Firm-level Evidence on Productivity Differentials and

Turnover in Taiwanese Manufacturing

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ABSTRACT

High rates of firm entry and exit have accompanied the rapid and sustained growth of output in Taiwan's manufacturing sector. A high rate of firm turnover can contribute to industry productivity growth if it reflects a transfer of resources from less efficient to more efficient producers. Using comprehensive firm-level panel data from the Taiwanese Census of Manufactures for 1981, 1986, and 1991, we measure total factor productivity for entering, exiting, and continuing cohorts of firms and quantify the contribution of firm turnover to industry productivity improvements. Across manufacturing firms, we find significant differences in productivity that are reflected in turnover patterns. Cohorts of new firms have lower average productivity than incumbents but are themselves a heterogeneous group. The more productive members of the group, on average, survive and, in many cases, their productivity converges to the productivity level of older incumbents. Exiting firms are less productive than survivors. The productivity differential between entering and exiting firms is an important source of industry-level productivity growth in Taiwanese manufacturing, accounting for as much as one-half of industry improvement in some industries and time periods.

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I. Introduction

The substantial growth of Taiwan's manufacturing sector since 1960, and the growth in world demand for its exports which spurred this expansion, has been well documented. While the growth of manufactured output after 1980 slowed relative to the 20 percent annual rate that was common in the previous two decades, it still averaged 6.5 percent per year from 1981-1991, with annual growth rates in double digits for several major industries. Output expansions of this magnitude are likely to require substantial changes in market structure but there is little evidence on the micro-level changes which have generated this supply growth.

One of the interesting features of Taiwan's supply expansion is that a substantial portion is attributable to new firm entry. The total number of manufacturing firms grew by 7.7 percent per year between 1981 and 1991. However, this large net change in the number of firms is still only a lower bound on the magnitude of structural adjustment that the sector has undergone. Even in slowly growing economies, the micro-level reallocation of resources that occurs as firms enter, expand, contract, and exit production is many times larger than the net change in sectoral output, employment, or the number of firms.[1] While there is a considerable literature debating the magnitude and sources of productivity growth in Taiwan, the evidence is based on aggregate or sectoral data and no studies have examined the role of micro-level reallocations as a determinant of productivity change.[2] The linkage is direct: if firms differ in their productivity, and their own efficiency is a determinant of their choice to enter, exit, or grow, then firm turnover contributes to changes in sectoral or aggregate productivity. The size of this contribution is an empirical question, but is potentially important in rapidly growing economies like Taiwan.

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[1] The literature on gross employment flows provides substantial evidence on this point. See Davis, Haltiwanger and Schuh (1996) for a review of this literature.

[2] Pack (1992b) provides a comprehensive review of productivity growth in the East Asian countries, including Taiwan. A number of recent studies have focused on the role of productivity growth and capital accumulation as determinants of Taiwan's output growth. Kim and Lau (1994), Krugman (1994), Rodrik (1995) and Young (1994, 1995) emphasize capital accumulation while others including Page (1994) and the World Bank (1993) emphasize productivity growth as the primary source of Taiwan's success.

In this paper we use comprehensive firm-level panel data from the Taiwanese Census of Manufactures for the years 1981, 1986, and 1991, to document the role of firm entry, exit, and growth in Taiwan's productivity growth. We quantify the extent of firm turnover, measure differences in total factor productivity between entering, exiting, and continuing firms, and determine the contribution of firm turnover to industry productivity growth. Our analysis parallels a number of recent studies of firm or plant turnover and productivity growth for manufacturing industries in the United States (Baily, Hulten, and Campbell 1992, Olley and Pakes 1996, Haltiwanger 1997, and Foster, Haltiwanger, and Kruzan 2001), Israel (Griliches and Regev 1995), and Chile and Colombia (Liu 1993, Tybout 1996a, and Liu and Tybout 1996). With the exception of Olley and Pakes (1996), these studies find that entry and exit of firms or plants within an industry contribute little to productivity growth, generally because there are only small productivity differences between entering and exiting producers and/or these groups account for a very small share of industry output.

Research on the institutional environment in Taiwan has emphasized that the low capital intensity of much of the production combined with the manufacturing sector's dense network of subcontracting relationships and trading firms result in low sunk entry and exit costs. Recent theoretical models of firm dynamics have emphasized that low sunk entry costs result in higher entry flows and increased pressure on inefficient firms to exit, and thus hasten the reallocation of resources from inefficient to more efficient producers. Finally, as we will document, entering and exiting firms account for a substantial share of industry production in Taiwan. Together these factors suggest that, if turnover and market share reallocations reflect productivity differentials across firms, they could be a much more important source of productivity growth in Taiwan than has been found in other countries.

A consistent finding of our empirical study is that there are significant differences in productivity across manufacturing firms and these differences are reflected in turnover patterns. Cohorts of new firms have lower average productivity than incumbents but are themselves a heterogeneous group. The more productive members of the group survive and, in many cases, their productivity converges to the productivity level of older incumbents. Firms that will exit in the future are less productive than their counterparts that survive. These patterns are consistent with the view that markets sort out high from low productivity firms and that the most efficient firms tend to survive.

For many, but not all, industries we find evidence of productivity growth at modest annual rates, two percent per year, over the entire decade. In most cases, the productivity improvement is widespread across the whole distribution of firms, suggesting that it may be less related to individual firm investments than it is to common improvements in worker quality and infrastructure. One implication of this general shift in the firm-level productivity distribution is that entering firms also shared in the higher productivity so that the turnover of firms through entry and exit made a significant positive contribution to industry productivity growth. Productivity growth of incumbent firms also was a significant source of industry productivity growth.

In the next section of the paper we summarize a dynamic model of firm turnover and market selection due to Hopenhayn (1992) with an emphasis on the model's implications for productivity differences between entering, exiting, and continuing cohorts of firms. The third section summarizes the importance of firm entry and exit in the market for nine major manufacturing industries in Taiwan. Sections four and five describe the index number methods used to measure firm-level total factor productivity and quantify the differences in productivity among entering, exiting, and continuing firms. The sixth section of the paper disaggregates industry productivity growth into the contributions of incumbents and the reallocation of production from less efficient to more efficient producers.

