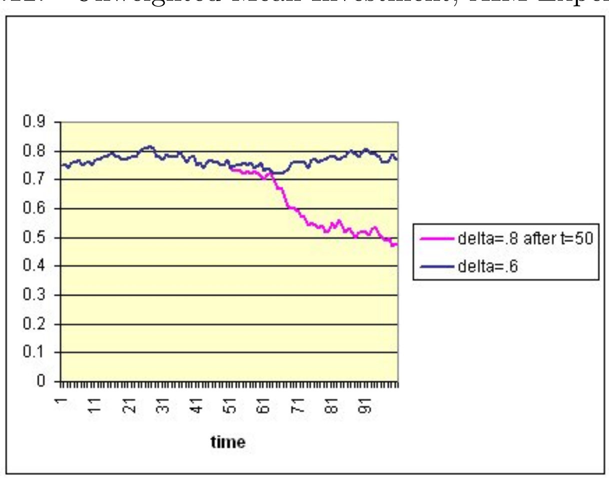


Fig. 2.13. Price-Cost Margin, AIM Experiment

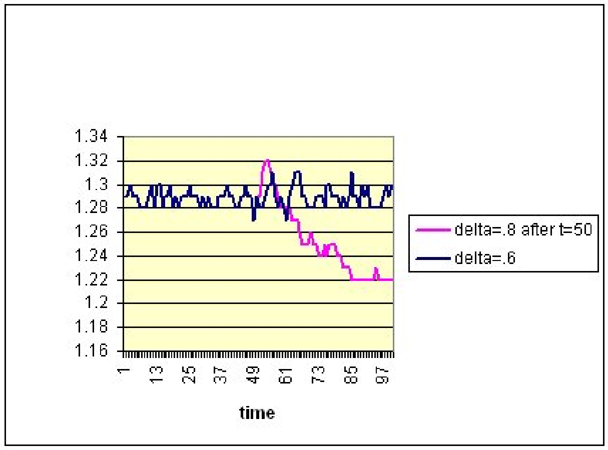


Fig. 2.14. One Firm Concentration, AIM Experiment

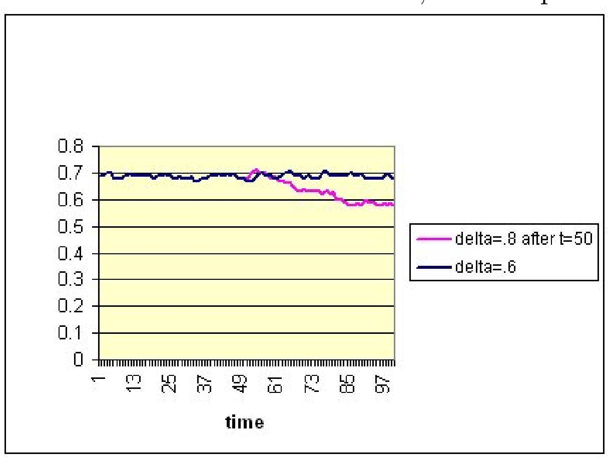


Fig. 2.15. Producer Surplus, AIM Experiment

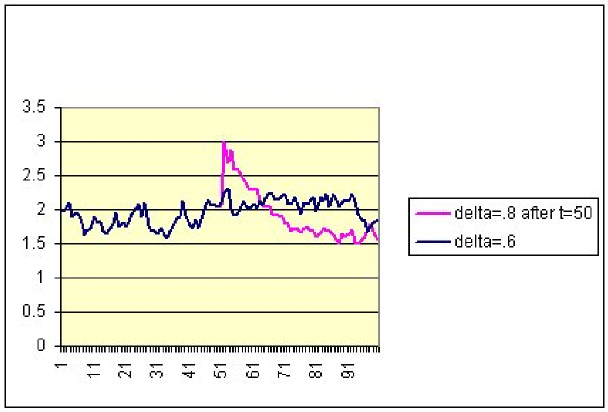
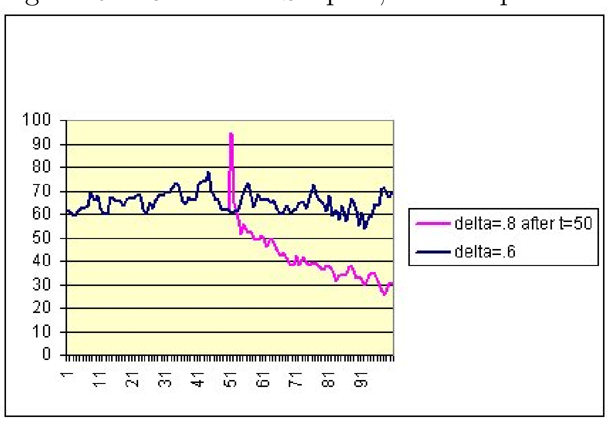


Fig. 2.16. Consumer Surplus, AIM Experiment



Chapter 3

An Empirical Model of Investment Behavior in Dynamic Oligopolies

3.1 Introduction

Policies often reflect a presumption that lowering entry costs[1] makes industries more competitive and leads to efficiency gains. For example, governments offer incentives in the form of tax breaks for new establishments. Hopenhayn [40] demonstrates that low sunk entry costs can force inefficient firms to exit the market and lead to efficiency gains in competitive markets. However, in oligopolies, lowering entry costs can have an adverse effect on the investment decisions of the firms. This is because it can weaken the incentives to affect rivals' investment decisions as well as potential firms entry decisions via strategic investment projects. Hence, if increased competition leads to a drop in investments, the long run effects of such policies might differ significantly from what is intended. Without detailed empirical work it is difficult to conclude whether the net effect of lower entry costs are welfare improving or not.

In this study, I empirically investigate the linkages between entry, investment decisions, and welfare. To do that, first, I develop an empirical model of investment with strategic interactions. In this multi-agent setup, firms recognize that their decisions influence the behavior of their competitors. Second, I estimate the parameters of the

[1] Sunk entry cost reflects the amount of money that a potential entrant has to spend to setup a firm. These costs may include planning, design, acquiring permits and licences, or setting up distribution channels.

model for the Colombian engines and turbines industry. I recover both the demand parameters and the dynamic parameters defining investment costs, scrap values and sunk entry costs. Finally, using this model, I analyze the effects of sunk entry costs on investment patterns and their effect on welfare.

Investment decisions have multiple purposes in my model. First, firms invest to be more productive by lowering their marginal cost of production. Hence, the direct effect of investment comes in the form of increased operating profits. Second, firms can use investment as a strategic tool to affect the investment decisions of their rivals, or force them to exit by lowering their profits. That is, by investing, a firm can lower its marginal cost and price increasing its own market share while lowering its rivals'. Such investments can also deter further entry into the industry by making the return to entering unattractive. This is the indirect effect of investments which can reduce the future level of competition in the industry.

The extent to which entry deterrence affects investment choices depends upon sunk entry costs. If entry costs are very low, it may optimal to accommodate entry, since entry deterrence requires significant amount of resources. If entry costs are very high, then entry may be blockaded naturally, and investments to deter entry may not be necessary. However, there is a range of entry costs, when incumbents find it optimal to spend resources on deterring entry.

The framework that I develop describes a dynamic structural model of imperfect competition. It is a richer and more general version of Pakes and Ericson [29] and

Pakes and McGuire [62] (PEM).[2] Firms produce differentiated goods using heterogeneous capital stocks. Those with higher capital stocks have lower marginal cost schedules. In any given period, incumbents compete in prices to maximize their profits. In the dynamic game, they make entry, exit and investment decisions to maximize the sum of the discounted stream of future profits. While making these decisions, firms form rational expectations, using all the information available to them optimally. Investments in capital stock can lower marginal cost and potentially increase future profits.

The generalizations that I make allow the model to better capture the properties of real industries. First, I allow firms to adjust their capital stocks (via investment) more flexibly. Firms can have large investment outcomes whereas PEM only allows for investments with slow capital accumulation. This is necessary since most data sets include both small and large changes in firms' capital stocks. I also allow for disinvestments by assuming capital is reversible. Second, I allow for multiple potential entrants in each period. Entrants can influence their entry-level capital stock by making pre-entry investments whereas PEM impose an exogenous entry level. Thus, potential entrants can choose whether to enter aggressively or not, given the state of the industry. Third, I use a more flexible investment cost function which includes a fixed cost, a linear cost and a quadratic cost component. This allows the model to better replicate the well-documented persistence and lumpiness in investment episodes. Finally, following Doraszelski and Satterthwaite [28], I allow incumbents' scrap values and entrants' entry costs to be private information. Hence, firms make entry, exit and investment decisions based on their beliefs

[2] See Pakes [60] for a more detailed description of the PEM algorithm and the extensions in the literature which has applied the model to various market settings.

about their competitors' private information. This is necessary since perfect knowledge of the competitors' decisions can significantly alter a firm's decisions.

