BLS WORKING PAPERS

U.S. Department of Labor
U.S. Bureau of Labor Statistics
Office of Productivity and Technology

Industry Competition and Total Factor Productivity Growth

Michael D. Giandrea, U.S. Bureau of Labor Statistics

Working Paper 399
September 2006

All views expressed in this paper are those of the author and do not necessarily reflect the views or policies of the U.S. Bureau of Labor Statistics.

Industry Competition and Total Factor Productivity Growth

Michael D. Giandrea, Ph.D.
U.S. Bureau of Labor Statistics
Office of Productivity and Technology
Postal Square Building, Room 2180
2 Massachusetts Ave., NE
Washington, DC 20212-0001
Email: giandrea.michael@bls.gov
Phone: (202) 691-5628

August 25, 2006

* All views expressed in this paper are those of the author and do not necessarily reflect the views or policies of the U.S. Bureau of Labor Statistics. The author would like to thank Frank Gollop for his assistance and advice, and James Monahan for his assistance with the Longitudinal Research Database. Any errors are the author's responsibility.

Industry Competition and Total Factor Productivity Growth

Michael D. Giandrea

August 25, 2006

Abstract

This paper analyzes the impact of changes in the competitive market structure on an industry's total factor productivity (TFP) growth. The impact of horizontal mergers on TFP growth is of particular interest. The number of proposed horizontal mergers among U.S. firms totaled 28,818 from 1996 to 2005, while the number of U.S. Department of Justice investigations of proposed mergers totaled 1,303 during the same time period. The impact of mergers upon total factor productivity growth is rightly a topic for consideration. Merger participants routinely claim that mergers will result in welfare improving efficiency gains. If true, these gains should translate into increased TFP growth. This paper estimates this effect and others after presenting a model of TFP growth as a function of changes in the competitive market structure of an industry, changes in production diversification measured at the establishment level, and changes in output per establishment and the number of establishments. Mergers are found to have a positive impact upon TFP growth, accounting for 0.36 percentage points of total factor productivity growth between census years.

JEL Classification: D2, L1, L4.

1. Introduction

This paper considers the processes by which changes in an industry's market structure affect total factor productivity. Its uniqueness lies in the development and application of a model explaining productivity changes at the four-digit SIC industry level as a function of changes in industry output, changes in diversification of production in establishments, and changes in the industry's market structure.

Changes in market structure due to mergers among competitors and the consequences of these mergers on total factor productivity growth are of particular interest. This is an especially important topic when one considers recent merger trends. The Hart-Scott-Rodino Act of 1976 requires notification of intended mergers if the parties involved in the mergers are of sufficient size. The United States Department of Justice Antitrust Division reports in its workload statistics a total of 28,818 Hart-Scott-Rodino merger notifications from 1996 through 2005 with a peak of 4,926 in 2000. The number of investigations into these proposed mergers totaled 1,303 from 1996 through 2005 with a high of 220 in 1997.[1]

Most, if not all, mergers are undertaken by firms that anticipate lower average costs or increased profits as a result. These increased profits may arise from economies of scale or synergies in production, distribution, management, and advertising. At the same time, however, mergers can lead to increased market power and potential anti-competitive effects. This paper will assess whether economies of scale and synergies resulting from mergers impact productivity growth, and, if so, the significance of that impact.

The current literature has not investigated the relationships among all the changes in market structure and productivity, but typically focused on only mergers or entry and exit. This paper considers all the reasons why industry market structure changes over time. In addition to mergers, the paper investigates factors loosely described as industry evolution or changes in competitive

[1] Workload statistics are available from the U.S. Department of Justice website at http://www.usdoj.gov/atr/public/workstats.pdf.

structure. These factors include births and deaths of establishments, changes in the market shares of existing and continuing establishments, and changes in establishment output. An industry's competitive structure evolves over time as new establishments enter an industry and old establishments exit. Entry occurs when new establishments are built or when changes to an existing establishment's product line result in its classification in a different industry. Exit of an establishment from an industry occurs either with the closure of an establishment or the transfer of an establishment from one industry to another due to a change in the product line. An explanation of changes in competitive structure due to births, deaths, mergers, and changing market shares is presented in Section 3.

This paper reaches a number of conclusions related to changes in market structure and productivity growth. Model estimation finds that mergers had a positive impact on total factor productivity growth and that this effect was predominant in nondurable goods industries and concentrated industries. This latter result poses a particular problem for antitrust authorities who are especially concerned with the anticompetitive effects of mergers in concentrated markets. Estimation also determined that births of new firms resulted in faster productivity growth. This may have been due to increased competition spurring existing firms to compete more vigorously and more efficiently, or from the utilization of state-of-the-art capital and production techniques by new firms.

In the existing literature, ownership change was considered by Healy et al. (1990) who studied the fifty largest mergers among U.S. firms between 1979 and 1983. They observed that the firms that participated in these mergers realized faster asset productivity growth than other firms in the industry. McGuckin, Nguyen, and Reznek (1995) investigated establishment ownership change within SIC 20, Food and Kindred Products, between 1977 and 1987, to determine the effect of ownership change on productivity growth, wage growth, and employment. They found that ownership change was positively associated with both productivity and wage growth, but that the effects were smaller for large firms. Their analysis also showed that establishments that experienced ownership change were more likely to survive than those that did not.

McGuckin and Nguyen (1995a) utilized an unbalanced panel of establishments in SIC 20 to find that both employment and productivity were positively related to ownership change for the representative establishment, but negatively related to establishment closings for large establishments. McGuckin and Nguyen (1995b) also investigated the effect that acquisitions of establishments had on both the acquiring firm and the acquired establishment. In their analysis of SIC 20, they found that the productivity growth of acquired establishments increased while acquiring firms suffered slower productivity growth.

Extensive literature exists studying both the entry and exit of firms. Baldwin and Gorecki (1991) used Canadian establishment level data from the 1970s to investigate the exit rates and growth paths of establishments based on different types of entry and exit. Johnson and Parker (1994) analyzed the births of new establishments and the deaths of old establishments to detect the effects on future births and deaths. They explained possible interactions between births and deaths, and determined which variables have an effect on births and deaths. Finally, Baily et al. (1992) explored the heterogeneity of productivity within four-digit industries. They concluded that entry and exit of establishments had little effect on industry output growth. Using a neoclassical production function they determined that increasing output shares of high productivity establishments, and decreasing shares of output in low productivity establishments, were the primary causes of industry output growth.

This paper builds on various aspects of these works and others. I develop a model where total factor productivity growth is affected by the changes in the competitive structure of an industry and the changes in the level and composition of industry output. I begin by adding functional form to the analyses in McGuckin and Nguyen (1995a, 1995b) and others to better explain the process of how industry evolution, measured at the establishment level, affects productivity growth. I also utilize a larger data set than the above papers which allows me to investigate all manufacturing industries over more than two decades. From this model and extensive data set, I find that changes in market structure in general, and changes in market structure due to mergers in particular, impact TFP growth.

2. Theoretical Framework

The analysis of productivity growth begins with a 4-digit industry cost function given by

$$C = (\mathbf{p}, Q, T, D, H), \tag{1}$$

Where industry subscripts are suppressed. Industry cost is determined by a number of variables, including a vector of input prices, **p**, where the four factors of production are capital, k, production workers, l, energy, e, and materials, m. Factor markets are assumed to be competitive. The 4-digit industry output, given by Q, is the real total value of shipments in the time period. The level of technology is given by T. As is the custom, technology is measured in terms of time, t, such that, $T=e^t$. D is an index of production diversification. Finally, H represents the level of competition that exists in the 4-digit industry. I will argue that the competitive structure of an industry can change for any of four reasons: deaths of existing companies, births of new companies, mergers among competitors, and changes in market share of existing firms. These changes will be explained in detail in Section 3.

The ideal level of output may be chosen endogenously in a model of profit maximization that is external to this cost function and is not considered here. Therefore, I assume that output is exogenous. Industry output is calculated as the product $Q_E \cdot E$, where Q_E is the average output of an establishment in the industry and E is the number of establishments in the industry. The industry cost function is restated as

$$C = (\mathbf{p}, Q_E, E, T, D, H). \tag{2}$$

An index describing the level of diversification within a firm was developed by Gollop and Monahan (1991). The index illustrates phenomena that exist due to the manner in which output data are measured. A 4-digit industry's output consists of the production of 5-digit products classified within the industry. The industry is comprised of firms, each of which owns one or more production establishments. The level of diversification will quantitatively account for three issues relating to a firm's output.