II. A Theoretical Framework Relating Productivity and Turnover

Recent theoretical models of industry dynamics by Jovanovic (1982), Lambson (1991), Hopenhayn (1992), and Ericson and Pakes (1995) have been developed to explain the divergent paths of growth and failure that characterize micro data on individual producers. These models all begin with the assumption that producers within the same industry differ in their productive efficiency and are subject to idiosyncratic shocks or uncertainty. Differences in the evolution of their productivity over time, in turn, lead producers to make different decisions regarding entry, growth, and exit.[3] As a result they provide a very useful framework for organizing micro firm-level productivity and turnover data.

We rely on the model of firm dynamics developed by Hopenhayn (1992) to organize our empirical analysis. In this model an industry is composed of a large number of price-taking firms which produce a homogeneous output. Firms are heterogeneous in terms of their efficiency with each firm's output depending on input levels and a random productivity shock, ϕ. This productivity shock follows a Markov process that is independent across firms. The distribution of future productivity for each firm is represented by the distribution function $F(\phi_{t+1} \mid \phi_t)$ which is strictly decreasing in ϕ_t. This implies that the probability a firm has high productivity in year $t+1$ increases with the firm's productivity in year t.

In each time period, before the new productivity shock is observed, incumbent firms may choose to exit the industry and earn zero profits or remain in the industry by paying a fixed cost C_f, after which they observe their productivity shock, and choose their output level for that period. Potential entrants may choose to enter by paying a sunk entry cost, C_e, after which they draw their initial productivity level ϕ from a common distribution function $G(\phi)$, and choose their output level. Output prices are determined competitively to equate industry demand and supply. The endogenous variables in the model are the flow of entrants into the market in each period and the minimum level of productivity required for an incumbent to remain in production. This productivity level, which we denote X_t, is the lowest productivity that will result in positive discounted expected firm profits.

Hopenhayn's model makes predictions about differences in the mean productivity of entering, exiting, and continuing producers. Given the conditional distribution function, $F(\phi_{t+1} \mid \phi_t)$, the future

[3] The actual source of uncertainty differs across models with Jovanovic emphasizing firm uncertainty about their own productivity level, Lambson focusing on uncertain future market conditions, Hopenhayn emphasizing randomness in productivity changes over time, and Ericson and Pakes modeling uncertainty in the return to firm investments.

trajectory of a firm's productivity is determined by their current productivity ϕ_t. If $\phi_t < X_t$, then firms expect low future profit streams and exit after period *t* while firms with $\phi_t > X_t$ will remain in the market. Therefore, exit is concentrated among the firms with the lowest productivity. We can test if this holds in our data by examining producers in period *t* and asking if there are systematic productivity differences between the group that exit the market after period *t* and the group that survive into period *t+1*.

The model also makes predictions about the productivity of a cohort of new entrants and cohorts of older surviving producers. The distribution function $G(\phi)$ summarizes the heterogeneity in the productivity of new entrants. The productivity of older cohorts also reflects the failure of the least productive members over time and the random changes in the survivors' productivity over time as summarized by the distribution function $F(\phi_{t+1} \mid \phi_t)$. Hopenhayn demonstrates that if this function is strictly decreasing in ϕ_t, then the productivity distribution of any surviving cohort stochastically dominates the productivity distribution of the entering cohort. Under some additional assumptions on the failure process, Hopenhayn demonstrates that the productivity distribution will be stochastically increasing in the age of the cohort. We will examine this relationship by comparing the average productivity of the entering cohort with the average productivity of all older cohorts at a point in time. We will also examine if the average productivity of different cohorts converge to the same level over time.

This theoretical framework has an important role for the sunk entry cost C_e. If the cost is not too large, industry equilibrium will involve simultaneous offsetting flows of entering and exiting firms, and changes in the level of entry cost will affect the magnitude of these flows. An increase in C_e will raise the level of discounted profits needed to make entry profitable thus discouraging entry. An increase in these costs will also lower the minimum productivity level X needed for incumbents to survive, thus reducing the amount of firm exit. In this framework low sunk entry costs produce high levels of firm turnover and demanding requirements on the productivity of incumbent firms. In this way Taiwan's institutional environment with low entry costs can promote the reallocation of resources from low to high productivity firms.

One limitation of the model for our application is that it describes an industry with stable demand and where the only shocks to the environment over time are to firm productivity. This leads to an equilibrium in which the flows of entering and exiting firms are equivalent and there is no change in industry output or market structure over time. In Taiwan, the period we examine is one of rapid growth in demand which leads to expansion of total output and the total number of firms in each industry. The model is still useful for explaining differences in the distribution of productivity between entering, surviving, and exiting firms at a point in time, but the flows of entry and exit will not cancel out to produce unchanged aggregate statistics.

III. Firm Turnover in the Taiwan Manufacturing Sector

To assess the importance of entering and exiting firms to Taiwan's supply expansion, we classify firms in each two-digit manufacturing industry into entry cohorts and summarize their cumulative output contributions over the 1981-1991 period. Specifically, we classify each producer into one of three cohorts based on when they first appeared in the industry. The first cohort consists of firms observed in operation in 1981, the second cohort is firms first observed in the industry in the 1986 census, and the third cohort is firms first observed in the 1991 census.[4] These three cohorts differ in composition. The 1981 cohort is not a true entry cohort because it includes all firms in operation in 1981, regardless of their entry date. The 1986 cohort includes any firms that enter between 1982 and 1986 and remain in operation in 1986. Similarly, the 1991 cohort includes all firms entering after 1986 that remain in operation in 1991.

[4] A small number of firms appear in a two-digit industry in 1981 and 1991 but not in 1986. Since we are interested in explaining how the flows of firms in and out of the industry contribute to industry productivity change, we classify these firms as exits in the 1986 data and as entrants in the 1991 data.