I estimate the structural parameters of the model for the engines and turbines industry in Colombia. I recover both the demand parameters of the static competition stage and the parameters of the dynamic investment process. The estimation is done in two stages. In the first stage, I estimate the demand and cost parameters using the differentiated product demand by Melitz and Ottaviano [54]. Then, in the second stage, I estimate the parameters of investment costs, scrap values and sunk entry cost distribution using the estimates from the first stage.

Finally, I provide simulation evidence that lower sunk entry costs might lead to a significant welfare loss. A drop in entry costs does not lead to a significant decrease in price-cost margins. Instead, it causes a drop in investment expenditures and average capital stock since the strategic importance of investments diminishes. This leads to an industry structure with high-cost firms which charge higher prices. The incentive to deter entry is also diminished since efforts to discourage a potential entrant are unlikely to be successful.

The organization of the rest of the paper is as follows. Section 3.2 relates my work to the existing literature. Section 3.3 lays out the model. Section 3.4 describes the data. The estimation methodology is described in section 3.5. Estimation results are presented in section 3.6. Section 3.7 details the policy experiment. Finally, I conclude in section 3.8.

3.2 Related Literature

There are three separate but relevant literatures that are associated with this study; empirical investment, entry deterrence, and dynamic estimation literatures. In this section I will discuss the first two and leave the discussion of the third to the section on estimation.

The empirical investment literature has proposed ways to explain micro-level investment patterns. Using micro data on U.S. manufacturing plants, Doms and Dunne [26] find periods of no investment activity followed by investment spikes which constitute most of the total capital investment of a firm. Cooper, Haltiwanger and Power [21] find that the probability of such an investment burst increases with the time that has lapsed since the previous spike. Both of these studies point to the fact that there might be non-convexities associated with the capital adjustment process at the micro level. Caballero and Engel [17] show that models with a stochastic fixed adjustment cost perform better than those with a linear cost function. Hall [37] also finds moderate levels of adjustment costs. Nilsen and Schiantarelli [58] find evidence of nonconvexities and irreversibilities using Norwegian micro data. Cooper and Haltiwanger [20] find that an investment cost function with both convex and non-convex adjustment cost components better fits the micro data for U.S. manufacturing firms. Bloom, Bond and Van Reenen [14] and Guiso and Parigi [36] analyze the effects of uncertainties and irreversibilities on the investment behavior of manufacturing firms in UK and Italy respectively. They find that uncertainties reduce the response of investment to demand and hinders investment activities.

Mulkay, Hall and Mairesse [57] find that level of profits affect firms' investment decisions. Attanasio, Pacelli and dos Reis [6] examine the irreversibilities and lumpiness for different types of capital investment.

The approach that is commonly used in this literature is single-agent. In single-agent models, the firm does not consider its rivals' decisions, while making the investment decision. Neither does it consider the fact that it can affect how other firms behave. Firms can use capital investments to signal tough competition to their competitors and discourage potential entrants. Use of a single-agent framework neglects the strategic interactions and might generate misleading results. Especially in oligopolistic industries, where strategic investment decisions are more important, the misspecification is expected to be more problematic.

A second group consists of studies have examined theoretically the strategic use of investment in capital stock or capacity as an entry deterrent. In Spence [72] firms make irreversible investments in capital stocks to preempt the market. Fudenberg and Tirole [31] show that strategic investment by the incumbent can forever deter entry. Dixit [25] shows that irreversible investment in capital will make the threat credible by lowering the firm's post-entry cost of production. Empirical findings concerning these results are few and inconclusive. Lieberman [50] cannot find evidence for capacity investment in chemical product industries. He finds evidence of entry deterrence only in three markets (out of thirty eight) which are highly concentrated and capital intensive. Fusillo [32] on the other hand finds evidence of excess capacity accumulation by ocean liners. Dafny [23] argues that hospitals might be investing in the number of surgical procedures in order to create a natural barrier to entry through experience and learning by doing. Bunch and Smiley [16] use a questionnaire completed by managers from various product markets to investigate the use of advertisement as a strategic investment tool. Their findings show that firms use advertising to build reputation and loyalty. They also find that firms do not spend resources on entry deterrence, if natural entry barriers already exist. Thomas [74] finds evidence of advertising in the cereal industry as a strategic entry deterrent, confirming the findings of Bunch and Smiley [16]. Koski [47] finds evidence of increased advertising by local U.S. telecommunication firms when faced with the threat of entry. Kadiyali [44] also finds that Kodak set low prices and high advertising spending to signal low cost of production or low demand prior to Fuji's entry into the film market. More recently, Morton [55] finds no evidence of use of advertising as an entry deterrent in the pharmaceutical industry.

The models that are provided by the empirical entry deterrence literature are simple and highly stylized reduced-form exercises that test for predicted patterns of correlation in the data. They do not provide a thorough analysis of what factors affect the incentives to deter entry. They have the multi-agent approach in the sense that incumbents invest strategically in capital stock or advertisement to deter entry. However, they ignore the fact that investments are also used to influence the investment decisions of existing competitors.

In the next section, I develop a theoretical model of firm investment that will embody the important insights from both of these literatures. Firms will make entry, exit and investment decisions in a dynamic, imperfectly competitive environment. Since each firm's decisions affect the decisions of its competitors, strategic use of investments will be important. In the short run, firms will choose prices to maximize profits in a differentiated product market. In the long run, they will make investments to maximize the value of their plants. In addition, investment costs will be modeled in a flexible way. Finally, uncertainties will be incorporated in multiple ways to better represent actual markets.

3.3 A Theoretical Model of Firm Investment

3.3.1 Overview

In this section I describe a model of dynamic competition in an oligopolistic market. It is a generalization of the PEM model. Time is discrete and indexed by $t = 1, 2, .., \infty$. Let n denote the total number of entrepreneurs in any period. N_t of them operate as active firms, each of which produces a single differentiated product, while the remaining $n - N_t$ are potential entrants. Firms differ in their holdings of capital stocks. The state of the industry is formed by assuming that a firm's capital stock can take one of K_{max} values. States are denoted by the vector $s_t = \{s_{1t}, s_{2t}, ..., s_{K_{max}t}\} \in S$, where s_{jt} is the number of firms at capital category j, and K_{max} is the highest state category any firm can reach. The state is publicly observed so that each firm knows the position of its rivals.

Given the state s_t, firms choose actions $a_t = \{a_{1t}, a_{2t}, ..., a_{nt}\} \in A$ which affect both current period's payoffs and future payoffs by influencing the state vector. These actions include decisions of price, investment, and exit for incumbents and entry for potential entrants. I assume that each firm observes a set of shocks $(\phi_{it}, \varepsilon_{it}, f_{it}) \in \Re^3$ before taking an action. These shocks are independently and identically distributed.

The first of these three shocks, f_{it}, is private information and denotes the scrap value (entry cost) draw for an incumbent (potential entrant). Incumbents from category j draw scrap values from a commonly-known distribution G_j and potential entrants draw their entry costs from a commonly-known distribution G_e. The second shock, ε_{it}, denotes the demand shocks for incumbents. I assume that the demand shocks are drawn from a distribution G_ε and are common knowledge, so the incumbents can observe the entire vector of demand shocks, $\varepsilon_t = \{\varepsilon_{1t}, \varepsilon_{2t}, ..., \varepsilon_{Nt}\}$. The third is a privately observed, firm-specific cost shock drawn from a distribution G_f.

In the static game an incumbent chooses a price to maximize period profits given the state of the industry and the shocks in that period. A firm's profit is a function of its state (capital stock) and its shock as well as its competitors' states and shocks. I assume that the profit function is increasing in a firm's own state. In particular, firms with more capital stock holdings have lower marginal costs of production. This creates the motive for investment in capital stock. In the dynamic game, firms choose investments (disinvestments) which improve (deteriorate) their states stochastically.

Given the current industry state and the shocks, firms enter and exit. Each period, active firms make independent draws of scrap values. If the value of staying and taking the optimal actions thereafter is greater than the scrap value, it is optimal for the firm to stay. There is also a pool of potential entrants, some of which may find it optimal to enter. Potential entrants make independent draws of sunk entry costs and compare them to the value of entering and becoming an incumbent next period. Entry takes place if a potential entrant's entry cost draw is smaller than the expected value of its resulting profit stream.

Firms maximize the expected sum of their discounted payoffs conditional on the current state s_t:

$$E[\sum_{s=t}^{\infty}\beta^{s-t}u_i(a_s, s_s, \varepsilon_s, \phi_s, f_s, \Omega)|s_t] \tag{3.1}$$

Here $\beta \in (0,1)$ is the discount factor and u_i includes firms' profits, investment costs, revenues from disinvestment, entry costs, and scrap values. The expectation is taken over the vector of random shocks and the firm's beliefs about the future state of the industry, which are given by the rivals' policy functions (entry, exit, and investment).