First, a representative firm in a 4-digit industry may produce goods classified across a large or small number of 5-digit product categories. For example, Firm A's entire output may consist of production of a single 5-digit product within a 4-digit industry. Firm B, on the other hand, may produce output that is classified across ten separate 5-digit product categories. The diversification index accounts for this difference in the number of products produced by the firms, such that a firm is viewed as increasingly diversified as its number of products increases.

Second, the index quantifies the different firm characteristics depending upon the distribution of output across a number of separate 5-digit product categories. Firm B may produce ten separate 5-digit products where one of the ten products accounts for 91% of the firm's total output and each of the nine remaining products accounts for only 1%. A hypothetical, and far more diversified, Firm C may also produce ten separate 5-digit products where each product accounts for 10% of total output. Gollop’s and Monahan's diversification index accounts for this difference in distribution across 5-digit product categories.

Third, the diversification index quantifies a heterogeneity factor among firms that produce multiple 5-digit products. Other things equal, a firm producing a number of products with very similar inputs to production is less diversified than a firm producing the same number of products requiring very different inputs to production. When aggregating numerous 5-digit products into a 4-digit industry, significant information that had previously been lost is recovered through the diversification index. Each of these three components of the diversification index could affect the industry cost function. Gollop (1997) demonstrated that production specialization, measured as a reduction in the diversification index, had a significant effect on productivity growth measured at the 2-digit industry level. He found that a 10% reduction in diversification within an industry increased TFP growth by 1.48 percentage points, thereby supporting the argument that increased specialization measured at the establishment level led to increased productivity growth.

By logarithmically differentiating equation (2) with respect to time, I obtain an expression of the growth in industry production cost in terms of the component variables given by

$$\begin{aligned}\frac{d\ln C}{dt} = \sum_h \frac{\partial \ln C}{\partial \ln p_h}\frac{d\ln p_h}{dt} + \frac{\partial \ln C}{\partial \ln Q_E}\frac{d\ln Q_E}{dt} + \frac{\partial \ln C}{\partial \ln E}\frac{d\ln E}{dt} \\ + \frac{\partial \ln C}{\partial \ln T}\frac{d\ln T}{dt} + \frac{\partial \ln C}{\partial \ln D}\frac{d\ln D}{dt} + \frac{\partial \ln C}{\partial \ln H}\frac{d\ln H}{dt},\end{aligned} \tag{3}$$

for each 4-digit industry. Moreover, h indexes k, l, e, and m in equation (3) and throughout the paper. Applying Shephard's lemma to equation (3) allows an economic explanation for each of the partial derivatives. The industry cost elasticities of each input price are equal to that input's share of total cost. Capital's share of input cost is given by

$$\frac{\partial \ln C}{\partial \ln p_k} = \frac{p_k k}{C} = \beta_k. \tag{4}$$

Similarly, the industry cost shares of production labor, energy, and materials, and are given respectively by

$$\frac{\partial \ln C}{\partial \ln p_l} = \frac{p_l l}{C} = \beta_l, \tag{5}$$

$$\frac{\partial \ln C}{\partial \ln p_e} = \frac{p_e e}{C} = \beta_e, \tag{6}$$

and

$$\frac{\partial \ln C}{\partial \ln p_m} = \frac{p_m m}{C} = \beta_m. \tag{7}$$

The cost elasticity of average establishment output is representative of scale economies and is given by

$$\frac{\partial \ln C}{\partial \ln Q_E} = \beta_{Q_E}. \tag{8}$$

If β_{Q_E} takes a value less (greater) than one, then the industry exhibits economies (diseconomies) of scale. Other things equal, if cost changes proportionately less (more) than average establishment output, then production displays economies (diseconomies) of scale. If β_{Q_E} takes a value equal to one, then the production function locally displays constant returns to scale.

The cost elasticity of the number of establishments within a 4-digit industry is given by

$$\frac{\partial \ln C}{\partial \ln E} = \beta_E . \tag{9}$$

By holding the level of competition, *H*, fixed with respect to equation (9), the number of firms is effectively held constant. Therefore, equation (9) is the elasticity of establishments per firm, which measures multiple establishment economies. A value of β_E that is less (greater) than one implies economies (diseconomies) of increasing the number of establishments per firm.

Technology is defined using census years where $T=e^t$ such that $\partial \ln T / dt = 1$ and the average rate of technical change between census years is given by

$$-\frac{\partial \ln C}{\partial \ln T} = \beta_T . \tag{10}$$

The average rate of technical change takes a negative sign since an increase in technology leads to a reduction in cost.

The elasticity of cost with respect to the diversification index is given by

$$\frac{\partial \ln C}{\partial \ln D} = \beta_D . \tag{11}$$

Other things equal, β_D describes the relationship between changes in industry cost and changes in the establishment-based measurement of production diversification.

Finally, consider the variable of particular interest in this paper, the measure of 4-digit industry competition. The elasticity of cost with respect to changes in competition is given by

$$\frac{\partial \ln C}{\partial \ln H} = \beta_H . \tag{12}$$

In Section 3 I consider in detail the development of this variable and how it changes over time.

In order to derive total factor productivity growth from the 4-digit industry cost growth function described by equation (3), replace the partial elasticities to obtain

$$\begin{aligned} \frac{\partial \ln C}{\partial t} &= \sum_h \beta_h \frac{d \ln p_h}{dt} + \beta_{Q_E} \frac{d \ln Q_E}{dt} + \beta_E \frac{d \ln E}{dt} \\ &\quad - \beta_T \frac{d \ln T}{dt} + \beta_D \frac{d \ln D}{dt} + \beta_H \frac{d \ln H}{dt}. \end{aligned} \tag{13}$$

From each side of equation (13) subtract the cost-share weighted input price growth rates, the growth rate of average establishment output, and the growth rate of the number of establishments to obtain

$$\begin{aligned} &\frac{d \ln C}{dt} - \sum_h \beta_h \frac{d \ln p_h}{dt} - \frac{d \ln Q_E}{dt} - \frac{d \ln E}{dt} \\ &= \left(\beta_{Q_E} - 1\right) \frac{d \ln Q_E}{dt} + \left(\beta_E - 1\right) \frac{d \ln E}{dt} \\ &- \beta_T \frac{d \ln T}{dt} + \beta_D \frac{d \ln D}{dt} + \beta_H \frac{d \ln H}{dt}. \end{aligned} \tag{14}$$

Multiply each side of equation (14) by negative one to obtain the negative of the growth rate of cost less the cost-share weighted growth of input prices, the growth rate of average establishment output, and the growth rate of the number of establishments given by

$$\begin{aligned} &-\left[\frac{d \ln C}{dt} - \sum \beta_h \frac{d \ln p_h}{dt} - \frac{d \ln Q_E}{dt} - \frac{d \ln E}{dt}\right] \\ &= \left(1 - \beta_{Q_E}\right) \frac{d \ln Q_E}{dt} + \left(1 - \beta_E\right) \frac{d \ln E}{dt} \\ &+ \beta_T \frac{d \ln T}{dt} - \beta_D \frac{d \ln D}{dt} - \beta_H \frac{d \ln H}{dt}. \end{aligned} \tag{15}$$

The left-hand side of equation (15) is the expression for total factor productivity, i.e. the reduction in industry cost not accounted for by a reduction in input prices or industry output. Therefore, equation (15) becomes

$$T\dot{F}P = \left(1-\beta_{Q_E}\right)\frac{d\ln Q_E}{dt} + \left(1-\beta_E\right)\frac{d\ln E}{dt} + \beta_T\frac{d\ln T}{dt} - \beta_D\frac{d\ln D}{dt} - \beta_H\frac{d\ln H}{dt}. \quad (16)$$

The intuition behind the right-hand side variables becomes clearer upon inspection of equation (16). For example, an increase in the average output per establishment, other things equal, would result in economies (diseconomies) of scale if β_{Q_E} is less (greater) than one. Likewise, an increase in the establishment level diversification within an industry would decrease (increase) total factor productivity if β_D is greater (less) than zero.