There are some limitations in the data that will affect the interpretation of the turnover results. Entering and exiting firms are identified in the data by comparing the census firm identification numbers over time. Legal reorganizations or ownership changes will lead to changes in firm id numbers between census years so the entry and exit numbers we construct will reflect changes in firm ownership as well as the creation or disappearance of the firm.[5] The five-year period between censuses makes it impossible to observe firms that enter and exit between census years. This has two implications for the gross entry and exit flows we will summarize. First, the gross flows will be underestimated in our data because we cannot account for the firms that both enter and exit between the census years. Second, a new entrant in our data is a firm that has entered and been in operation for an average of 2.5 years. Similarly, firms that exit will, on average, remain in operation 2.5 years after the point we last observe them. To the extent that entrants increase their size and/or productivity gradually after entry and exits gradually contract prior to exit, our data will underestimate the size and/or productivity differences between entrants and exits at the same point in time.

Table 1 summarizes the cumulative effect of entry and exit over time. The first two columns of the table summarize the contribution of the 1986 and 1991 entry cohorts to the total number of firms (column 1) and total industry output (column 2) in 1991. For the textile industry, the 1986 entry cohort accounts for 23.8 percent of the number of firms in 1991 and 24.2 percent of industry output, while the 1991 entrants account for 59.4 and 33.4 percent of the firms and output, respectively. A similar pattern is reported for every other industry. Across industries, the 1991 entry cohort accounts for approximately two-thirds of the number of firms in operation and between one-third and one-half of each industry's

[5] The distinction between plant and firm-level data is also important when comparing our figures with those from other countries. The datasets for the countries referenced above generally have the manufacturing plant as the unit of observation. In some of these countries, including the U.S., efforts are made to follow the plant over time independent of ownership changes. In other countries plants can be reclassified when the parent firm changes. These reporting conventions make it impossible to construct turnover statistics for different countries that are directly comparable.

production in 1991.[6] The 1986 entry cohort accounts for approximately an additional 20 percent of the firms and 25 percent of industry output in 1991. Taken together, the two cohorts indicate that firms less than 10 years old in 1991 are responsible for at least 50 percent (transport equipment) to much as 78 percent (fabricated metals) of industry output.

The importance of entering firms in total production reflects, at least partially, the net expansion of these industries during the decade of the 80's. The average annual rate of output growth over the 1981-1991 period for these manufacturing industries varied from 3.3 percent in the clothing industry to over 16 percent in basic metals and electrical machinery. It exceeded 11 percent per year in six of the nine industries we examine. The net increase in the number of firms over each of the five-year periods 1981-1986 and 1986-1991 exceeded 25 percent in all but the apparel industry and the textile industry in the 1986-1991 period. Net entry rates of over 65 percent were observed in the electrical machinery and chemicals industries in 1981-1986 and in basic metals in 1986-1991.

However, the overall expansion of the manufacturing industries and the high rates of entry were also accompanied by significant firm exit. The last two columns in Table 1 summarize the magnitude of firm exit by reporting the percentage of 1981 production that was accounted for by firms that later exited. Two exit cohorts are defined. The 1986 exit cohort includes all firms present in 1981 that were not present in the industry in 1986, that is, exited between 1982 and 1985. The 1991 exit cohort includes all firms that were present in 1981 and 1986 but were not present in 1991, that is, exited between 1987 and 1990. For the textile industry, firms that exited the industry by the 1986 census account for 60.9 percent of the number of firms in 1981 and 42.2 percent of 1981 production. Firms that exited textiles between 1987 and 1990 account for an additional 17.8 percent and 21.1 percent of the number of firms and value

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[6] Similar statistics are available for the manufacturing sectors in three countries. Using data for Colombian manufacturing plants, Roberts (1996, Table 10.4) finds that the combined market share of one to five year old plants varies between 18.3 and 20.8 depending on the year. With similar data for Chile, Tybout (1996b, Table 9.5) finds one to five year old plants account for 15.0 to 15.7 percent of manufacturing output. Using data for U.S. manufacturing firms, Dunne, Roberts, and Samuelson (1988, Table 3) find the market share of one to five year old firms varies from 13.6 to 18.5 depending on the year. In Taiwan, comparable aged entrants have approximately two to three times the market share of entrants in these other countries. One reason for this large market share is that, unlike these other countries, Taiwan's older incumbent producers are not very large.

of production, respectively, in 1981. Overall, more than 78 percent of the 1981 textile firms, which account for over 63 percent of 1981 output, are not present ten years later. A similar pattern with the number of firms holds for every industry: between 70 and 87 percent of the 1981 producers are not present in 1991. These failing firms' share of output in 1981 is always less than their share of firm numbers, reflecting the fact that the failures are smaller, on average, than the survivors. The amount of 1981 production which these exiting firms account for also varies across industries, from a low of 37.9 percent in transport equipment to a high of 66.3 in clothing, indicating that the average size difference between failing and surviving firms varies across industries.

The high rates of entry and exit documented in Table 1 indicate substantial simultaneous movement of firms in and out of production. In most countries in which firm turnover patterns have been quantified, it is not uncommon to find firm entry and exit rates in excess of 10 percent per year. However, because entering and exiting firms are so much smaller, on average, than incumbent or surviving producers, they tend to contribute much less as a share of industry production. While turnover rates in Taiwan are larger than what has generally been found for other countries, the importance of entering and exiting firms to total industry production is unusually high. Entrants over a five-year period account for between one-third and one-half of industry output at the end of the period. Exiting firms over a five-year period account for between one-quarter and one-half of production at the start of the period.

A factor that is likely to contribute to the high turnover rate of Taiwanese firms is that the sunk costs of entering or exiting markets are quite low. Pack (1992a), Wade (1990) and Levy (1988, 1991) argue that the dominance of small-scale firms in Taiwan, combined with a well developed network of subcontracting, allows firms to enter production with relatively small amounts of capital, thus lowering the sunk costs of entry. In a field survey, Levy and Kuo (1991) find evidence that firms entering the electronics industry are often characterized by little up-front investment and that they subcontract the manufacture of a substantial number of components of the finished product. In addition, there is also little emphasis among Taiwan manufactures on brand or product differentiation thus reducing the need for sunk advertising or R&D expenditures by entering firms (Hobday 1995).