The expectation is taken over actions in the current period and the beliefs of the firm about the future state of the industry. These beliefs include the future industry state, competitors' future shocks and future actions of entry, exit and investment.

To summarize, one can define the action set a_{it} as a triplet including a choice of price, a decision to be active or not, and a choice of investment (disinvestment). These actions both define the period payoffs as well as the evolution of the industry structure in the future. At any point in time, firms' profits are functions of the price decisions which depend only on the demand shocks and the industry state. The static Bertrand game can be modeled independently of the dynamic game since price decisions of the static game do not influence the future states and payoffs. Firms' entry, exit, and investment decisions are functions of the payoffs implied by the state and the shocks in any period, but not the history of the game that is played. These actions transform the state s_t into s_{t+1}. While choosing their actions, firms form beliefs about the future state of the industry. These beliefs about s_{t+1} are embedded in a probability distribution $P(s_{t+1}|s_t, a_t)$, which will be described later. The industry is at a Markov Perfect Nash Equilibrium (MPNE) if these beliefs are consistent with the optimal policies generated by these beliefs.[3]

To analyze the equilibrium of this environment, I focus only on pure strategy MPNE. A markov perfect strategy for a firm is a mapping from the state, the private shock and the commonly observed shocks to actions denoted by $\sigma_i : S \times \Re \times \Re \times \Re^N \in A_i$. Let $\sigma = \{\sigma_1, \sigma_2, ..., \sigma_N\}$ be the set of strategies or decision rules where $\sigma : S \times \Re^N \times \Re^N \times \Re^N \in A$. If a strategy profile σ is a MPNE, then no firm i would prefer σ_i' to the strategy σ_i given its rivals' strategies σ_{-i}. That is, given the rivals' strategies σ_{-i}, σ_i maximizes the expression in (3.1). Let V_i be the Bellman equation representing the firm's expected sum of discounted payoffs in (3.1). Then, for every i, MPNE requires

$$V_i(s, \varepsilon, \phi, f | \sigma_i, \sigma_{-i}) \geq V_i(s, \varepsilon, \phi, f | \sigma_i', \sigma_{-i}). \tag{3.2}$$

The exact form of this value function is provided in the next section.

3.3.2 Timing of Actions

The order of decisions and outcomes between two time periods is given in Table 3.1. First, incumbents draw their demand shocks. Given the demand shocks, firms play the pricing game and profits are realized. Next, incumbents observe their scrap value draws and potential entrants observe their entry costs. Given the scrap values and entry costs, firms make optimal investment decisions. Next, entry and exit takes place. Finally, investment outcomes and depreciation shocks are realized.

[3]See Maskin and Tirole (1987,1988a, 1988b), PEM, and Doraszelski and Satterthwaite (2005) for MPNE in such models.

Note that scrap values and entry costs are private values but their distributions are public information. That is why firms have beliefs about the probability of exit for other incumbents and the probability of entry for the potential entrants. These probabilities are the same for every potential entrant and incumbents that are at the same state. I will elaborate on this in the dynamic environment.

3.3.3 Static Environment

3.3.3.1 Supply

Each firm produces a single differentiated product using a Cobb-Douglas production technology:

$$q_{it} = K_{it}^{\theta} L_{it}^{1-\theta} \qquad i = 1, \cdots, N_t \tag{3.3}$$

Here i indexes firms, and N_t represents the number of firms in period t. I omit the time subscript for the remainder of the static environment description since the static game is independent of the dynamic game. A firm's short run total cost consists of its labor cost and a fixed cost shock:

$$TC_i = w_i L_i + f_i \;=\; q_i^{\frac{1}{1-\theta}} K_i^{\frac{-\theta}{1-\theta}} + f_i \tag{3.4}$$

where f_i is a firm-specific fixed cost shock and w_i is the unit labor cost, which I set equal to 1. These cost shocks are drawn from a normal distribution $N(0, \sigma_f)$ and are independent across firms and time periods. The implied marginal cost is

$$mc_i = \frac{1}{1-\theta} q_i^{\frac{\theta}{1-\theta}} K_i^{\frac{-\theta}{1-\theta}} \tag{3.5}$$

which is increasing in quantity and decreasing in capital stock. For a given amount of production, firms with larger capital stocks have lower marginal cost of production. In the dynamic game, firms make investments to increase their capital stocks and become more efficient. This is described in more detail in the dynamic section.

3.3.3.2 Demand

The demand side is a generalization of the Ottaviano, Tabuchi and Thisse [59] and Melitz and Ottaviano [54] models. Consider an economy with L consumers. Preferences are defined over the set of differentiated varieties (firms) indexed by i and a homogeneous good chosen as numeraire. The utility of a consumer is given by

$$U = q_0^c + \sum_{i=1}^{N}(\alpha + \varepsilon_i)q_i^c - \frac{1}{2}\gamma\sum_{i=1}^{N} q_i^{c2} - \frac{1}{2}\eta(\sum_{i=1}^{N} q_i^c)^2 \tag{3.6}$$

where q_0 is the numeraire, N is the set of active firms at a given period, q_i^c is the amount of good i consumed, and ε_i is the firm specific demand shock. The parameter γ shows the degree of substitution between the differentiated varieties. An increase in γ decreases the degree of substitution. or equivalently, increases the differentiation between the varieties. The parameters α and η show the degree of substitution between the differentiated goods and the numeraire. Increases in α and decreases in η increase the demand for differentiated products. Demand shocks, ε_i, are drawn from a normal distribution $N(0, \sigma_\varepsilon)$ and are independent across firms and time periods. I assume that firms can observe the complete vector of demand shocks. An individual's inverse demand for each good is then given by

$$p_i = \alpha + \varepsilon_i - \gamma q_i^c - \eta \sum_{j=1}^{N} q_j^c \tag{3.7}$$

Solving (3.7) for q_i^c gives

$$q_i^c = \frac{1}{\gamma}(\alpha + \varepsilon_i - \eta \sum_{j=1}^{N} q_j^c - p_i) \tag{3.8}$$

One can manipulate this equation and sum over all the consumers to get quantity as a function of the demand parameters $(\alpha, \gamma, \eta, L)$, number of firms, firm's own price and demand shock as well as its competitors prices and demand shocks [4]

$$q_i = Lq_i^c = \frac{L}{\gamma}(\frac{\alpha\gamma}{\gamma + \eta N} + \frac{\eta N}{\gamma + \eta N}(\overline{p} - \overline{\varepsilon}) - p_i + \varepsilon_i) \tag{3.9}$$

where $\overline{p} = \frac{1}{N}\sum p_i$ and $\overline{\varepsilon} = \frac{1}{N}\sum \varepsilon_i$ Given their marginal cost schedule, firms which face the demand function (3.9) choose prices to maximize current profits:

$$\pi_i = (p_i - mc_i(1 - \theta))q_i - f_i. \tag{3.10}$$

The price decision implied by the firm's optimization problem is[5]

$$p_i = 0.5[mc_i + \varepsilon_i + \frac{1}{2\gamma + \eta N}(2\alpha\gamma + \eta N(\overline{mc} - \overline{\varepsilon}))] \tag{3.11}$$

[4]Let $\overline{q} = \frac{1}{N}\sum_{i=1}^{N} q_i$. Sum (3.8) over i to get $\overline{q} = \frac{1}{\gamma+\eta N}(\alpha + \overline{\varepsilon} - \overline{p})$. Then substitute q back into (3.8) and multiply by L to get (3.9).

[5]See the Appendix for details.

where $mc = \frac{1}{N}\sum mc_i$. Note that price is a function of own cost, number of firms, demand parameters, average cost level for the market, and average of the demand shocks. Given a firm's choice of price and quantity, total revenue and total costs are given by[6]

$$TR_i = p_i q_i, \quad TC_i = mc_i(1-\theta)q_i + f_i. \tag{3.12}$$

The static equilibrium is Bertrand-Nash in prices. Each firm sets a price level given its rivals' price decisions. Equilibrium is obtained whenever firms' beliefs about others' price decisions are consistent with the actual prices that are set by them. Since the choices of price in the current period do not affect future states the equilibrium in prices is subgame perfect.

3.3.4 Dynamic Environment

3.3.4.1 States

Consider a game with discrete time $t = 1, 2, .., \infty$. At any given time there are N_t active firms and they play the pricing game described in the previous section. Firms differ in their capital stocks. A firm's capital stock can take one of K_{max} values where K_{max} represents the highest state category any firm can reach. The relationship between the levels of capital stock is given by $k_{j+m} = k_j(1+\triangle)^m$, where k_{j+m} is the capital level in category $j+m$ and $\triangle \in (0,1)$. Hence the movements between capital categories correspond to percentage changes in the levels of capital stocks.