3. Competitive Market Structure

An important contribution of this paper is the treatment of changes in competitive structure of the market. Therefore, I further decompose $d\ln H/dt$ into separate components reflecting changes in the competitive market structure due to the deaths of existing firms in an industry, the births of new firms into an industry, horizontal mergers, and changes in the market shares of continuing firms in the industry. Previous authors have argued that the competitive forces within an industry will affect industry cost. The theory that the level of competition affects production cost was described by Leibenstein (1966) as x-efficiency. Leibenstein wrote that there is "more to output than the obviously observable inputs. The nature of management, the environment in which it operates, and the incentives employed are significant."[2] Leibenstein argued that both competition and adversity create pressure for changes to improve x-efficiency. Many authors have built upon the x-efficiency framework to explain why firms may not operate in a cost minimizing fashion and, furthermore, how firms might improve x-efficiency.

Nickell (1996) asked whether competition improves firm performance. His analysis of 670 U.K. manufacturing companies supported the view that a more

[2] Leibenstein (1966), p. 401.

competitive market, measured by both the number of competitors and by decreased monopoly rents, was associated with higher total factor productivity growth. Stennek (2000) developed a model where both financial constraints and the level of competition within an industry act as disciplining powers resulting in higher effort and increased x-efficiency. Scherer and Ross (1990) found that x-inefficiency was low when competition was strong and that the losses due to x-inefficiency were as large as losses from allocative inefficiency.

As a measure of competition, albeit an imperfect measure, I will utilize the Herfindahl-Hirschman (HH) index. The HH index is calculated as the sum of squared market shares of each company within an industry. The HH takes a maximum value of 10,000 when one company produces the entire industry output and a minimum value approaching zero under perfect competition. Changes in the HH index are prominent indicators of changes in competition and these changes are utilized in the U.S. Department of Justice Merger Guidelines. Changes in the HH index of a certain magnitude due to a proposed merger invite increased scrutiny of the merger by the Department of Justice or Federal Trade Commission. Markets with HH indexes below 1000 are considered unconcentrated. Those markets with HH indexes between 1000 and 1800 are considered moderately concentrated. Finally, those markets with HH indexes above 1800 are highly concentrated. Establishment data are aggregated to the company level since an establishment level HH index would be artificially low as in the following example. If a monopolist had ten establishments, each producing 10% of industry output, the HH index should take the maximum value of 10,000 and not the more competitive appearing value of 1,000.

The changes in competitive structure due to deaths, births, mergers, and changes in market share can be approximated by the changes in the HH index. The HH index can change as a result of the death of a company within the industry.[3] A company can close its establishments that produce within the given

[3] I consider deaths to occur separately from other changes in competitive structure. The direct change in the HH index as a result of the death of companies is given by

industry or it can sell its establishments and cease production in this industry. If a company exits the industry by selling its establishments to a new entrant, I consider this action to be the death of the existing firm and the birth of a new firm as the establishment's ownership changes.

The change in the HH index due to deaths will likely be positive reflecting a potentially less competitive market with fewer competitors. This increase in the HH index due to deaths could impact TFP growth in any or all of three separate effects. First, the closing of establishments may remove the least productive and highest cost plants from the industry. Therefore, the increase in the HH index due to the deaths of companies will increase TFP growth. Second, a company exiting the industry can sell its productive establishments to other companies. Matching theory of establishment turnover suggests that ownership change of continuing plants would reduce average cost and increase TFP growth. The third potential effect is that the death of a company reduces the number of competitors within an industry. The theory of x-efficiency would lead one to believe that this reduction in competition could reduce the cost-cutting incentives of the remaining firms. Conversely, one also suspects that a dying firm is likely a high cost and low TFP

$\Delta HH = 2\sum_l s_{l,t-1} \frac{\sum_i s_{i,t-1}^2}{\sum_i s_{i,t-1}} + \sum_l s_{l,t-1}^2 \frac{\sum_i s_{i,t-1}^2}{\left(\sum_i s_{i,t-1}\right)^2} - \sum_l s_{l,t-1}^2$, where *l* indexes firms that exist in census year *t*-1 and do not exist in year census year *t*, and *i* indexes companies that exist in both census years. The market share of each company is denoted by *s*. Therefore, the change in the HH index due to a death can be described through the following example where one of three firms exits between periods.

$$HH_{t-1} = s_1^2 + s_2^2 + s_3^2$$

and if the continuing firms grow proportionately to their own size in period *t*-1, then

$$HH_t = \left(s_1 + \frac{s_1}{s_1+s_2}s_3\right)^2 + \left(s_2 + \frac{s_2}{s_1+s_2}s_3\right)^2.$$

This is rewritten as

$$HH_t = s_1^2 + s_2^2 + 2s_3\frac{s_1^2+s_2^2}{s_1+s_2} + s_3^2\frac{s_1^2+s_2^2}{(s_1+s_2)^2}.$$

Then the change in the HH index between periods due to the death of company 3 is

$$HH_t - HH_{t-1} = 2s_3\frac{s_1^2+s_2^2}{s_1+s_2} + s_3^2\frac{s_1^2+s_2^2}{(s_1+s_2)^2} - s_3^2,$$

which can be generalized as in the equation above.

growth firm. Therefore, the effect of deaths of existing companies upon TFP growth is unclear.

A birth is defined as a company that does not produce any output in industry A in census year *t*-1, but by census year *t*, the company has at least one establishment that produces primarily in industry A.[4] The company can either build a new establishment to enter the industry or it can purchase an existing establishment and produce in industry A in census year *t*.

This change in the HH index will likely be negative,[5] reflecting a potentially more competitive market structure with more competitors. Entry into an industry can take one of two forms. First, entry can take place when a company builds new establishments or purchases unused establishments. One would suspect that the latest technology in production would put downward pressure on cost and increase TFP growth. Second, entry can occur through a change in ownership of an existing establishment. In this case, a firm that does not produce in SIC A purchases an existing establishment inside or outside of SIC A and begins

---

[4] I consider births to occur separately from other changes in competitive structure. The direct change in the HH index resulting from a company birth is given by

$$\Delta HH = \sum_m s_{m,t}^2 - 2\sum_m s_{m,t} \frac{\sum_i s_{i,t-1}^2}{\sum_i s_{i,t-1}} + \sum_m s_{m,t}^2 \frac{\sum_i s_{i,t-1}^2}{\left(\sum_i s_{i,t-1}\right)^2}$$

, where *m*, indexes companies that do not exist in census year *t*-1, but do exist in census year *t*, and *i* indexes companies that exist in both census years. Therefore, the change in the HH index due to a birth can be described by the following example where two incumbents are joined by a new entrant, companies 1, 2, and 3, respectively.

$$HH_{t-1} = s_1^2 + s_2^2$$

and if the new firm takes market share proportionately from the two incumbents, then

$$HH_t = \left(s_1 - \frac{s_1}{s_1 + s_2} s_3\right)^2 + \left(s_2 - \frac{s_2}{s_1 + s_2} s_3\right)^2 + s_3^2.$$

This can be restated as

$$HH_t = s_1^2 + s_2^2 + s_3^2 - 2s_3 \frac{s_1^2 + s_2^2}{s_1 + s_2} + s_3 \frac{s_1^2 + s_2^2}{\left(s_1 + s_2\right)^2}.$$

Then the change in the HH index between periods due to the birth of company 3 is

$$HH_t - HH_{t-1} = s_3^2 - 2s_3 \frac{s_1^2 + s_2^2}{s_1 + s_2} + s_3 \frac{s_1^2 + s_2^2}{\left(s_1 + s_2\right)^2},$$

which can be generalized as in the equation above.

[5] An increase in the number of competitors could increase the Herfindahl-Hirschman index if the new companies have large enough market shares.

producing goods in SIC A. The matching theory of plant turnover argues that low productivity results from a poor match between the establishment and the parent company. This theory would predict lower cost and an improvement in TFP growth as a result of the ownership change.