In summary, two of the most striking characteristics of the manufacturing sector in Taiwan are the high rates of entry and exit from production and the fact that these firms account for significant shares of total output. If these entering firms are, on average, more productive than the firms they replace then this heterogeneity, when combined with the large turnover rate, may be a substantial source of industry productivity growth.

IV. Firm Total Factor Productivity

Measurement Issues

For each firm in the Taiwanese manufacturing data we construct an index of total factor productivity (*TFP*) in each of the three census years 1981, 1986, and 1991.[7] We use this index as a single measure of the firms' relative efficiency, a proxy for ϕ_t in the theoretical model.[8] A *TFP* index captures many factors that can lead to profit differences across firms, including differences in technology, age or quality of capital stock, managerial ability, scale economies combined with size differences, or differences in output quality. We do not attempt to explain why *TFP* varies across firms but rather focus on whether firms' relative efficiency is correlated with their decisions to enter, exit, or remain in operation.

We wish to make comparisons of efficiency across firms in the same year and across different census years. A multilateral *TFP* index number formula*,* which is well-suited to making comparison in

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[7] A description of the data set and the measurement of firm inputs and output is provided in the Appendix.

[8] Tybout (1996a) discusses alternative productivity measures based on econometric estimation of production functions and summarizes the literature on the sources of productivity differences across producers. Olley and Pakes (1996) develop an econometric methodology for estimating production functions that is consistent with a dynamic, stochastic model of industry development.

firm-level panel data sets, was developed by Caves, Christensen, and Diewert (1982).[9] In order to guarantee that comparisons between any two firm-year observations are transitive, the index expresses each firm's inputs and outputs as deviations from a single reference point. As the reference point, the multilateral index uses a hypothetical firm with input revenue shares that equal the arithmetic mean revenue shares over all observations and input levels that equal the arithmetic mean of the log of the inputs over all observations. Each firm's output, inputs, and productivity in each year is measured relative to this hypothetical firm.

Good, Nadiri, and Sickles (1997) discuss an extension of the multilateral index that uses a separate hypothetical-firm reference point for each cross-section of observations and then chain-links the reference points together over time in much the same way as the conventional Tornqvist index of productivity growth. This productivity index is particularly useful in our application because it provides a consistent way of summarizing the cross-sectional distribution of firm productivity, using only information specific to that time period, and how the distribution moves over time.

Let each firm f in year t produce a single output Y_{ft} using the set of inputs X_{ift} where $i=1,2,...n.$ The firm's expenditure on input X_{ift}, as a share of total revenue, is denoted S_{ift}. Let $\overline{S_{it}}$, $\overline{lnY_t}$, $\overline{lnX_{it}}$, be the arithmetic means of the corresponding firm level variable over all firms in year t. The total factor productivity index for firm f in year t is defined as:

$$lnTFP_{ft} = \left(lnY_{ft} - \overline{lnY_t}\right) + \sum_{s=2}^{t}\left(\overline{lnY_s} - \overline{lnY_{s-1}}\right) - \left[\sum_{i=1}^{n}\frac{1}{2}\left(S_{ift} + \overline{S_{it}}\right)\left(lnX_{ift} - \overline{lnX_{it}}\right) + \sum_{s=2}^{t}\sum_{i=1}^{n}\frac{1}{2}\left(\overline{S_{is}} + \overline{S_{is-1}}\right)\left(\overline{lnX_{is}} - \overline{lnX_{is-1}}\right)\right] \quad (1)$$

[9] This index has been used to measure productivity in U.S. airlines by Caves, Christensen, and Tretheway (1981). It can also be applied to input and output quantity and price measurement. Aw and Roberts (1987) use the index to measure U.S. import prices by country of origin.

The first line of equation (1) measures firm output and consists of two parts. The first expresses firm output in year t as a deviation from the mean output in that year and thus embodies the information in the cross-sectional distribution of output. The second part sums the change in the mean output across all years, effectively capturing the shift of the output distribution over time by chain-linking the movement in the output reference point. The next two lines in the equation perform the same operation for each input X_i. The inputs are summed using a combination of the input revenue share for the firm S_{ift} and the average revenue share $\overline{S_{it}}$ in each year as weights. The index provides a measure of the proportional difference in *TFP* for firm f in year t relative to the hypothetical firm in the base time period. In our application we will use 1981 as the base time period.

Summary Measures of the Productivity Distribution

The distribution of firm productivity measured by equation (1) is summarized in figure 1 with kernal density estimates. Separate densities are drawn for each of the three annual cross-sections for the clothing, textile, chemical, and electrical machinery industries. All of these industries have a clear rightward shift in the productivity distribution over time, indicating productivity improvements that are widespread across all firms. In addition, the textile industry shows a clear narrowing of the productivity differences across firms between 1981 and 1991. This could reflect a narrowing of the range of technologies used by firms in this industry.

An alternative way of summarizing the movement in the firm productivity distributions, which is more tractable when a large number of industries are involved, is to summarize the quartiles of each cross-sectional distribution. Table 2 reports the 25th, 50th, and 75th percentiles for each of the nine two-digit manufacturing industries in each of the three census years. The table clearly indicates that there has been a systematic shift in the productivity distributions over time in the direction of higher productivity. Three industries, textiles, chemicals and electrical machinery, have increases in productivity for the median firm of at least 32 percent over the ten years. Five of the remaining industries have productivity growth for the median firm of between 11 and 20 percent for the decade. Only one industry, transportation equipment, shows a decline in productivity, in this case with the productivity of the median firm falling 7.5 percent over the decade.