[6] Total costs and total revenues are relevant for the discussion of estimation in section 6 given that they are the variables observable to the econometrician.

An industry structure in period t is described by the number of firms at each category and denoted by $s_t = \{s_{1t}, s_{2t}, ..., s_{K_{max}t}\}$. The state of the industry is common knowledge. Firms with higher capital stocks are located in higher categories and have lower marginal cost of production as explained in the static environment. Moving from one period to another firms invest in their capital stocks to lower their marginal costs in the future. The investment process is explained next.

3.3.4.2 Investment

Firms make investment efforts, x_{it}, to improve their state between any two time periods. Investments outcomes are random and they denote the discrete increments to a firm's position in the state vector. The biggest step they can take is at most τ categories every period. That is, a firm in category j can move up to any of the categories $j+1, j+2, ..., j+\tau$ in the next period. If a firm moves up m categories, then the investment as a percentage of capital stock is $(1+\triangle)^m - 1$. The probability function for the investment outcomes is given by the Binomial distribution

$$Pr(\upsilon|x) = \begin{pmatrix} \tau \\ \upsilon \end{pmatrix} r^{\upsilon}(1-r)^{\tau-\upsilon} \qquad \upsilon = 0, 1, \cdots, \tau \tag{3.13}$$

where υ is the outcome and r is the probability of success. Success probability is given by $r = \frac{\rho x_{it}}{1+\rho x_{it}}$ where $\rho > 0$ is a constant denoting the effectiveness of investment. High values of ρ imply a greater probability of success, r, and thus, a greater expected investment realization. [7] Note that this functional form implies diminishing marginal

[7] The mean investment outcome is $r\tau$.

expected increments to capital as x_{it} increases. Investment outcomes are independent and spill-over effects are excluded. Hence firms' investments affect only their own states. An investment decision of $x_{it} > 0$ for a firm in category j has a total cost given by

$$c(x_{it}, k_{jt}) = c_f + \sum_{\upsilon=1}^{\tau} Pr(\upsilon|x_{it})[c_l((1+\triangle)^{\upsilon}-1)k_{jt} + c_q((1+\triangle)^{\upsilon}-1)^2 k_{jt}] + c_p x_{it}^2 \quad (3.14)$$

where c_f, c_l, c_q and c_p are nonnegative parameters to be estimated. Here, c_f represents the fixed investment cost, which does not depend on the size of the investment. The first term in the summation, $c_l((1+\triangle)^{\upsilon}-1)k_{jt}$, represents the purchase value of capital where c_l is the price of new capital. The second term, $c_q((1+\triangle)^{\upsilon}-1)^2 k_{jt}$, represents the adjustment costs of investment which are associated with machine setup costs.[8] Since the investment outcomes are random, the firm spends an expected cost of possible increments to its capital stock plus the cost of planning this investment project, $c_p x_{it}^2$. If optimal, a firm can choose not to invest in which case it does not incur an investment cost, i.e., $c(0, k_{jt}) = 0$.

Firms can also choose to sell capital (disinvest), if it is optimal to do so. Similar to the investment mechanism, disinvestment outcomes are also discrete, random, and can take a maximum of τ steps. A firm in category j can move down to any of the categories $j-1, j-2, \cdots, j-\tau$ in the next period.[9] The probability function of these outcomes is given by (3.13) with $r = \frac{\rho(-x_{it})}{1+\rho(-x_{it})}$. A disinvestment decision of $x_{it} < 0$ for

[8] Cooper and Haltiwanger [20] and Cooper, Haltiwanger and Willis [22] use similar cost functions with both convex and nonconvex components.

[9] Not every firm's investment (disinvestment) outcome can be t steps since states are bounded from above by the highest category, K_{max}, and from below by the lowest, 1. In such cases maximum step is smaller than τ.

a firm in category j has a revenue of

$$r(x_{it}, k_{jt}) = \sum_{\upsilon=1}^{\tau} Pr(\upsilon|x_{it})[c_l((1+\triangle)^{\upsilon}-1)k_{jt} - c_q((1+\triangle)^{\upsilon}-1)^2 k_{jt}] \tag{3.15}$$

That is, if a firm disinvests, it can recover an expected amount net of the adjustment cost. Clearly, $r(0, k_{jt}) = 0$.

Firms also receive random depreciation shocks, ς, with a probability function g_{ς}. Depreciation, if it takes place, forces a firm from category j to $j-1$ with a loss of $\triangle$ percent of its capital stock. More specifically, $g_{\varsigma}(1) = \delta$ and $g_{\varsigma}(0) = 1-\delta$. Given the characterization of investment (disinvestment) and depreciation, a firm in category j will be in category $j \pm \upsilon - \varsigma$ for a given realization of investment outcome υ and depreciation outcome ς. Note that the capital decays stochastically with depreciation, and investment is necessary for improvement. Given firms' investment/disinvestment strategies and independent depreciation draws, the industry state changes from s_t to s_{t+1}. However, these are not the only factors influencing the transition of the state. Firms' exit and entry decisions also contribute to the transition of the state. I explain these decisions next.

3.3.4.3 Entry & Exit

In the beginning of each period, incumbents choose between quitting and staying after observing a private scrap value draw, ϕ_{it}, from a commonly known uniform distribution $G_j = U[0, \nu_x ln(k_j)]$, where $\nu_x > 0$ and $\nu_x ln(k_j)$ represents the maximum amount that a firm in category j can recover. An incumbent's objective is to maximize its discounted sum of net profits by choosing investment (disinvestment) in the dynamic game. If the expected value of staying and making the optimal investment (disinvestment) decision is greater than the scrap value draw, then the firms chooses to stay. The incumbent's Bellman equation is thus given by

$$\begin{aligned} V_i(s,\varepsilon,f) = \pi_i(s,\varepsilon,f) + max\{\phi_i, max_{x_i}\{(1-I_i)r(x_i,k_j) - I_i c(x_i,k_j) + \\ \beta \textstyle\int_{\varepsilon',f'}[\sum_{s',\varsigma} V(s',\varepsilon',f')P(s'|x,s)g_\varsigma(\varsigma)]dG_\varepsilon(\varepsilon')dG_f(f')\}\} \end{aligned} \tag{3.16}$$

where I_i is the shorthand for the indicator function $I(x_i \geq 0)$, $G_\varepsilon(\varepsilon')$ and $G_f(f')$ are the probability distributions for future demand and cost shocks, and $P(s'|x,s)$ defines the probabilities over future states conditional on current state and optimal policy decisions. It also includes the firms's beliefs about its competitors' exit decisions as well as potential entry. The firm chooses to stay in the industry as long as its expected value of staying is greater than its private scrap value draw.

Entry takes place from a pool of potential entrants which is publicly observed. Since there are a total of n firms and N_t incumbents, the number of potential entrants is given by $n - N_t$. If $N_t = n$, then further entry is not allowed. Potential entrants compare the expected value of making the optimal pre-entry investment, $x_{it} > 0$, and becoming an incumbent to the cost of entering this industry. The initial state of each entrant is a random outcome with a Binomial distribution

$$Pr(\omega|x) = \begin{pmatrix} K_{max} \\ \omega \end{pmatrix} r^{\omega}(1-r)^{K_{max}-\omega} \quad \omega = 0,1,..,K_{max} \tag{3.17}$$

where $r = \frac{\rho x_{it}}{1+\rho x_{it}}$ and ω denotes the entry category. ω can take any of the values $0, ..., K_{max}$ depending on the entrant's initial investment.[10] When it comes to calculating the cost of the investment effort, an entrant is treated as an incumbent that is in the lowest category with a capital stock of k_{1t}. Hence the cost of this initial investment is given by

$$c(x_{it}, k_{1t}) = c_f + \sum_{\omega=1}^{K_{max}} Pr(\omega|x_{it})[c_l((1+\Delta)^{\omega} - 1)k_{1t} + c_q((1+\Delta)^{\omega} - 1)^2 k_{1t}] + c_p x_{it}^2. \tag{3.18}$$

Entrants are not operational until the next period, however, they are subject to depreciation. So, an entrant starts from $\omega - \varsigma$ for given realizations of ω and ς. A potential entrant draws a private entry cost ϕ_{it} from a commonly known distribution, G_e, and chooses to enter if the expected value of entering exceeds ϕ_{it}. g_e is common for all potential entrants and is given by $G_e = U[0, \nu_e]$, where $\nu_e > 0$ is to be estimated. Thus, the entrant's Bellman equation is:

$$V_i^e(s) = max_{x_i}\{-I_i c(x_i, k_1) + \beta \int_{\varepsilon', f'} [\sum_{s', \varsigma} V(s', \varepsilon', f')P(s'|x, s)g_{\varsigma}(\varsigma)]dG_{\varepsilon}(\varepsilon')dG_f(f')\} \tag{3.19}$$

Once they enter, entrants become incumbents and solve the incumbent's problem in 3.16. Note that ex ante all potential entrants are identical. Only the ones with favorable entry cost draws will choose to enter. The others will have to wait until next period.