The HH index can also change as a result of a merger among competitors.[6] A merger among competitors will always increase the HH index. Mergers can have one or both of two effects. First, as enforcers of antitrust law assert, mergers among competitors can result in a reduction in competition and therefore a reduction in x-efficiency as firms lose some cost cutting incentives. This would lead to lower TFP growth. Second, nearly every merger among competing companies is described by the participants as an opportunity to cut costs and take advantage of synergies among the companies involved. This would lead to lower cost and higher TFP growth. Therefore, the effect of mergers on TFP growth may in theory be either positive or negative.

A fourth reason why the competitive structure of the market and the HH index will change from one census year to the next is as a result of a simple change in market share for continuing firms in the industry. For example, four firms with equal market shares, 25% each, would exhibit a HH index calculated as 2,500. If, between periods, the market share of one firm grows to 40% while the market

[6] I consider mergers to occur separately from other changes in competitive structure. Only horizontal mergers are considered such that the change in the HH index due to a merger is the result of a merger among two or more firms within the same 4-digit industry. The direct change in the HH index due to the merger of two competitors is given by

$$\Delta HH = 2\sum_{i}\sum_{j\neq i} s_{i,t-1}s_{j,t-1},$$

where firms *i* and *j* merge between census years *t*-1 and *t*. Three firms merging can be described by the following example where three competitors merge to become a single firm between periods such that,

$$HH_{t-1} = s_1^2 + s_2^2 + s_3^2 + s_4^2 \text{ and}$$

$$HH_t = s_1^2 + \left(s_2 + s_3 + s_4\right)^2,$$

which can be rewritten as

$$HH_t = s_1^2 + s_2^2 + s_3^2 + s_4^2 + 2s_2s_3 + 2s_2s_4 + 2s_3s_4.$$

The change in the HH index due to the merger of the three firms is therefore

$$HH_t - HH_{t-1} = 2s_2s_3 + 2s_2s_4 + 2s_3s_4,$$

which can be generalized as in the equation above.

shares of the competing firms fall to 20% each, the HH index is calculated as 2,800. This change in the HH index of over 11% arises from a change in the market shares of the continuing firms. The HH index can therefore change, possibly by a large amount, even if there are no births or deaths of companies or no mergers among competitors. I measure the change in the HH index due to a change in company market share as a residual; it is the change in the HH index from census year *t*-1 to census year *t* that is not due to deaths, births, or mergers.

A fifth reason why the HH index can change from census year to census year is due to a phenomenon I designate as "switching." Switching is essentially an artifact of the definition of a four-digit industry. Consider a single establishment company that produces two different products. One product is classified as being within industry A, while the other is classified within industry B. In census year *t*-1, fifty-one percent of the establishment's total value of shipments is classified within industry A while the remaining forty-nine percent is in industry B. This establishment is classified within the LRD as producing in industry A. If, in the next census year, forty-nine percent of the establishment's sales are in industry A and fifty-one percent are within industry B, then the establishment would be classified within industry B. This process is an example of switching. I separate it from other types of firm evolution because, for example, there may be no change in the production of the above establishment within industry A, but an increase in its industry B production. Switching will therefore be considered separately from deaths, births, mergers, and changes in market share.

I substitute the separate changes in the HH index for $d\ln H/dt$ into equation (16) to obtain

$$\begin{aligned} T\dot{F}P = {} & \left(1-\beta_{Q_E}\right)\frac{d\ln Q_E}{dt} + \left(1-\beta_E\right)\frac{d\ln E}{dt} + \beta_T\frac{d\ln T}{dt} \\ & -\beta_D\frac{d\ln D}{dt} - \beta_{H_{death}}\frac{d\ln H_{death}}{dt} - \beta_{H_{birth}}\frac{d\ln H_{birth}}{dt} \\ & -\beta_{H_{merger}}\frac{d\ln H_{merger}}{dt} - \beta_{H_{mktshare}}\frac{d\ln H_{mktshare}}{dt}. \end{aligned} \tag{17}$$

A contribution of this paper to the existing literature is its development and treatment of the changes in competition, measured as changes in the HH index. Section 4 further describes the development of variables that estimate the change in the HH index.

4. Data Set Construction

To estimate the coefficients of the above theoretical model, I construct a data set from two separate resources. The first source of data is the Manufacturing Industry Database maintained by Eric J. Bartelsman, Randy A. Becker, and Wayne B. Gray. The database is a joint effort between the National Bureau of Economic Research (NBER) and the U.S. Census Bureau's Center for Economic Studies (CES). The database contains input price indexes and 4-digit industry output that are used in the calculation of total factor productivity. Bartelsman and Gray (1996) described the calculation of total factor productivity that will be utilized in this paper. The database also contains 4-digit industry output price deflators. These data are available for download from the NBER website.[7]

The second source of data is the U.S. Census Bureau and the Longitudinal Research Database (LRD). Maintained by the CES, the LRD is an unbalanced panel containing cost and output data on all U.S. manufacturing establishments collected through the Census of Manufactures. The Census of Manufactures has collected this information in the census years: 1963, 1967, 1972, 1977, 1982, 1987, 1992, and 1997. The LRD contains data on each establishment's inputs of labor, materials, and capital, its total value of shipments of goods and services in each 7-digit product, its location, and its legal form of organization. Within the LRD, each establishment is assigned a permanent identification number allowing it to be tracked from census year to census year. The establishment is classified by the industry that accounts for the largest percentage of the plant’s output. Each establishment ID contains an identifier number that links the establishment to its parent company which similarly is assigned an identification number. The LRD

[7] The NBER – CES website can be found on the world-wide-web at http://www.nber.org/nberces/.

can therefore identify whether the establishment is part of a single establishment company or a multiple establishment company. Because of the identifier linking an establishment to a parent company, the LRD can determine ownership changes. It is also possible to detect the birth of new establishments by the appearance of a new establishment ID, and likewise the LRD can detect the death of an existing establishment when plant ID numbers disappear from one census year to the next. I have obtained 4-digit industry data by rolling up establishment level data to both the company level and the industry level.[8]

The LRD provides three key variables for my analysis. First the total value of shipments of each establishment within a 4-digit industry provides industry output and the number of establishments in the industry. I compute real industry output by utilizing these data and the 4-digit industry price deflators from the NBER-CES database. Then, for each 4-digit industry, calculate the average real output per establishment and the number of establishments. The product of the average real output per establishment, Q_E, and the number of establishments, E, is equal to 4-digit industry output.

Second, the diversification index is developed utilizing the LRD. A complete explanation of its construction exists in Gollop and Monahan (1991). Third, the data enable the calculation of the Herfindahl-Hirschman index (HH) for each 4-digit industry. The change in the HH index between census years is decomposed into the change in the HH index due to "switching," deaths, births, mergers, and the change in market share. Ideally, the calculations of the changes would occur simultaneously, as if all deaths, births, and mergers happened at the same time. Since this is computationally impossible, I assume that the different types of firm evolution happen sequentially. Therefore, the change in the HH index is calculated as the sum of the five changes listed above.

Begin with the population of companies within an industry and compute the HH index for year t-1. Designate this HH index as $H_{1,t-1}$. Then alter the population of firms by adjusting for switching and calculate the HH index,

[8] Special thanks to James Monahan of the Center for Economic Studies whose assistance was invaluable.

designated as $H_{2,t\text{-}1}$. Next, adjust the population by accounting for all company deaths that occur between census years t-1 and t. Designate the HH index calculated from this population as $H_{3,t\text{-}1}$. Again adjust the population, this time by adding to the population those companies that enter the industry between census years t-1 and t. Designate the HH index calculated from this population as $H_{4,t\text{-}1}$. Finally, adjust the population of firms by accounting for all the horizontal mergers between census years t-1 and t. Designate the HH index calculated from this population as $H_{5,t\text{-}1}$. Then calculate the HH index for the census year t population of firms and designate it as $H_{1,t}$. Therefore, the change in the log of the HH index is given by

$$\begin{aligned}\ln H_{1,t} - \ln H_{1,t-1} = &\left(\ln H_{2,t-1} - \ln H_{1,t-1}\right) + \left(\ln H_{3,t-1} - \ln H_{2,t-1}\right) \\ &+ \left(\ln H_{4,t-1} - \ln H_{3,t-1}\right) + \left(\ln H_{5,t-1} - \ln H_{4,t-1}\right) \\ &+ \left(\ln H_{1,t} - \ln H_{5,t-1}\right).\end{aligned} \tag{18}$$

Switching is calculated initially and this makes sense intuitively. I attempt to obtain a more accurate value of the true level of competition within a 4-digit industry as measured by the HH index. I therefore want to remove those companies that enter or exit the industry simply as a result of the changes in the classification of an establishment's output without obvious physical changes. Moreover, the change due to mergers should be calculated after births since new firms may be involved in mergers with existing firms. The choice of calculating first the change due to deaths and then the change due to births is completely arbitrary and yet likely has little impact upon the estimation results.