In the majority of cases the rightward shift of the distribution is not accompanied by a significant change in the shape of the distribution from one census year to the next. In particular, there is no evidence of a significant narrowing of the cross-sectional distributions over time for most of the industries. The interquartile range (IQR) does fall over time for the clothing industry and increases substantially over time for chemicals. Clothing is the industry with the lowest output growth over the period and the only industry in which real output actually fell over one of the five year periods. In this case most of the narrowing of the IQR comes from the relatively large increase of the 25th percentile. The 25th percentile increase approximately 17 percent over the decade while the 75th percentile rises only 11 percent. This indicates it is a reduction in the mass of low productivity firms that generates the narrowing of productivity differentials in the industry. In contrast, the chemical industry had the second highest rate of output growth among our nine industries and is the one industry with an increase in the IQR over time. In this case the 75th percentile increases more rapidly than the 25th percentile, indicating that an increase in the mass of high productivity firms accompanies the rapid output growth and results in the increased dispersion.

The comparison of the productivity distributions across years indicates that the productivity increase is widespread across most firms. What the comparison cannot reveal, however, is the movement of individual firms through the distributions over time. The rightward shift in the distribution could reflect, at one extreme, productivity growth for all firms at approximately the same rate, or, at the other extreme, no productivity growth by any firm but rather the exit of all firms in the low productivity tail of the distribution and their replacement by a cohort of new, higher productivity firms. The movements in the productivity distribution also cannot reveal the change in industry-level productivity, which is a size-weighted average of the firm productivities, since the distributions do not take into account differences in the size of the firms. If the size distribution of firms is quite skewed, as is true in most manufacturing industries, then movements of output, or the reallocation of market shares, among firms with different productivity levels can have an impact on industry-level productivity change.

V. Productivity Differentials and Firm Turnover

In this section we document whether firms that undergo transitions in or out of production tend to be located in different parts of the productivity distribution. We do this by quantifying (unweighted) mean differences in productivity across groups of firms with different transition patterns. The goal is to determine if turnover patterns reflect the underlying differences in productivity as even the simplest models of firm heterogeneity and market selection predict. To clarify our productivity comparisons, figure 2 defines groups of firms based on year, entry cohort, and transition status.

Each of the three rows in figure 2 summarizes a different cohort of firms: firms that are present in 1981 and firms that first appear in 1986 or 1991. These three cohorts are denoted α, β, and γ. The α cohort includes all firms that are present in 1981, the first year of our data, while the β and γ cohorts include only firms that are entrants in each of the subsequent census years. Each column in the figure summarizes a census year, with the subscripts 1, 2 and 3 representing the years 1981, 1986 and 1991, respectively. Finally, for firms observed in 1981 and 1986 we can divide them into groups of survivors (S superscript) and failures (X superscript). We will focus on summarizing the average productivity of each cohort in each year. Thus, for example, α_1 represents the average of *lnTFP* over all firms observed in 1981, α_1^S the average productivity in 1981 of firms that will survive until 1986, and α_2 the average productivity of this surviving group in 1986.

We make four comparisons based on this dichotomy, the first two are implications of the theoretical model developed above and the last two are useful in determining the effect of turnover on aggregate productivity growth. First, we compare the productivity of surviving and exiting firms in the same cohort to see if the former have higher productivity than the latter, as predicted by the theoretical model. This is based on the mean differences $(\alpha_1^X - \alpha_1^S)$, $(\alpha_2^X - \alpha_2^S)$, and $(\beta_2^X - \beta_2^S)$. Second, we compare the productivity of entering cohorts and incumbents in each year to see if older cohorts are more productive, on average, than younger ones, as predicted. This involves the mean differences $(\beta_2 - \alpha_2)$, $(\gamma_3 - \beta_3)$, and $(\gamma_3 - \alpha_3)$. Notice that for these comparisons we are interested in how the entire group of new firms perform, in the year they first appear, relative to the incumbents and thus we do not distinguish the β and γ cohorts based on their subsequent survival or exit. Third, in the next section we will summarize a "replacement effect," that compares the productivity of an entering cohort with the group of firms that have recently exited. This will be based on the mean differences $(\beta_2 - \alpha_1^X)$, $(\gamma_3 - \beta_2^X)$, and $(\gamma_3 - \alpha_2^X)$. Finally, the productivity improvement of surviving firms will be also be a key component of industry productivity change and will be summarized by the coefficients $(\alpha_2 - \alpha_1^S)$, $(\alpha_3 - \alpha_2^S)$, and $(\beta_3 - \beta_2^S)$.

We estimate the average productivity of firms in the nine separate entry cohort/year/transition status categories. The mean productivity for each category for nine manufacturing industries is reported in table 3.[10] Table 4 summarizes the average productivity differences between the exiting and surviving firms. For the firms in 1981, column 1 indicates that, in all industries, firms that will exit before 1986 have lower total factor productivity, on average, than the firms that will survive. In the eight industries in which the difference is statistically significant, exits are between 1.4 (fabricated metals) and 8.3 percent (electrical machinery) less productive than firms that survive until 1986. Following this same cohort of firms over time, the differentials in column 2 indicate that the firms that will survive until 1991 are more productive in period 2 (1986) than their counterparts that will not survive. This holds for all industries except clothing and plastics, but the positive differentials there are not statistically significant. For this

[10] For the comparison of entrants and incumbents we specify the unrestricted model with six parameters, one for each cohort/year combination, rather than the nine parameters reported in table 3.

cohort, the exit-survivor differential is smaller in absolute value in 1986 than in 1991 for seven of the industries, indicating that as the cohort ages the productivity advantage of surviving firms diminishes.[11]

The third column reports the exiting-surviving firm productivity differential for the cohort of firms that enter in 1986. In all the industries exiting firms are less productive, on average, and the difference is statistically significant in six of the nine industries. The productivity differential varies from 1 percent in fabricated metals to 3.5 percent in basic metals. The last two columns of the table report F-statistics for the hypotheses that there is no productivity differential between exiting and surviving firms and that the differential is constant across the three cohort/years combinations we observe. The hypothesis of no exit differential is rejected at the .05 significance level for eight of the nine industries and the hypothesis that it is equal across cohorts is rejected in the three key industries of textiles, plastics and electrical machinery. Overall, the results lead to the conclusion that exit is concentrated among the least productive firms in any cohort and year, but that the differential between exiting and surviving firms will vary with the year and age of the cohort in a few industries.