[10]If an investment of $x_{it} = 0$ is optimal for an entrant, the entry takes place from the lowest category, i.e., $\omega = 0$.

Entry costs and scrap values are private information. Since each firm knows its own draw, the decision to enter or exit is a binary outcome. If firm i is an incumbent and $V_i(s) < \phi_{it}$, then it exits. Similarly, if firm i is a potential entrant and $V_i^e(s) > \phi_{it}$, then it enters. However, other firms only know the probability distributions of scrap values and entry costs. Given any state s_t, the probability of entry being optimal for a potential entrant is the probability of getting an entry cost draw smaller than the expected value of entering. Similarly, the probability of exit being optimal for an incumbent is the probability of getting a scrap value draw greater then the expected value of staying.

Within this framework each firm's payoff is dependent not only on its own actions but also on the actions of every other firm. So firms must form beliefs about the strategies of their competitors and make forward-looking decision accordingly. That is, they make decisions to stay, enter, exit, or invest based on their beliefs on others' strategies. The industry is said to be at a Markov Perfect Nash Equilibrium if these beliefs are consistent with the optimal policies generated by these beliefs. The conditions for the existence of an equilibrium are provided in the earlier literature (Ericson and Pakes [29] and Doraszelski and Satterthwaite [28] and are not reproduced here. The set of industry structures that will occur in equilibrium is shown to be recurrent and ergodic. That is, the industry evolves around a certain set of states once it reaches there and this set does not depend of the initial state of the industry.

To summarize, equations 3.9, 3.11, and 3.12 characterize the equilibrium in static game. Given the parameters of the model and draws of demand and costs shocks, these equations define per-period profits for the incumbents. In the dynamic game, equations 3.13 - 3.19 characterize optimal entry, exit, and investment decisions given the state of the industry and draws of scrap values and sunk entry costs.

3.4 Data

In the remainder of this paper, I develop the econometric methodology needed to estimate both the static and the dynamic parameters of the model. To do so, I use the plant level panel data on engines and turbines from Colombia. The sample period covers 1977-1991 and includes a total of 8 plants which appear at various years. There are several reasons why this industry is appealing. First, there are never more than 4 plants in any given year. Hence estimation can be done by computing the continuation values and the strategies for the entire state space and then simulating the model forward. Table 3.2 shows the changes in the number of active firms over the sample period. The minimum number of plants at any given year is 2 whereas the maximum is 4. Second, the size of the industry allows for strategic interaction within an oligopolistic market structure. If the size of the industry was larger, then one would expect the marginal effect of a competitor to be insignificant. Third, this is a stable industry with a an average of 2.53 plants over the sample period. This suggests a lack of large market shocks which might hinder the estimation. Fourth, there is sufficient entry and exit over the sample period. This allows for the estimation of entry costs and scrap values. Finally, it is a capital intensive industry where investments might play an important role within the competition.

I treat each plant as the decision-making firm. The data were collected by Colombia's Departamento Administrativo Nacional de Estadistica (DANE) and later cleaned as described in Roberts and Tybout [67]. The data set contains information on 38 plant-year observations on total revenues, total costs, investments and inputs of labor, capital and raw materials. Table 3.3 provides descriptive statistics from the data. There are an average of 2.53 plants in a given period with an approximate average markup of 21%. Plants have a short life span of approximately 4.63 years. Average entry and exit rates are approximately 20%. However, annual entry and exit rates vary significantly because of the small size of the industry. For example, the total number of active plants doubles between 1980 and 1981 whereas half of the plants exit between 1988 and 1989.

Investment behavior is summarized in Table 3.4. Out of the 8 firms in the data, 3 of them never make investments, 3 of them invest every period, and the remaining 2 make both investment and disinvestments throughout their lives. Mean investment as a percentage of capital stock (inclusive of zero investment observations) is 14% whereas mean disinvestment (of two observations) is 39%. Maximum investment ever observed is approximately 67%. The disinvestment observations come from two small firms which exist between 1985-1987. Aggregate investment behavior has a lumpy pattern as documented by Doms and Dunne [26] and others. Figure 3.1 shows periods of high average investment rates followed by periods of no investment activity. However, it is harder to detect lumpy investment at the firm level since firms live short lives. Figure 3.2 shows a right skewed investment pattern. Most investments are in the form of small adjustments rather than large investment projects.

3.5 Estimation

Next, I describe the estimation methodology to recover parameters of the static and the dynamic model. These estimations can be done independently since MPNE depends on current payoffs but not the history of the game. Firms' individual demands, and thus price decisions, depend only on the current state s_t and the demand and cost shocks. Moreover, price decisions in the static game does not affect the transition of the state of the industry. The profit levels implied by the static equilibrium determine firms' entry, exit, and investment strategies in the dynamic game.

3.5.1 Static Estimation

The structural parameters of the model relevant to the static estimation are $\Omega = \{\alpha, \eta, \gamma, L, \theta, \sigma_\varepsilon, \sigma_f\}$. This equilibrium is defined by the individual demand, the first order condition from the profit maximization problem, and the definitions of total revenue and total costs given in equations 3.9, 3.11, and 3.12. The sources of variation in firms' profits are their cost and demand shocks, and capital stocks. Note that the data do not include information on prices and quantities. Therefore the estimation is based on matching moments related to total revenues and total costs.

Given $\alpha, \eta, \gamma, L, \theta$ and the data on total revenues, total costs and capital stocks, one can recover q_{it}, f_{it}, and ε_{it} precisely. Since both shocks can be recovered given the parameters and the data, their variances, σ_ε and σ_f, can be computed as their actual variances at the estimated parameter values. This reduces the set of parameters to be estimated to $\Omega = \{\alpha, \eta, \gamma, L, \theta\}$.

The steps of recovering q_{it}, f_{it}, and ε_{it} are as follows. First, substituting the expression for price from the first order condition $p_{it} = mc_{it} + \frac{\gamma}{L}q_{it}$ into the total revenue equation $TR_{it} = p_{it}q_{it}$ gives

$$TR_{it} = \frac{1}{1-\theta} q_{it}^{\frac{1}{1-\theta}} K_{it}^{\frac{-\theta}{1-\theta}} + \frac{\gamma}{L} q_{it}^2 \tag{3.20}$$

for $i = 1, \cdots, N_t$ and $t = 1, .., T$. Define $F(q_{it}) = TR_{it} - \frac{1}{1-\theta} q_{it}^{\frac{1}{1-\theta}} K_{it}^{\frac{-\theta}{1-\theta}} - \frac{\gamma}{L} q_{it}^2$. Since this is a monotone decreasing function of q_{it}, there is a unique q_{it} which satisfies $F(q_{it}) = 0$. Then, quantities would suffice to recover both marginal costs and prices. Next, demand shocks can be recovered from the demand equation

$$q_{it} = \frac{L}{\gamma}\left(\frac{\alpha\gamma}{\gamma + \eta N} + \frac{\eta N}{\gamma + \eta N}(\overline{p} - \overline{\varepsilon}) - p_{it} + \varepsilon_{it}\right) \tag{3.21}$$

Finally, the cost shocks can be recovered by inverting the total cost expression $TC_{it} = mc_{it}(1-\theta)q_{it} + f_{it}$ and substituting the expression for marginal cost

$$f_{it} = TC_{it} - q_{it}^{\frac{1}{1-\theta}} K_{it}^{\frac{-\theta}{1-\theta}} \tag{3.22}$$

The estimation is done by generalized method of moments (GMM). Moment conditions are derived from the fact that observed capital stocks are not correlated with the shocks to demand and costs, and total revenues are not correlated with the fixed cost shocks. They are given by

$$E(f) = E(\varepsilon) = Corr(K, \varepsilon) = Corr(\varepsilon, f) = Corr(TR, f) = 0 \tag{3.23}$$

Note that these moment conditions depend on the assumption that neither of the shocks are serially correlated.[11] Let $\Psi(\Omega)$ be the vector of the moment conditions constructed with the sample moments.

Then the method of moments estimator is simply

$$\widehat{\Omega} = argmin_{\Omega}\pounds_1(\Omega) = argmin_{\Omega}(\Psi(\Omega))' W(\Psi(\Omega)) \tag{3.24}$$

where W is an optimal weight matrix. First, a minimum distance estimation is done by setting $W = I$. Then, these estimates are used as the initial values and the asymptotic variance covariance matrix evaluated at these estimates as the optimal weight matrix for the efficient GMM estimation.

Overall, the static estimation allows us to recover the demand and marginal cost curves for each firm. These estimates, in turn, allows us to characterize firms' profits. Since profits shape both the value of being an incumbent and the incentives to invest in capital stock, the static estimation will be the basis for estimating the dynamic parameters of the model; investment costs, scrap values, and sunk entry costs.