5. Econometric Model

I select a functional form for the industry cost function to test the hypothesis that changes in the competitive structure of an industry impact TFP growth. Consider the Cobb-Douglas cost function as an approximation of industry cost

$$C = \alpha \prod_h p_h^{\beta_h} Q_E^{\beta_{Q_E}} E^{\beta_E} T^{\beta_T} D^{\beta_D} H^{\beta_H}, \tag{19}$$

where h indexes the four input prices. As with the model described in Section 2, take the natural log of each side of equation (19) to obtain

$$\ln C = \alpha + \beta_h \sum_h \ln p_h + \beta_{Q_E} \ln Q_E + \beta_E \ln E$$
$$+ \beta_T \ln T + \beta_D \ln D + \beta_H \ln H. \tag{20}$$

Differentiate equation (20) with respect to time and rearrange to obtain

$$T\dot{F}P = \left(1 - \beta_{Q_E}\right)\frac{d \ln Q_E}{dt} + \left(1 - \beta_E\right)\frac{d \ln E}{dt}$$
$$+ \beta_T - \beta_D \frac{d \ln D}{dt} - \beta_H \frac{d \ln H}{dt}, \tag{21}$$

which is an expression for TFP growth in continuous time derivatives in terms of the parameters from the Cobb-Douglas cost function, equation (19).

To estimate the coefficients of equation (21), continuous time derivatives need to be converted to discrete differences. The Cobb-Douglas cost function is evaluated at two discrete points in time. To obtain the average TFP growth between two points in time, restate the left-hand side of equation (21) as a discrete change from time *t*-1 to *t*,

$$\ln TFP_t - \ln TFP_{t-1} = -[\ln C_t - \ln C_{t-1} - \sum_h \overline{\beta}_h \left(\ln p_{h,t} - \ln p_{h,t-1}\right)$$
$$- \left(\ln Q_{Q,t} - \ln Q_{E,t-1}\right) - \left(\ln E_t - \ln E_{t-1}\right)]. \tag{22}$$

Since it is possible that the industry input cost elasticities, β_h, change from one census year to another, calculate the average elasticity as

$$\overline{\beta}_h = \frac{1}{2}\left(\beta_{h,t} + \beta_{h,t-1}\right). \tag{23}$$

These expressions allow measurement of TFP growth using discrete data. The right-hand side of equation (21) is also converted from continuous to discrete time. TFP change is then given by

$$\ln TFP_t - \ln TFP_{t-1} = \left(1 - \overline{\beta}_{Q_E}\right)\left(\ln Q_{E_t} - \ln Q_{E_{t-1}}\right) + \left(1 - \overline{\beta}_E\right)\left(\ln E_t - \ln E_{t-1}\right)$$
$$+ \overline{\beta}_T \left(\ln T_t - \ln T_{t-1}\right) - \overline{\beta}_D \left(\ln D_t - \ln D_{t-1}\right)$$
$$- \overline{\beta}_H \left(\ln H_t - \ln H_{t-1}\right). \tag{24}$$

Again, the average industry cost elasticities are as given in equation (23). The resulting final form for the model that can be estimated using discrete data is obtained by combining equations (22) and (24) and substituting the components of the change in the HH index from equation (18) to obtain

$$
\begin{aligned}
\ln TFP_t - \ln TFP_{t-1} = &\left(1-\beta_{Q_E}\right)\left(\ln Q_{E_t} - \ln Q_{E_{t-1}}\right) + \left(1-\beta_E\right)\left(\ln E_t - \ln E_{t-1}\right) \\
&+ \beta_T\left(\ln T_t - \ln T_{t-1}\right) - \beta_D\left(\ln D_t - \ln D_{t-1}\right) \\
&- \beta_{death}\left(\ln H_{3,t-1} - \ln H_{2,t-1}\right) - \beta_{birth}\left(\ln H_{4,t-1} - \ln H_{3,t-1}\right) \\
&- \beta_{merger}\left(\ln H_{5,t-1} - \ln H_{4,t-1}\right) - \beta_{mktshare}\left(\ln H_{1,t} - \ln H_{5,t-1}\right).
\end{aligned} \tag{25}
$$

Using equation (25), I estimate the impact of each described category of industry evolution upon TFP growth. For example, if β_{birth} is positive (negative), then births, which likely reduce the HH index, will increase (decrease) TFP growth. Likewise, if β_{merger} is positive (negative), then mergers, which will always increase the HH index, will decrease (increase) TFP growth.

Finally, I append a random error to equation (25) and assume that the error structure possesses the characteristics appropriate to the assumptions for ordinary least squares estimation. Because the data are first-differenced, I also estimate models that account for the possibility of serial correlation.

6. Econometric Results

The data set includes observations of approximately four hundred 4-digit industries across six census years. All variables except the diversification index are available for seven census years. I have obtained TFP growth, real output, the number of establishments, the number of companies, the diversification index, and the Herfindahl-Hirschman index for each census year from the sources described above. Since $T=e^t$, the change in ln*T* reflects the time between census years. Therefore, the elasticity of cost due to the growth of technology is the average annual technological growth across all industries between census years. I estimate a series of model specifications using fixed effects estimation methods.

Table 1 presents the estimation results of four variations of equation (25). The two-sided significance levels (p-values) are given below the estimates in parentheses. The fixed effects (within) estimator is used to estimate each specification in Table 1. Model (1) is the basic model specification reflecting estimation of equation (25). Model (2) includes only the change in the HH index due to mergers and drops the changes due to deaths, births, and changes in market

Table 1: Fixed Effects Estimation Results for All Industry Observations

Coefficients	(1)	(2)	(3)	(4)
Output per Est. ($1-\beta_{QE}$)	0.0672	0.0713		0.0707
	(0.000)	(0.000)		(0.000)
Establishments ($1-\beta_E$)	-0.0230	-0.0085		-0.0146
	(0.041)	(0.384)		(0.150)
Industry Output ($1-\beta_Q$)			0.0386	
			(0.000)	
Technology β_T	0.0001	0.0142	0.0026	0.0177
	(0.991)	(0.000)	(0.760)	(0.000)
Diversification $-\beta_D$	-0.0244	-0.0243	-0.0091	-0.0244
	(0.001)	(0.001)	(0.197)	(0.001)
Deaths $-\beta_{death}$	-0.0360		0.0559	
	(0.302)		(0.092)	
Births $-\beta_{birth}$	-0.1260		-0.0365	
	(0.001)		(0.308)	
Mergers $-\beta_{merger}$	0.1135	0.1146	0.1163	
	(0.026)	(0.025)	(0.024)	
Mkt. Share $-\beta_{mktshare}$	0.0409		0.0441	
	(0.005)		(0.003)	
HH $-\beta_{HH}$				-0.0124
				(0.181)
R^2 Overall	0.0720	0.0781	0.0481	0.0768
F-Test u_i=0	0.0002	0.0011	0.0001	0.0007
n	2138	2148	2138	2138

share. Model (3) estimates coefficients for a modified equation (25) where 4-digit industry output growth is substituted for average establishment output growth and growth in the number of establishments. Model (4) substitutes the change in the HH index between census years in place of the separate changes in the HH index due to deaths, births, mergers, and changes in market share. In model (1), the estimated coefficient on the change in establishment output is 0.0672 and is significant at a 1% level. Other things equal, a 10% increase in the average output per establishment leads to a 0.62 percentage point increase in TFP growth. We therefore observe economies of scale in production since the elasticity of cost with respect to average establishment output growth is 0.9328. An increase in the average establishment output growth rate of 1% leads to a 0.9328 percentage point increase in cost growth. When estimated at the means (provided in Table 3) and other things equal, economies of scale contributed 0.68 percentage points to

TFP growth between census years (calculated as the product of the estimated coefficient, 0.0672, and the average growth rate in average establishment output, 0.1005).