The second set of implications of the theoretical model focuses on the productivity difference between entering and incumbent firms. Table 5 summarizes the difference in average productivity between the groups by cohort and year. The first column reports differences in productivity in 1986 between new entrants in 1986 and firms from the 1981 cohort that survived through 1986. The second (third) column reports the productivity differences between new entrants in 1991 and survivors from the 1986 (1981) entry cohort. Entrants are less productive, on average, than incumbents. The coefficients in column 1 indicate that entrants in 1986 are between 0.5 percent (fabricated metals) and 5.2 percent (basic metals) less productive than incumbents. In the seven industries in which the difference is statistically significant it always exceeds 2 percent. A very similar pattern is found for the entrants in 1991. When

[11] This is consistent with models in which firms are initially uncertain about their productivity but learn about it as they age and gain production experience (Jovanovic, 1982). In this case older firms will require higher levels of productivity to remain in operation than young firms and, depending on the shape of the productivity distribution for a cohort, this toughening of the failure condition can result in a smaller productivity differential between surviving and exiting firms as they age.

compared with the incumbents from the 1986 cohort (column 2), entrants are between 0.7 and 5.2 percent less productive than incumbents and the difference is statistically significant in seven industries. When compared with the 1981 cohort (column 3), the productivity disadvantage of the entrants is even larger in four of the nine industries. Thus, in these industries, older cohorts have higher average productivity than younger cohorts, including entrants.[12] The hypothesis that entrants and incumbents are equally productive is rejected in eight of the nine industries (column 4). Only in the traditional, slowly-growing clothing industry is there no significance difference in the average productivity of the two groups. The hypothesis that the difference in productivity between entrants and incumbents is constant across cohorts and years (column 5) is rejected in only one industry. This last result suggests that the productivity distributions of entering firms and incumbents shift over time in similar ways.

The results from table 4 and 5, together with the turnover numbers from section III, indicate that there is substantial firm turnover and that entering, exiting, and continuing cohorts differ systematically in their average productivity.[13] This micro-level turnover can contribute to industry productivity growth. In the next section we disaggregate growth in industry productivity into components that reflect the underlying micro-level productivity differences and turnover patterns.

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[12] The magnitude of the productivity difference between entrants and incumbents depends on how the productivity distribution of entrants, $G(\phi)$ in the theoretical model, is altered as the entrants age. Failure and productivity improvements of the survivors transform this initial distribution as the cohort ages. From the estimates in columns one and three of table 5, we observe the largest productivity disadvantage is faced by entrants in the most capital intensive industries: chemicals, basic metals, electrical machinery, and textiles. The high productivity of older cohorts probably arises from benefits of scale economies that are realized by the older, larger producers in the capital intensive industries. In the highly labor-intensive industries, apparel and fabricated metals, the productivity disadvantage of entrants is either small and not statistically significant, or, in one case, small and positive.

[13] In Aw, Chung, and Roberts (2000) we focus on the export markets of Taiwan and Korea and show that differences in productivity are also reflected in movements of firms in and out of the export market. Firms that remain exporters over multiple years have the highest productivity while beginning exporters follow behind them. All are more productive, on average, than firms that exit the export market who, in turn, are more productive than firms that never exported. This pattern is consistent with the view that firms that enter and/or survive in the export market come from the higher productivity tail of the distribution.

VI. Implications for Industry Productivity Growth

We begin by defining industry productivity as the market-share weighted sum of the firm productivity levels:

$$lnTFP_t = \sum_f \theta_{ft} \, lnTFP_{ft} \qquad (2)$$

where firm productivity is defined in equation (1) and θ_{ft} is the value of firm *f* sales relative to total industry sales in year *t*. With this formulation, shifts of output from low productivity to high productivity firms will contribute positively to industry productivity growth, even if no individual firm experiences a productivity increase. This is appropriate because our ultimate interest is in the ability of the firms in the industry to convert the set of inputs used in the industry into output, and movements of resources from low to high productivity firms can be just as effective in increasing industry output as are productivity improvements in individual firms.

As shown by Olley and Pakes (1996, eq. 16), equation 2 can be rewritten as:

$$lnTFP_t = \overline{lnTFP_t} + \sum_f \Delta \theta_{ft} \, \Delta lnTFP_{ft} \qquad (3)$$

where $\overline{lnTFP_t}$ is the unweighted mean productivity over all firms in year *t* and the Δ is used to represent a deviation from the unweighted mean in year *t*. The second term in equation (3) is the sample covariance between firm productivity and market share in year *t*, multiplied by the number of firm observations in the year. The larger this covariance, the higher the share of output that is allocated to more productive firms and the larger is industry productivity.

Table 6 reports the aggregate productivity level for each of the nine industries in the three Census years and the two components identified in equation 3. Two main features stand out in the table. First, the unweighted mean level of productivity increases over time for every industry except transportation equipment. The increase over the decade is largest for the electrical machinery, textiles, and chemicals industries. This pattern is consistent with that observed for the median of the productivity distributions reported in table 2. Second, in every industry there is a positive covariance between firm productivity and market share indicating that a larger share of industry output is concentrated in the more productive firms and thus industry productivity is higher than the unweighted firm mean. The positive covariance is present in every year and, unlike the unweighted mean productivity, its magnitude does not vary greatly or systematically over time, indicating that shifts in the productivity distribution rather than market share reallocations are likely to be the main source of industry productivity growth.

Griliches and Regev (1995) decompose industry productivity growth, defined as the change in equation (2) over time, into contributions due to the productivity growth of continuing firms, the difference in average productivity between entering and exiting cohorts of firms, and the reallocation of market shares among all firms. They show that the contribution of a single firm *f* to the change in the weighted sum in equation (2) between years *t* and *t+1* can be written as:

$$\theta_{ft+1}\, lnTFP_{ft+1} - \theta_{ft}\, lnTFP_{ft} = \left(\frac{\theta_{ft} + \theta_{ft+1}}{2}\right)\left(lnTFP_{ft+1} - lnTFP_{ft}\right) + \left(\frac{lnTFP_{ft+1} + lnTFP_{ft}}{2}\right)\left(\theta_{ft+1} - \theta_{ft}\right) \tag{4}$$

A single firm's contribution to industry productivity growth is the combination of its own productivity growth between the two years, weighted by the firm's average market share in the two years, and the change in its market share, weighted by its average productivity. If there were no entry or exit, then industry productivity growth would equal the sum of equation (4) over all the firms and would rise if individual firm productivity increased or if there was a reallocation of market shares from low productivity to high productivity firms.