3.5.2 Dynamic Estimation

3.5.2.1 Overview

Despite the availability of data and theoretical models, very few studies have estimated the structural parameters of a dynamic oligopolistic model. This is simply

[11] Allowing for serial correlation in any of the shocks would mean adding another state variable to the model, and would complicate the computation of the equilibrium.

because estimating such a multi-agent game of interaction by computing the continuation values is demanding. The difficulty arises from the fact that computation of the continuation values at different parameter values until the implied behavior matches the actual decisions in the data is time consuming. At each set of parameter values one needs to find the fixed point of a Bellman equation which may not be guaranteed. Computation of equilibrium policies, especially for a large number of firms, is practically impossible even with the current state of computer technology.[12] There are, however, two empirical studies which adopt the PEM framework and follow the classical estimation method. Gowrisankaran and Town [34] adopt the model to the hospital industry and estimates some of the parameters using aggregate data. In their data, there were never more than 3 firms in any market which allowed for pursuing the classical estimation. Benkard [9] could examine the pricing decisions in the aircraft industry simply because he had detailed cost data which simplified his analysis.[13]

Recently, a few studies have proposed econometric techniques which significantly reduce the computational burden of estimating dynamic games. Not surprisingly, the idea is to avoid computing the continuation values entirely and approximate them using a semi-parametric estimation approach. These studies adopt a method which was first implemented by Hotz and Miller [41] and Hotz, Sanders and Smith [42] for single-agent

[12] This is the so called curse of dimensionality, the fact that time and space required for computation of the equilibrium increase exponentially with the number of state and control variables. For more on curse of dimensionality, see Rust [69] and Pakes [60].

[13] A few studies have proposed alternative ways of computing the numerical integration associated with the value functions. Pakes and McGuire [63] improves on the algorithm by introducing a stochastic algorithm. Doraszelski and Judd [27] propose the use of a continuous-time approach to speed up computation. Other studies include randomization (Rust [69]) and Monte Carlo integration (Keane and Wolpin [46]).

dynamic models. Dynamic discrete choice games (Aguirregabiria and Mira [5]), both discrete and continuous choice models (Bajari, Benkard and Levin [8], Jofre-Benet and Pesendorfer [43], and Berry and Pakes [13] (2000)), entry/exit games without investment (Pakes, Ostrovsky and Berry [64] and Pesendorfer and Schmidt-Dengler [66]) and dynamic games of incomplete information (Fershtman and Pakes [30] (2005)) are some examples.[14] The most relevant studies from this literature are Ryan [70] and Bajari et al [8]. Ryan [70] provides estimates of scrap values and entry costs for the U.S. Portland cement industry using the technique proposed by Bajari et al [8]. This approach breaks the estimation into two stages. In the first stage, firms' policy functions are recovered by regressing observed actions (such as investment, entry and exit) on the observed state variables. The probability distribution which defines the evolution of the state of the industry is also recovered at this stage. In the second stage, the structural parameters which make these observed policies optimal are estimated. Since the approach does not require computation of the fixed point, the computational difficulties are eliminated. However, estimating the continuation values rather than calculating them creates a sampling error which has important implications for the properties of the second-stage estimates. The first-stage estimation is also problematic because some states may never be visited in the equilibrium. Hence estimating the policy and value functions at these states consistently may not be possible. Also, for the states that are visited, consistent first-stage estimates require a large number of observations. Moreover, the observed actions in these states should be the same which may not be the case in reality.

[14]Ackerberg et al [1] provides a detailed summary of these studies.

In this study, I follow the classical estimation method to recover the dynamic parameters of the model. Since the engines and turbines industry is small, the computational burden does not hinder estimation. Moreover, the estimates do not have the approximation errors since I compute the equilibrium of the model at every set of parameters. The details of the estimation are described next.

3.5.2.2 Methodology

Since capital stock is a nonnegative and continuous real variable, the state space is discretized into K_{max} categories. For the number of state categories I choose $K_{max} = 12$. The minimum and maximum values of capital stock that are observed in the data are \$17,220 and \$383,840. The percentage change in capital stock is given by $\Delta = \frac{\ln \overline{K} - \ln \underline{K}}{K_{max}}$ where I choose $\underline{K}$ =15,181\$ and $\overline{K}$ =542,182\$. With $K_{max} = 12$, moving one category up corresponds to approximately 30% increase in the capital stock and moving up two categories corresponds to approximately 81% increase in the capital stock. Since the largest investment ever observed in the data is 67%, I set $\tau = 2$.

Depreciation appears to create small decreases in capital stocks. Average depreciation is approximately 8% with a maximum depreciation observation of 22%. Hence the assumption that depreciation forces the firm to a lower category generates a larger change than the average depreciation in the data. However, the probability of depreciation is set as $\delta = 0.5$ implying an expected depreciation rate of 15%. So every firm has a 50% chance of losing 30% of its capital stock every period.

Finally, I exclude the discount factor and the parameter for effectiveness of investment effort by setting $\beta = 0.9$ and $\rho = 1.0$. The choice of ρ is arbitrary and can also be included in estimation. The parameters that are not estimated are summarized in Table 3.5.

The remaining structural parameters of the dynamic model are given by $\Phi = \{c_f, c_l, c_q, c_p, \nu_x, \nu_e\}$. The first four of these parameters shape the investment (disinvestment) process whereas ν_x and ν_e shape entry and exit. Recall that firms' entry, exit, and investment decisions are characterized by equations 3.13 - 3.19 in the model.

Estimation of Φ is done by method of simulated moments (Gourieroux and Monfort [33]). The technique is based on finding the parameter values which generate moments close to the moments of the actual data. The moments that are used in estimation include moments that are based on investment behavior, entry and exit decisions, and macro moments. Let Λ^d be the $M \times 1$ vector of moments from the actual data. To construct the objective function a total of 8 moments ($M = 8$) are used: average number of firms, average exit rate, average entry rate, average capital stock, average number of firms with zero investment, average number of firms with positive investment, average investment, average capital stock of entrants. Then the method of simulated moments estimator is given by

$$\widehat{\Phi} = argmin_{\Phi} \pounds_2(\Phi) = argmin_{\Phi} (\Lambda^d - \Lambda(\Phi))' W (\Lambda^d - \Lambda(\Phi)) \tag{3.25}$$

where W is an $M \times M$ efficient weight matrix and $\Lambda(\Phi)$ is the vector of moments from each simulation-period pair.

At each step, first, the equilibrium strategies are computed for the entire state space. Given $K_{max} = 12$ and $n = 4$, the entire state space, denoted by S, would include a total of $|S| = \sum_{N=1}^{n} \frac{(K_{max}+N-1)!}{N!(K_{max}-1)!} = 1918$ states. The algorithm uses a simple backward induction approach to compute the equilibrium policies and value functions. Value functions and entry, exit and investment decisions are iterated until these values reach a fixed point and satisfy the convergence criteria. The convergence criteria that is used in the algorithm is a point by point convergence of values and investment policies. Even though this is a strict way of defining convergence, MPNE in pure strategies is obtained almost every time. Since each state consists of K_{max} categories the total number of value functions, investment decisions and exit probabilities to be computed are all $|S| \times K_{max}$. Entrants' investment decisions and the entry probabilities are given by a $|S| \times 1$ vector.

Since computation of the continuation values requires summing over many future states, I use an approximation technique to reduce the computational burden. Instead of considering all possible future states, I approximate the sum of expected flow of profits in 3.16 and 3.19 using monte carlo integration. The continuation values are computed by randomly drawing R future states, denoted by s', from the distribution implied by the optimal entry, exit, and investment strategies at any state. Let $\widetilde{V}_r(s'|s)$ be the continuation value of a firm when the industry state moves to a particular s' from s in the r^{th} generated case. Then as $R \to \infty$, we have

$$\frac{1}{R}\sum_{r=1}^{R} \widetilde{V}_r(s'|s) \approx V(s'|s).P(s'|a,s)F_{\varsigma}(\varsigma) \tag{3.26}$$

The right hand side of 3.26 denotes the continuation value if one considered all the future possibilities. This deterministic method would require a total of $(2+2\tau)^{N_t}$ future states to consider for an industry with N_t firms. This is because each firm can 1) depreciate, 2) stay in the same category because of a zero investment outcome, 3) move up or down a maximum of t steps. With $N_t = 4$ and $\tau = 3$ this would mean $8^4 = 4,096$ future states to be calculated, which would be extremely costly. As R is increased, the approximation would converge to the true value.[15] Moreover, the advantage of the random approach would sharply increase with both τ and N_t and help cope with the curse of dimensionality.

Given optimal strategies at every state point, 100 data sets are simulated for 115 periods. The simulations start with a random state and the observations from the first 100 periods are discarded to remove the effects of the initial state. Then, using the remaining 15 periods, the differences between the moments from each simulation-period and the actual moments from the data are computed to form the criterion function in 3.25.