The estimated coefficient of the growth in number of establishments is -0.0230, significant at a 1% level. We therefore observe diseconomies of multiple plant operations. The estimated elasticity of cost with respect to diversification growth is -0.0244 and is significant at a 1% level. Therefore, a reduction in diversification of 10% leads to a 0.24 percentage point increase in TFP growth. When estimated at the means, the reduction in average establishment diversification contributed 0.20 percentage points of TFP growth between census years (calculated as the product of the estimated coefficient, -0.0244, and the average growth rate of diversification, -0.0838).

The coefficients of particular interest are those elasticities of cost with respect to deaths of existing companies, births of new companies, mergers among existing companies, and changes in market share of existing companies. The estimated coefficient on the change in the HH index due to deaths is not significantly different from zero. The estimated coefficient on the change in TFP growth due to the change in the HH index due to births is -0.1260 and is significant at a 1% level. Note that a change in the HH index due to births is negative such that as new firms enter, the HH index decreases in magnitude. Estimated at the means, the births of new firms contributed 2.14 percentage points of TFP growth between census years (calculated as the product of the estimated coefficient, -0.1260, and the average change in the HH index due to births, -0.1701). The estimated coefficient on the change in the HH index due to mergers is 0.1135 and is significant at better than a 5% level. Estimated at the means and other things equal, mergers contributed 0.36 percentage points to TFP growth between census years (calculated as the product of the estimated coefficient, 0.1135, and the average change in the HH index due to mergers between census years, 0.0320). The overall R^2 for the fixed effects model is 0.0720. An F-test of the hypothesis that the industry specific effects, u_i, are jointly zero can be rejected at a 1% confidence level. The hypothesis is rejected at a 1% level for each model (1) through (4).

Model (2) does not include the changes in the HH index due to deaths, births, and changes in market share. The estimated coefficients on changes in output per establishment, changes in the number of establishments, changes in diversification, and mergers are nearly identical to those estimates from model (1). Likewise, the effect of technological growth becomes positive and significant. Finally, the overall R^2 for the model is 0.0781. In comparing models (1) and (2) it appears that the effect of technological growth may be largely due to the entry of new firms with the newest technology and management methods. When the births variable is excluded, technological growth is significant and positive, but when births are included in the model, technological growth is negative and significant.

Model (3) substitutes industry output growth for growth of average establishment output and growth of the number of establishments. The estimated coefficient for TFP growth due to growth in industry output is 0.0386 and is significant at a 1% level. The impact of deaths on TFP growth was positive and significant at a 10% level. The impact of births on TFP growth was insignificantly different from zero. The estimated coefficient on mergers is 0.1163 and is nearly identical to the estimates from models (1) and (2). The overall R^2 is only 0.0481.

Model (4) substitutes the change in the HH index between census years for the changes in the HH index due to deaths, births, mergers, and changes in market share. The estimated coefficient for TFP growth due to the change in the HH index is not significantly different from zero. Except for the estimated coefficient for technology, which is positive and significant at a 1% level, the other estimated coefficients are similar to those in model (1).

I then estimate the fixed effects model with an AR(1) error term for model (1). Therefore, rather than assuming that the error term e_{it} is independently and identically distributed, assume that $e_{it} = \rho e_{it-1} + u_{it}$, where u_{it} is iid normal with

Table 2: Fixed Effects Estimation Results for Selected Industry Observations

	(5)	(6)	(7)	(8)	(9)	(10)
Coefficients	Conc.	Unconc.	Dur.	Nondur.	High Tech	Low Tech
Output per Est. (1-β_{QE})	0.0281	0.1442	0.0438	0.1180	-0.0230	0.1593
	(0.237)	(0.000)	(0.000)	(0.000)	(0.194)	(0.000)
Establishments (1-β_E)	-0.0403	0.0660	-0.0603	0.0338	-0.1205	0.0829
	(0.203)	(0.000)	(0.000)	(0.020)	(0.000)	(0.000)
Technology β_T	0.0203	-0.0173	-0.0008	0.0088	0.0601	-0.0124
	(0.313)	(0.027)	(0.947)	(0.428)	(0.000)	(0.131)
Diversification -β_D	0.0004	-0.0375	-0.0343	-0.0215	-0.0122	-0.0230
	(0.980)	(0.000)	(0.004)	(0.009)	(0.480)	(0.001)
Deaths -β_{death}	0.1140	0.0774	-0.0859	0.0045	-0.2663	0.0516
	(0.323)	(0.016)	(0.096)	(0.919)	(0.002)	(0.100)
Births -β_{birth}	0.0484	-0.0299	-0.2068	0.0353	-0.1802	-0.0074
	(0.714)	(0.354)	(0.000)	(0.512)	(0.023)	(0.842)
Mergers -β_{merger}	0.3797	0.0871	0.0539	0.1686	0.1932	0.1013
	(0.070)	(0.048)	(0.510)	(0.003)	(0.234)	(0.015)
Mkt. Share -$\beta_{mktshare}$	-0.0392	0.0218	0.0476	0.0250	0.0436	0.0155
	(0.420)	(0.075)	(0.013)	(0.260)	(0.217)	(0.243)
R^2 Overall	0.0099	0.1168	0.0417	0.1559	0.0104	0.2223
F-Test u_i=0	0.9995	0.0000	0.0000	0.3869	0.0000	0.0257
n	468	1670	1226	912	588	1550

mean zero. After estimating model (1) using fixed effects and the AR(1) error structure, the modified Durbin-Watson statistic, defined by Bhargava, Franzini, and Narendranathan (1982), is determined to be 2.29. The null hypothesis that $\rho = 0$ cannot be rejected and serial correlation is no longer considered in this paper.

I next investigate various data subsets to determine whether the estimated relationships differ among different types of industries. Model (5) estimates coefficients for equation (25) using only concentrated industry observations. A 4-digit industry is considered concentrated if the HH index is greater than or equal to 1000. Likewise, those industries with HH indexes below 1000 are considered unconcentrated. Model (6) estimates coefficients for the basic model using only unconcentrated industries. Model (7) estimates the model using only durable good industry observations and model (8) is estimated with only nondurable goods industry observations. I utilize the Bureau of Economic Analysis definition of durable and nondurable goods industries. Durable good 2-digit industries include SICs 24, 25, and 32 through 39. Similarly, nondurable goods industries include SICs 20 through 23 and 26 through 31. Finally, I consider high technology and low technology industries separately. Hadlock et. al (1991) classify 3-digit industries as high tech if their proportion of R&D employment is greater than or equal to the average proportion for all 3-digit industries (see appendix).

Table 2 presents the results from these industry specific regressions. Model (5) is estimated using only the 468 concentrated industry observations. The estimated coefficient for the change in the HH index due to mergers is 0.3797 and is significant at a 7% level. Estimated at the means, and other things equal, mergers accounted for 0.62 percentage points of TFP growth in concentrated industries between census years (calculated as the product of the estimated coefficient and the average change in the HH index due to mergers, 0.0162). The overall R^2 for this model is equal to 0.0099.

Model (6) is estimated with only unconcentrated industry observations. Economies of scale are observed in these industries with an estimated coefficient on growth of output per establishment of 0.1442. The coefficient on establishment growth is 0.0660 and is significant at a 1% level. Surprisingly, technological growth is -0.0173 and significant at a 5% level. The estimated coefficient on deaths is 0.0774 and is also significant at better than a 5% level while the estimated coefficient on births is not significantly different from zero. The estimated coefficient for TFP growth due to the change in the HH index due to mergers is 0.0871 and is significant at a 5% level. Estimated at the means, and other things equal, mergers added 0.32 percentage points to TFP growth between census years (calculated as the product of the estimated coefficient and the average change in the HH index due to mergers in unconcentrated industries, 0.0364). The R^2 for this model is 0.1168.

Model (7) is estimated using only durable goods industry observations. Economies of scale are observed in the coefficient estimate of 0.0438 for growth in average establishment output. The elasticity of cost with respect to diversification is -0.0343 and is significant at a 1% level. The estimated coefficient on the change in the HH index due to births is -0.2068 and is significant at a 1% level. Estimated at the means, and other things being equal, births accounted for 3.73 percentage points of TFP growth (calculated as the product of the estimated coefficient and the average change in the HH index due to births, -0.1805). The estimated coefficient on mergers is not significantly different from zero. Finally, the overall R^2 for this model estimation is 0.0417.