While this contribution can be constructed for any firm *f* that remains in operation in both years *t* and *t+1*, it cannot be constructed for any firm that enters or exits between the two years. To incorporate entry and exit, we follow Griliches and Regev (1995) and aggregate all firms that exit following year *t* into a single exiting firm with market share θ_{Xt} and productivity level $lnTFP_{Xt}$ where the latter is a share-weighted sum over the productivity of all exiting firms. Similarly, we aggregate all new firms in year *t+1* into a single entrant with market share θ_{Et+1} and productivity level $lnTFP_{Et+1}$.

Denoting all firms that remain in operation in both years as $f \in C$ we can write the growth in industry productivity as:

$$
\begin{aligned}
dlnTFP &= lnTFP_{t+1} - lnTFP_t \\
&= \left(\frac{\theta_{Xt} + \theta_{Et+1}}{2}\right)\left(lnTFP_{Et+1} - lnTFP_{Xt}\right) \\
&+ \sum_{f \in C}\left[\left(\frac{\theta_{ft} + \theta_{ft+1}}{2}\right)\left(lnTFP_{ft+1} - lnTFP_{ft}\right)\right] \\
&+ \left(\frac{lnTFP_{Et+1} + lnTFP_{Xt}}{2}\right)\left(\theta_{Et+1} - \theta_{Xt}\right) \\
&+ \sum_{f \in C}\left[\left(\frac{lnTFP_{ft} + lnTFP_{ft+1}}{2}\right)\left(\theta_{ft+1} - \theta_{ft}\right)\right]
\end{aligned} \tag{5}
$$

This decomposition consists of four parts. The first line is the contribution that results if the productivity of the entering cohort in *t+1* differs from the period *t* productivity of the exiting cohort. The second line summarizes the contribution of productivity growth among the continuing firms. The third and fourth lines capture the reallocation of market shares between the entrants and exits and the continuing firms, respectively. We will combine the last two terms into a single "market share reallocation" term.[14]

[14] Various permutations of this decomposition have been reported in the literature. Griliches and Regev (1995) combine the last three components into a single measure of the contribution of firm "mobility" and distinguish it from the "within firm" productivity improvements captured by the first term. Like us, Tybout (1996a) reports a three-term decomposition in which the last two terms of equation (5) are combined into a single market share reallocation term that captures the shift of market shares among all three categories of firms. Bailey, Hulten, and Campbell (1992), and Haltiwanger (1997) report alternative decompositions. As suggested by Haltiwanger's decomposition we can further disaggregate the second term in (5) into two components:

$$\sum_{f \in C} \theta_{ft}(\ln TFP_{ft+1} - \ln TFP_{ft}) + \tfrac{1}{2} \sum_{f \in C} (\theta_{ft+1} - \theta_{ft})(\ln TFP_{ft+1} - \ln TFP_{ft}).$$

The first component reflects the productivity improvements of incumbents with fixed, initial period weights, while the second term captures the comovement of incumbent firm productivity and market share. The second term will be positive if incumbents with higher rates of productivity improvement also expanded their market share and thus contributed to aggregate productivity improvement. See Foster, Haltiwanger, and Kruzan (2001) for discussion of the differences in decomposition methods.

We begin by summarizing the unweighted mean difference in the productivity of entering and exiting firms, $lnTFP_{Et+1}$ - $lnTFP_{Xt}$, in the first three columns of Table 7. This "replacement effect," differs between cohorts and year and is determined by the mean differences $(\beta_2 - \alpha_1^X)$, $(\gamma_3 - \beta_2^X)$, and $(\gamma_3 - \alpha_2^X)$. In virtually all cases this replacement effect is positive, indicating that the new cohort of entering firms has higher average productivity than the group they replace. This reflects the rightward shift in the productivity distribution observed in table 2 and figure 1. While the entrants and exits tend to be concentrated in the left tail of the relevant cross-sectional distributions, as shown in Tables 4 and 5, the shifting of the productivity distribution over time leads the entrants to be more productive in year *t+1* than the exits were in year *t*.

The last three columns of table 7 summarize the unweighted mean productivity growth of the group of firms that survive from one census year to the next, $lnTFP_{ft+1}$ - $lnTFP_{ft}$. These are measured for the different years and cohorts by the coefficients $(\alpha_2 - \alpha_1^S)$, $(\alpha_3 - \alpha_2^S)$, and $(\beta_3 - \beta_2^S)$. The positive values indicate that surviving firms have productivity gains over time and, thus, that the rising average productivity of a surviving cohort is not just due to increased failure of the least efficient cohort members. Both the positive productivity growth of survivors and the replacement through entry and exit contribute to the shift in the productivity distribution over time.[15]

Two useful comparisons can be made across the columns of table 7. First, the last two columns summarize the productivity growth of the 1981 (α) and 1986 (β) cohorts between 1986 and 1991. For six out of the eight industries with positive growth, the 1986 entry cohort has higher average productivity growth for the survivors than the 1981 cohort. This implies that the average productivity level of the 1986 cohort survivors is converging toward the higher average level of productivity of the older cohort. Second, we can compare the magnitude of the replacement effect with the average productivity growth of

[15] The one exception to this pattern is the transportation equipment sector which shows a leftward shift in the productivity distribution over time (table 2). Even within this industry we observe that exiting firms are less productive than survivors and entrants are less productive than incumbents.

survivors for the same time period. A comparison of columns 1 and 4 shows that the replacement effect was larger than the survivor growth effect in the 1981-1986 period for six of the industries. In the 1986-1991 period, which was one of slower output growth for most of the industries, the replacement effect is larger than the surviving firm effect in only six of the eighteen industry/cohort comparisons.