Search is done by a Nelder-Meade Simplex search. The algorithm evaluates the criterion function at the vertices of a simplex, then iteratively expands or contracts as it attempts to find a minimizer Similar to this static estimation, the dynamic estimation is done in two stages. First, minimum distance estimates are computed by using an identity weight matrix, $W = I$. Then these estimates are used as starting values in the second stage where the weight matrix W is replaced with the inverse of the asymptotic variance-covariance matrix of the moment conditions. Finally, once $\widehat{\Phi}$ is estimated, the asymptotic variance-covariance matrix of the estimates is computed as $[G'WG]^{-1}$ where G is the matrix of derivatives of moments with respect to Φ. Since the calculation of

[15] Throughout the estimation I set $R = 25$. Experimenting with various values for R showed that $R = 25$ is sufficient to get a good approximation to the actual continuation values.

these variances rely on simulations, the estimates that are reported in the next section are averages of 5 estimation trials.[16] Next, I present the estimation results.

3.6 Results

3.6.1 Static Estimation

The estimates of the consumers' utility function and the cost parameter are provided in Table 3.6. The intercept of the demand curve is found to be $\alpha = 1.975$ though insignificant. The degree of product differentiation between the product varieties is $\gamma = 0.051$ and is estimated precisely. The fact that it is significant points to the fact that the product market competition is important and that the varieties are not perfect substitutes. The degree of substitution between the differentiated varieties and the numeraire is found to be $\eta = 1.235$. However, it appears to be insignificant. The size of consumers is estimated as $L = 1014.85$. This can interpreted as either number of consumers or number of households. Recall that each of these L units consume multiple units from each variety as implied by the consumer's utility function. The capital's coefficient in the production technology, θ, is 0.199 which is significant and consistent with the literature. The standard deviation of the demand and cost shocks implied by these estimates are $\sigma_f = 39.6$ and $\sigma_\varepsilon = 0.707$. Finally, the objective function at these estimates is 0.0044. Table 3.7 provides the values of each moment at the estimated parameter values.

[16] The choice of 5 estimation trials is completely arbitrary.

These estimates and the equilibrium prices and quantities lead to a mean own price elasticity of 8.42. Note that the price elasticities implied by the demand system depend on the average price and the number of firms in the market. The price elasticity of demand increases with the number of varieties and decreases with average price. That is, the product market becomes more competitive as the number of firms increase and average price decreases.

3.6.2 Dynamic Estimation

Table 3.8 lists the estimates of the dynamic game, Φ, and their standard deviations. The value of the moments at the estimates are given in Table 3.9. Overall, the parameters have reasonable magnitudes and are precisely estimated. Fixed cost's share in the total investment expenditure is approximately 12% for the biggest firms whereas this share increases to 32% for the smallest firms. The share of the convex planning costs, $c_p x_{it}^2$, range between 4% and 45%. Note that investment decisions have a concave appearance with respect to the state categories. This inverted-U shape of investments makes the share of the planning costs largest for mid-sized firms. The main reason behind this is the fact that state categories are bounded from above as one of the properties of the model. This puts a natural bound on firms' investment decisions as they move up in the state distribution. Finally, adjustment costs seem to be low but significant. This is consistent with findings of Haltiwanger and Cooper [20] for single-agent investment models.

The parameter of the scrap value distribution is estimated as $\nu_x = 150.7$ with a standard deviation of 4.73. Recall that the scrap value distribution varies with firm size and is given by $\nu_x ln(k_j)$ for the j^{th} category. The bounds for the lowest and highest categories are approximately $684,689 and $1,755,888 in 1977 dollars. Average value functions for these categories are $366,255 and $1,903,340 respectively. One important observation is that firms' values are approximately 10 years of profits. The model requires the upper bound of the scrap value distribution to be greater than 10 years of profits for exit to be possible. The way the scrap value distribution is defined induces more exit from the lower end of the state distribution and makes exit of big firms unlikely.

The upper bound of the entry cost distribution is estimated as $\nu_e = \$3,908,913$ with a standard deviation of 200,434. As Table 3.9 shows, new firms are mid-sized firms with a choice of capital stock close the average capital stock of the market. Hence, the probability of entry is approximately 20-25% for the states when entry is possible.[17] It is worth mentioning that expected sunk entry costs are significantly greater than the scrap values. This could be one explanation why the industry has not attracted more firms over the sample period. Note that even the mean of the entry cost distribution is greater than the maximum value a firm can generate.

3.7 Policy Experiment

Policy makers favor increased competition and lowering sunk entry costs is one way of achieving this. However, as discussed in the introduction, it is not clear how firms react to an increased threat of entry in oligopolistic markets. It might eliminate the incentives to invest since the market would be divided among a larger group of firms

[17]The probability of entry is given by expected value of entering divided by the upper bound of the entry cost distribution, ν_e.

and this decreases the incentives to improve marginal costs. More importantly, it might eliminate the use of investment as a strategic tool by which incumbents can influence the decisions of their rivals. If promoting entry discourages investments, it can lead to a welfare loss.

To answer all these questions I perform a policy experiment by lowering sunk entry costs. For the base-case I use the complete set of estimates, $\widehat{\Omega}$ and $\widehat{\Phi}$, from the previous section. For the experiment I lower the upper bound of the sunk entry cost distribution by 50% from \$3,908,913 to \$1,954,456. First, I compute the equilibrium of the game with the new entry cost distribution. Second, similar to the steps of the estimation algorithm, I simulate 100 data sets for 200 periods. I start the simulations with a random state and discard the observations from the first 100 periods. Then, I compare the moments with the moments from the base case.

To see the effect on the consumer welfare rewrite 3.6 as

$$U = q_0^c + Z(\underline{q}^c) \tag{3.27}$$

where $Z(\underline{q}^c)$ represents the total utility from the vector of differentiated varieties, $\underline{q}^c$, when the vector of prices are $\underline{p}$. When sunk entry costs are lowered, the industry competition and the composition of the product varieties change and lead to a new set of prices, $\underline{p}'$, for the firms and consumption bundles $q_0^{c'}$ and $\underline{q}^{c'}$ with a utility level of U' for the consumer. For a representative consumer the change in welfare is given by

$$U' - U = (q_0^{c'} - q_0^c) + (Z(\underline{q}^{c'}) - Z(\underline{q}^c)). \tag{3.28}$$

Since a consumer's income is fixed we also have

$$q_0^{c'} - q_0^{c} = \underline{pq}^{c} - \underline{p}'\underline{q}^{c'} \tag{3.29}$$

which is the difference of expenditures on differentiated varieties.[18] Hence the change in consumer welfare is given by $\Delta W = L(U' - U)$.

The results from the experiment are presented in Table 3.10. Lower expected sunk entry costs lead to more turnover. More firms enter the industry taking advantage of low entry costs and lead to an increase in the average number of active firms from 2.61 to 2.91. Increased rates of entry removes incentives to invest in capital accumulation. Average investment spending decreases by approximately 9%, from $39,796 to $36,153. This is partly because the consumers have a "love of variety"; it is always optimal to consume some of each variety. Since some important factors, such as brand loyalty and experience, do not matter, any new firm can generate an adequate market share. More entry to the industry lowers firms' profits, and thus, their values. This drop in the expected value forces the firms to cut back on investment projects. Consistent with this average investment rate drops from 15% to 14%.

Another reason why firms invest less is the fact that lower entry costs dampen the incentives to use investment as a strategic tool to deter entry. In fact, it is optimal to accommodate entry rather than spending resources on entry deterrence. To measure the incentives to deter entry, I compare investment decisions when incumbents expect entry and when they do not. In the base case firms spend approximately 15% more ($49,317

[18] Assuming that price of the numeraire good is normalized and fixed at $p_0 = 1$.

versus $42,897) when they expect entry whereas it is only 6.4% more ($42,550 versus $39,991) when sunk costs are lowered.

Increased competition also causes a small drop in potential entrants' pre-entry investments. As a result average capital stock of new firms decrease by 2.3% (from $115,550 to $112,996). This is also because profits are shared among a larger group of incumbents which leads to lower firm values. Hence, the expected value of becoming another incumbent is lower than the base case. This allows us to conclude that potential entrants behave less aggressive when the returns to entering an industry is low.

As a result of lower investment spending, the industry evolves around states where firms are smaller in size and consequently less efficient. Average capital stock falls by about 6% (from $144,199 to $135,242). Less efficient firms lead to higher marginal costs and prices. The effects of increased competition on price-cost margins and profit levels are quite interesting. Since firms pass most of the increase in costs to consumers by raising prices price-cost margins do not change much. Both costs and prices go up approximately 1.3% on average. Firms' profits decrease by less than 0.5% on average implying a slightly "tougher" competition.[19]

Consumers spend more of their income on the differentiated varieties for two reason; prices are higher and there are more varieties to spend on. The expenditures on the differentiated products increase 4.3%. Even with higher average prices the market share of the differentiated varieties go up because of consumers' love of variety ($q_0^{c'} < q_0^c$).