Compare the results of model (7) with those of model (8) which is estimated with nondurable goods industry observations. Economies of scale become larger with an estimated coefficient of 0.1180. Estimated at the means, other things being equal, economies of scale accounted for 1.78 percentage points of TFP growth (calculated as the product of the estimated coefficient and the average growth of output per establishment, 0.1507). The estimated coefficient on establishment growth is significant in both models (7) and (8), but is negative for durable goods industries and positive for nondurable goods industries. Also the estimated coefficient on births is not significantly different from zero in nondurable goods industries, compared to the strong positive effect of births on TFP growth in durable goods industries. Another difference between models (7) and (8) is the estimated effect of mergers on TFP growth. The estimated coefficient on mergers in nondurable industries is 0.1686 and is significant at a 1% level. Other things equal and estimated at the means, mergers accounted for 0.61 percentage points of TFP growth (calculated as the product of the estimated coefficient and the average change in the HH index due to mergers, 0.0359). Finally, the R^2 for model (8) is 0.1559 and the F-test that u_i are jointly zero can not be rejected as it could be in model (7).

Model (9) is estimated using only high tech industry observations and model (10) is estimated with low tech (non-high tech) industries. The estimated coefficient for growth of output per establishment is not significantly different from zero in high tech industries. The same estimated coefficient for low tech firms is 0.1593 and is significant at a 1% level. Economies of scale in low tech industries accounted for 1.57 percentage points of TFP growth (calculated as the product of the estimated coefficient and the average change in output per establishment, 0.0983).

Comparing models (9) and (10), note the difference between coefficients on growth in number of establishments, -0.1205 in the former and 0.0829 in the latter. The average growth in the number of establishments was 0.0850 in high tech industries and 0.0057 in low tech industries. Therefore, the growth in establishments accounted for -1.02 percentage points of TFP growth in high tech industries and 0.05 percentage points of TFP growth in low tech industries. The estimated coefficient describing technological growth is 0.0601 in high tech industries and is insignificantly different from zero in low tech industries. The estimated coefficient of technological growth is -0.0124 in low tech industries but is only significant at a 13.1% level. The estimated coefficient on diversification is not significantly different from zero in high tech industries and is -0.0230 in low tech industries. Estimated at the means, reductions in diversification accounted for 0.17 percentage points of TFP growth in low tech industries (calculated as the product of the estimated coefficient and the average change in diversification in low tech industries, -0.0746).

The estimated coefficient on births is -0.1802 in high tech industries and is significant at better than a 5% level. When estimated at the means, births of new firms added 2.74 percentage points to TFP growth (calculated as the product of the estimated coefficient and the average change in the HH index due to births, -0.1523). The estimated coefficient on births in low tech industries is not significantly different from zero.

Finally, the estimated coefficient on mergers is not significantly different from zero in high tech industries, but is equal to 0.1013 and is significant at a 5% level in low tech industries. When estimated at the means, other things equal, mergers accounted for 0.36 percentage points of TFP growth in low tech industries (calculated as the product of the estimated coefficient and the average change in

Table 3: Variable Means for Varying Industry Samples

	All	Conc.	Unconc.	Dur.	Nondur.	High Tech	Low Tech
TFP Growth	0.0264	0.0301	0.0253	0.0249	0.0283	0.0449	0.0193
Output per Est.	0.1005	0.0501	0.1146	0.0632	0.1507	0.1063	0.0983
Establishments	0.0275	0.1049	0.0059	0.0632	-0.0204	0.0850	0.0057
Diversification	-0.0838	-0.1231	-0.0727	-0.1008	-0.0608	-0.1081	-0.0746
Deaths	0.1656	0.0842	0.1884	0.1622	0.1701	0.1279	0.1799
Births	-0.1701	-0.1000	-0.1897	-0.1805	-0.1561	-0.1523	-0.1768
Mergers	0.0320	0.0162	0.0364	0.0291	0.0359	0.0238	0.0351
ΔMkt Share	-0.0245	-0.0455	-0.0186	-0.0350	-0.0103	-0.0416	-0.0180
n	2138	468	1670	1226	912	588	1550

the HH index due to mergers in low tech industries, 0.0351). The overall R^2 for high tech industries is 0.0104 and is 0.2223 in low tech industries.

Table 3 presents the means for each variable. When the models are estimated at the means, one is able to determine which variables contribute most to TFP growth. TFP growth has averaged 2.64% in manufacturing industries between census years. In model (1) observe that for all industries, births contribute most to TFP growth, followed by economies of scale and then mergers. Births may increase TFP growth through three separate processes. First, the new firms may enter by building new establishments with cutting edge technology. Second the new firms may take over existing establishments and manage the establishment more successfully than the previous management. Third, the entry of new firms may increase the degree of competition in the industry, thereby reducing x-inefficiency. Mergers likely increase TFP growth by creating cost cutting opportunities for the firms involved.

The estimated models for concentrated industries, durable goods industries, and high tech industries are relatively poorly estimated so they are not considered here. In unconcentrated industries, technological growth had a strongly negative impact on TFP growth. Economies of scale and deaths were the largest contributors to TFP growth followed by births and mergers. In nondurable goods industries, economies of scale were the largest contributor to TFP growth, followed by technological growth and mergers.

The model estimated with low tech industry observations displays the highest R^2 among the regressions presented, equal to 0.2223. Economies of scale were the prime contributor to TFP growth, followed by deaths and mergers.

An appendix to this paper includes additional regressions not discussed in the paper. These regressions include feasible generalized least squares regressions where autocorrelation within panels is allowed.

7. Conclusion

This paper attempts to explain some portion of total factor productivity growth through changes in the competitive structure of a 4-digit industry. Estimations of different specifications lead to a number of conclusions. First, in the initial model, the changes in the Herfindahl-Hirschman index due to births, mergers, and changes in market share had a statistically significant impact on total factor productivity growth. Second, the effect of mergers on TFP growth varied across different industry samples. The impact of mergers was greatest in concentrated industries, nondurable goods industries, and low tech industries. When the model is estimated using only observations from concentrated industries, the importance of mergers increased. Conversely, when the model specification is estimated using observations from only unconcentrated industries, the coefficient on mergers is positive, smaller than for concentrated industries and significant at a 5% level, compared to an 8.2% level in concentrated industries. Therefore, the argument that mergers lead to greater productivity growth appears to be most valid in those industries in which the Department of Justice is especially vigilant in regulating mergers. Third, a reduction in the HH index due to the births of new companies within an industry also led to an increase in TFP growth. Again, this is especially true in durable goods industries and high tech industries.

Using the Herfindahl-Hirschman index as a measure of competition within an industry is imperfect, but it is arguably a more complete measure than others, such as the number of competitors or a four-firm concentration ratio. The importance that I assign to the HH index as a measure of competition is supported by the U.S. Department of Justice Merger Guidelines' dependence upon the index as a key component in determining whether a merger will reduce competition enough to adversely impact consumers. The results of the model estimation suggest a number of potential conclusions. Mergers increased TFP growth by a substantial amount, supporting claims by merger participants that mergers allow exploitation of economies in production. The births of new companies within an industry increased competition and likely introduced the newest technology to the industry. This supports the x-inefficiency arguments advanced in Nickell (1996) and Stennek (2000). In this instance, increased competition, measured as a decrease in the HH index, led to faster TFP growth. A reduction in the competitive forces within an industry may reduce cost cutting initiatives and increase x-inefficiency, but efficiency gains from mergers often appear to offset the reduction in competition.

Bibliography

Baily, Martin Neil, Charles Hulten and David Campbell "Productivity Dynamics in Manufacturing Plants," *Brookings Papers on Economic Activity: Microeconomics*, Vol. 1992. (1992), pp. 187-249.

Baldwin, John R. and Paul K. Gorecki "Firm entry and exit in the Canadian manufacturing Sector, 1970-1982," *Canadian Journal of Economics*, Vol. 24, No. 2. (May, 1991), pp. 300-323.

Bartelsman, Eric J. and Wayne Gray "The NBER Manufacturing Productivity Database," NBER Technical Working Paper 205 (Oct., 1996).

Bhargava, A., L. Franzini, and W. Narendranathan "Serial Correlation and the Fixed Effects Model," The Review of Economic Studies, Vol. 49, No. 4 (Oct., 1982), 533-549.

Gollop, Frank M. "The Pin Factory Revisited: Product Diversification and Productivity Growth," *Review of Industrial Organization*, Vol. 12, No. 3. (Jun., 1997), pp. 317-334.

Gollop, Frank M. and James L. Monahan "A Generalized Index of Diversification: Trends in U.S. Manufacturing," *The Review of Economics and Statistics*, Vol. 73, No. 2. (May, 1991), pp. 318-330.

Hadlock, Paul, Daniel Hecker, and Joseph Gannon, "High Technology Employment: Another View," *Monthly Labor Review*, Vol. 114, No. 7 (Jul., 1991), pp. 26-30.

Healy, Paul M., Krishna G. Palepu, and Richard S. Rubak, "Does Corporate Performance Improve After Mergers?" *Journal of Financial Economics*, Vol. 31, No. 2. (Apr., 1992), pp. 135-175.

Johnson, Peter and Simon Parker "The Interrelationships Between Births and Deaths," *Small Business Economics*, Vol. 6, No. 4. (Aug., 1994), pp. 283-290.

Jorgenson, Dale W., Frank M. Gollop and Barbara M. Fraumeni *Productivity and U.S. Economic Growth*, Cambridge: Harvard University Press, 1987.

Leibenstein, Harvey "Allocative Efficiency vs. 'X-Efficiency'," *The American Economic Review*, Vol. 56, No. 3, (Jun., 1966), pp. 392-415.

McGuckin, Robert H. and Sang V. Nguyen "On Productivity and Plant Ownership Change: New Evidence from the Longitudinal Research

Database," *The RAND Journal of Economics*, Vol. 26, No. 2. (Summer, 1995), pp. 257-276.

McGuckin, Robert H. and Sang V. Nguyen "Exploring the Role of Acquisition in the Performance of Firms: Is the 'Firm' the Right Unit of Analysis?" Discussion Paper, CES 95-13, Center for Economic Studies, U.S. Bureau of the Census, Washington D.C. 1995.

McGuckin, Robert H., Sang V. Nguyen and Arnold P. Reznek "The Impact of Ownership Change on Employment, Wages, and Labor Productivity in U.S. Manufacturing 1977-87," Discussion Paper, CES 95-8, Center for Economic Studies, U.S. Bureau of the Census, Washington D.C. 1995.

Nickell, Stephen J. "Competition and Corporate Performance," *The Journal of Political Economy*, Vol. 104, No. 4. (Aug., 1996), pp. 724-746.

Scherer, F.M. and D. Ross *Industrial Market Structure and Economic Performance*, Boston: Houghton Mifflin Company, 1990.

Schumpeter, Joseph A. *Capitalism, Socialism, and Democracy*, New York: Harper and Row Publishers, 1950.

Stennek, Johan "Competition increases x-efficiency: A limited liability mechanism," *European Economic Review*, Vol. 44, (2000) 1727-1744.

U.S. Department of Justice. (2006). *Ten Year Workload Statistics*. Retrieved August 21, 2006 from http://www.usdoj.gov/atr/public/workstats.pdf.

Appendix

Table 4: Estimation Results for All Industry Observations

Coefficients	(1a)	(2a)	(3a)	(4a)
Output per Est. $(1-\beta_{QE})$	0.1015	0.1062		0.1090
	(0.000)	(0.000)		(0.000)
Establishments $(1-\beta_{E})$	0.0104	0.0229		0.0154
	(0.313)	(0.010)		(0.100)
Industry Output $(1-\beta_{Q})$			0.0720	
			(0.000)	
Technology β_{T}	0.0061	0.0110	0.0073	0.0130
	(0.264)	(0.002)	(0.183)	(0.000)
Diversification $-\beta_{D}$	-0.0310	-0.0312	-0.0146	-0.0311
	(0.000)	(0.000)	(0.033)	(0.000)
Deaths $-\beta_{death}$	-0.0466		0.0488	
	(0.107)		(0.068)	
Births $-\beta_{birth}$	-0.0794		0.0052	
	(0.006)		(0.849)	
Mergers $-\beta_{merger}$	0.0773	0.0728	0.0872	
	(0.085)	(0.105)	(0.055)	
Mkt. Share $-\beta_{mktshare}$	0.0248		0.0284	
	(0.264)		(0.035)	
HH $-\beta_{HH}$				-0.0196
				(0.025)
Common Corr. Coeff.	0.0321	0.0284	0.0270	0.0235
n	2130	2143	2130	2130
Regression Method	f.g.l.s.	f.g.l.s.	f.g.l.s.	f.g.l.s.

Table 5: Estimation Results for Selected Industries

Coefficients	(5a) Conc.	(6a) Unconc.	(7a) Durable	(8a) Nondurable	(9a) High Tech	(10a) Low Tech
Output per Est. $(1-\beta_{QE})$	0.0573	0.1593	0.0892	0.1320	0.0317	0.1681
	(0.002)	(0.000)	(0.000)	(0.000)	(0.057)	(0.000)
Establishments $(1-\beta_E)$	0.0016	0.0727	-0.0165	0.0477	-0.0686	0.0818
	(0.946)	(0.000)	(0.289)	(0.000)	(0.002)	(0.000)
Technology β_T	0.0100	-0.0088	0.0079	0.0045	0.0381	-0.0057
	(0.477)	(0.135)	(0.313)	(0.513)	(0.006)	(0.242)
Diversification $-\beta_D$	-0.0030	-0.0427	-0.0458	-0.0227	-0.0310	-0.0254
	(0.837)	(0.000)	(0.000)	(0.004)	(0.071)	(0.000)
Deaths $-\beta_{death}$	0.0807	0.0517	-0.1115	0.0198	-0.1903	0.0368
	(0.346)	(0.058)	(0.014)	(0.558)	(0.014)	(0.149)
Births $-\beta_{birth}$	-0.0613	0.0008	-0.1395	0.0112	-0.1890	0.0117
	(0.497)	(0.975)	(0.001)	(0.772)	(0.007)	(0.657)
Mergers $-\beta_{merger}$	0.4569	0.0780	0.0596	0.0908	0.1183	0.0754
	(0.009)	(0.060)	(0.414)	(0.066)	(0.437)	(0.037)
Mkt. Share $-\beta_{mktshare}$	0.0110	0.0151	0.0237	0.0240	0.0169	0.0177
	(0.773)	(0.194)	(0.187)	(0.209)	(0.622)	(0.133)
Common Corr. Coeff.	0.1642	0.2110	0.0206	0.0319	0.0732	0.0417
n	432	1641	1223	907	585	1545
Regression Method	f.g.l.s.	f.g.l.s.	f.g.l.s.	f.g.l.s.	f.g.l.s.	f.g.l.s.

High Technology Industries by 1987 3-Digit SIC from Hadlock et al. (1991)

SIC Code	Industry Description
211	Cigarettes
229	Msc. Textile goods
261	Pulp mills
267	Misc. converted paper products
281	Industrial inorganic chemicals
282	Plastics, materials & synthetics
283	Drugs
284	Soap, cleaners, & toilet goods
285	paints & allied products
286	Industrial organic chemicals
287	Agricultural chemicals
289	Misc. chemical products
291	Petroleum refining
299	Misc. petroleum & coal products
335	Nonferrous rolling & drawing
348	Ordnance & accessories n.e.c.
351	Engines & turbines
355	Special industry machinery
356	General industrial machinery
357	Computer & office equipment
359	Industrial machines n.e.c.
362	Electrical industrial apparatus
365	Household audio & visual equipment
366	Communications equipment
367	Electronic components & accessories
369	Misc. electrical equipment & supplies
371	Motor vehicles & equipment
372	Aircraft & parts
376	Guided missiles, space vehicles & parts
379	Misc. transportation equipment
381	Search & navigation equipment
382	Measuring & controlling devices
384	Medical instruments & supplies
386	Photographic equipment & supplies