[19] One might want to use the changes in price elasticities to measure the level of competition. Note that price elasticities increase with the number of varieties and decrease with the average price. Since both the average number of firms and the average price go up the net effect on the elasticities is not clear.

However, this does not lead to an increase in their utility. Consumers buy smaller quantities of differentiated varieties because of high prices. The change in a representative consumer's utility is -82.02 causing a total consumer welfare loss[20] of $\Delta W = -83,238$.

To summarize, this experiment makes it clear that low entry costs may have unintended Schumpeterian consequences for this industry. This conclusion is contrary to what some policy makers believe. The experiment demonstrates that low entry cost does not squeeze price-cost margins. To the contrary, it allows high-cost firms to survive and charge higher prices. Moreover, it diminishes the strategic power of investment projects by making entry accommodation optimal. Higher prices lead to a significant welfare loss for the consumers

3.8 Conclusion

In this paper, I accomplish multiple objectives. I provide a structural model with strategic interactions and analyze the investment behavior in oligopolies. The framework that I develop includes most of the important determinants of oligopolistic competition. Most importantly, it allows for firms' decisions to affect the decisions of the others in the industry.

I estimate the structural parameters of the model for the engines and turbines industry in Colombia. I recover both the demand parameters of the static pricing game and the parameters of the dynamic investment process. I estimate the parameters of the investment cost function and the entry cost and scrap value distributions.

[20] Without more information on the income spent by a consumer for the products of this industry, we cannot determine the percentage change in welfare.

I simulate the model to examine how lower sunk entry costs affect the industry equilibrium. To my knowledge, this is the only study to answer this question empirically in a dynamic multi-agent environment. Contrary to what's expected, I find that lower entry costs lead to a welfare loss. This is because increased entry reduces investment expenditures and increases the average marginal cost and price of the industry. Consumer welfare decreases significantly since firms pass higher costs onto consumers. Firms' profits decrease very slightly on average. I also find that lower entry costs reduce the incentives to deter entry. Firms spend more on investment projects when they expect entry. However, it is significantly less than the case when entry costs are high.

Having such a detailed model comes at a cost. Even without the generalizations estimation of the model is a computationally demanding exercise. However, analyzing the effects of various policies requires resolving the model with altered parametrizations which takes a few minutes. I examined the effects of lower sunk entry costs. Similar experiments can be done with the rest of the structural parameters of the model, such as the degree of product differentiation in the goods market and the fixed costs of investment. I leave those for future work.

I should stress that modelling how the actual oligopolies work is not a simple task. Hence there is still more room for improvement. Depending on the characteristics of the industry, potential improvements include incorporating financial markets, market regulation, tax systems, and mergers and acquisitions. Pakes [60] summarizes previous applications of this class of models. These additions will help us more clearly understand how a particular industry operates and how it would respond to a policy change.

Table 3.1.
Timing of Events

Period t
$\Downarrow$
Incumbents draw (commonly observed) demand shocks.
$\Downarrow$
Incumbents play the pricing game. Profits are realized.
$\Downarrow$
Incumbents draw (private) scrap values.
Potential entrants draw (private) entry costs.
$\Downarrow$
Incumbents and entrants make investments decisions.
$\Downarrow$
Firms enter and exit.
$\Downarrow$
Investment and depreciation outcomes are realized.
$\Downarrow$
Period t+1

Table 3.2.
Entry and Exit

Year	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91
Entry	0	0	0	0	2	0	1	0	0	1	1	1	0	0	1
Exit	0	0	0	0	0	0	2	1	0	1	0	0	2	0	1
Incumbent	2	2	2	2	4	4	3	2	2	2	3	4	2	2	2

Table 3.3.
Descriptive Statistics

Average markup	1.216
Entry rate	0.22
Exit rate	0.17
Average number of firms	2.53
Average life span	4.63
Firms which never invest	3
Firms which invest every period	3
% of periods with investment by at least one firm	93.3
% of periods with zero investment by at least one firm	66.6
% of periods with disinvestment by at least one firm	13.3

Table 3.4.
Investment Behavior

	% of Observations	Mean	95% C.I.
Positive Investment	50	0.27	[0.15, 0.39]
Negative Investment	6.6	-0.39	[-0.5, -0.28]
Zero Investment	43.4	0.0	[0.0, 0.0]

Table 3.5.
Dynamic Parameter Values

Parameter		
β	Discount Factor	0.9
δ	Depreciation Probability	0.5
τ	Maximum Step	2
ρ	Investment Efficiency	1.0

Table 3.6.
Static Estimates

Parameter	Description	Estimate ($\widehat{\Omega}$)	S.E.
α	Intercept	1.975	5.06
η	Substitution between varieties and numeraire	1.235	10.29
γ	Substitution between varieties	0.051	0.01
θ	Coefficient of capital in production function	0.199	0.02
L	Number of consumers	1014.85	965.71
$L_1(\widehat{\Omega})$	Objective Function	0.0044	

Table 3.7.
Static Moments

Moment	Value at $\widehat{\Omega}$
corr(K,ε)	0.016
corr(f,ε)	0.009
corr(TR,f)	0.034
$E[\varepsilon]$	0.028
$E[f]^*$	1,542

* In 1977 dollars.

Table 3.8.
Dynamic Estimates

Parameter	Definition	Estimate ($\widehat{\Phi}$)	S.E
c_f^*	Fixed cost	7,643	2,728
c_l	Linear cost	1.244	0.42
c_q	Quadratic (adjustment) cost	1.513	0.64
c_p	Planning cost	28,519	9,044
ν_e^*	Upper bound of entry cost	3,908,913	200,434
ν_x	Upper bound of scrap value	150.7	4.73
$£_2(\widehat{\Phi})$	Objective Function	1.22	

* In 1977 dollars.

Table 3.9.
Dynamic Moments

Moment	Actual	Simulated at $\widehat{\Phi}$
Average number of firms	2.53	2.61
Average exit rate	0.17	0.12
Average entry rate	0.22	0.22
Average capital*	132,726	144,199
Average zero investment	0.34	0.40
Average positive investment	0.61	0.59
Average investment rate	0.14	0.15
Average capital (entrant)*	136,435	115,550

* In 1977 dollars.

Table 3.10.
Investment and Entry Deterrence

Average number of firms	2.61	2.91
Average exit rate	0.12	0.19
Average entry rate	0.22	0.38
Average capital*	144,199	135,242
Average capital (entrant)*	115,550	112,996
Average positive investment	0.59	0.64
Average zero investment	0.40	0.35
Average investment rate	0.15	0.14
Average investment spending when entry expected*	49,317	42,550
Average investment spending when entry is not expected*	42,897	39,991
Average investment spending*	39,796	36,153
Average price*†	3,875	3,925
Average marginal cost*†	3,839	3,891
Average profit*†	296,053	294,947
Expenditures on differentiated varieties* ($\underline{pq}^c$)	1,903	1,985
Utility from differentiated varieties ($Z(\underline{q}^c)$)	0.559	0.539

* In 1977 dollars. †Weighted by market shares.

Fig. 3.1. Average Investment Rates by Year

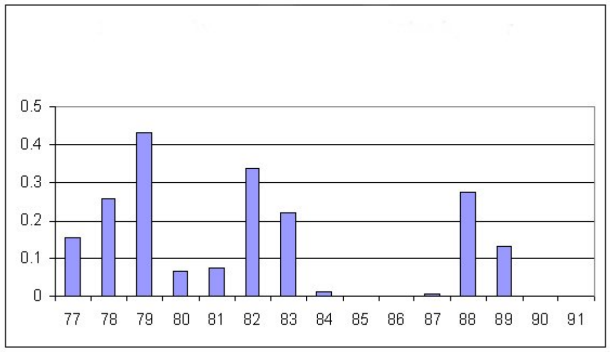
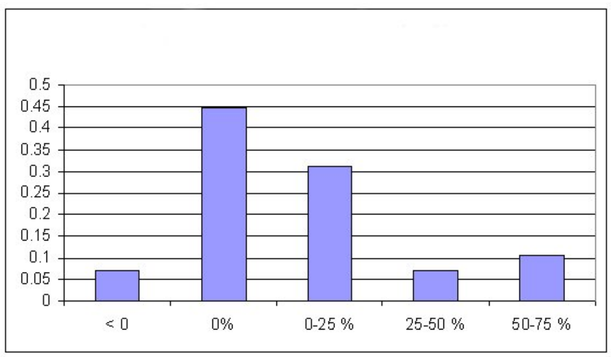


Fig. 3.2. Investment Rates by Size



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