Combining the productivity differences in Table 7 with the appropriate share weights gives the decomposition in equation (5). The components of the decomposition are reported in Table 8 along with the growth rate of industry *TFP*, and, for comparison, the growth in industry labor productivity.[16] As reported in column 1, over the five-year interval real output per worker grew for all but the transportation equipment industry, between 15.7 percent (clothing) and 74.3 percent (electrical machinery). A weighted average of the industry growth rates for the five-year intervals is 39.5 percent for an average annual growth rate in labor productivity of 7.9 percent.[17] In contrast, the *TFP* growth rates reported in column 2 are much more modest, with a weighted average of the industry rates equaling 16.2 percent for the five-year interval or 3.2 percent per year.[18] Table 8, however, provides evidence that some of the manufacturing industries have experienced high rates of *TFP* growth during at least one of the time periods. Textiles, chemicals, and electrical machinery each have at least one of the five-year periods in which they average over 3 percent annual productivity growth. In contrast, several industries including transport equipment and clothing had periods of negative productivity growth.

The decomposition of *TFP* growth is reported in the last three columns of table 8. The first component indicates that *TFP* growth of continuing firms is a significant source of industry productivity growth. Except for fabricated metals in 1981-1986, the industry *TFP* in every industry and time period

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[16] The growth in labor productivity is also constructed as a market-share weighted sum of the firm labor productivities.

[17] Each industry is weighted by its share of manufacturing value of shipments in 1986. The industries with the largest shares are electrical machinery (.238), textiles (.154), and plastics (.135).

[18] The *TFP* growth rates are slightly higher than those reported by Young (1995). Using aggregate data for the whole manufacturing sector, he reports (Table VIII) that Taiwan's manufacturing output grew at an average annual rate of 7.2 percent from 1980-90. Labor productivity grew 5.1 percent and *TFP* grew 2.8 percent per year during the decade.

reflects what happens to the continuing firms. Thus the shifts in the productivity distributions documented in table 2 appear to characterize the experience of continuing firms. The importance of this term mirrors the findings of virtually all other productivity studies that report this type of decomposition.[19]

In contrast to the other studies, we find that differences in productivity between entering and exiting firms (column 4) are frequently an important source of industry productivity growth. The sign of this effect is virtually always the same as the sign of the continuing firm effect, indicating that the average productivity of entering cohorts is rising over time. In other words, the rightward shift in the productivity distributions found for most industries in table 2 result from higher levels of productivity among the entering cohort, relative to the failing cohort from the previous year, as well as higher productivity of the continuing firms. The higher productivity levels in the second year of each pair of years reflect widespread productivity improvements across all producers in the latter year. This pattern is unusual, as most other studies find that entering firms have approximately the same productivity levels, on average, as exiting firms so that the differential contributes little to industry productivity growth.[20]

The final column of table 8 reports the effect of changing market shares. The total contribution of market share reallocation is very close to zero in most cases. For example, in the high productivity industries of textiles, chemicals, and electrical machinery the total contribution of changing market shares is never more than 1.4 percent over any five year period and is generally much smaller.[21] This mirrors

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[19] Further disaggregating the continuing firm term into the two components identified in footnote 14 we find the productivity improvement with initial period weights to be negative for the fabricated metal, nonelectrical machinery, and transportation industries in all years and the clothing industry in 1981-86. It is positive in all other cases and generally the dominant source of the incumbent firm change reported in column 3 of table 8. The comovement of incumbent productivity and market share makes a positive contribution to the aggregate in all cases except the chemical industry.

[20] The difference may also arise because of the five-year interval between our entering cohorts, so that the entrants are, on average, 2 ½ years old when we first observe them. The studies for Israel, Colombia, and Chile use annual data. Productivity improvements that occurred following entry would appear as continuing firm productivity improvements in those studies but as more productive entrants in our data.

[21] As shown in equation 5 the market share reallocation term can be further divided into changes in incumbent market shares and the difference in the share of the entering and exiting cohort with average productivities as weights. These separate components are heavily affected by the substantial net expansion in the number of Taiwanese manufacturing firms. This expansion results in a decline in the incumbent firm market share over time and an entrant market share that is greater than the exiting firm

findings for Israel, Colombia, and Chile. Bailey, Hulten, and Campbell (1992) and Haltiwanger (1997) report a much larger role for output reallocations among producers, accounting for as much as one-half of productivity change in U.S. manufacturing.

Overall, the decomposition in table 8 indicates that the productivity growth of incumbents and the productivity differential between entering and exiting firms are both major sources of sectoral productivity growth in Taiwan manufacturing. Market share reallocations, in total, contribute little to productivity change in most industries. The most unusual feature of this decomposition is the substantial role which entry and exit play. In the high productivity growth sectors of textiles, chemicals, and electrical machinery, the entry-exit differential contributes between 4.1 and 10.5 percentage points of *TFP* growth over a five-year interval.

From the decomposition in equation (5), there are two reasons why entry and exit may play a more important role in Taiwan than in other countries: the productivity difference between entering and exiting firms is large and the market shares of entrants and exits are large. The fact that, on average, entering cohorts are more productive than the exiting cohorts they replace is seen clearly from the replacement effect in Table 7. It is also the case that entrants and exits account for a larger share of market activity in Taiwan than other countries. Many of these applications are to countries, industries, or time periods in which there are stable market conditions and few significant changes in market structure.[22] None of the other studies have focused on environments where manufacturing output is growing as rapidly as it did in Taiwan. Manufacturing output grew at an average annual rate of 6.5 percent for the decade of our data and in several major industries annual output growth rates exceeded 10 percent. The

market share. As a result, the market share reallocation among incumbents always makes a negative contribution to aggregate productivity growth and the difference between entering and exiting firm market share always makes a positive contribution. The magnitudes of these two effects largely offset each other and generate the small market share reallocation term in table 8.

[22] One exception is Olley and Pakes (1996) who study the U.S. telecommunications industry in the period surrounding deregulation. They find that the reallocation of output from older, less productive plants that contract or exit to more productive entering establishments is a significant source of industry productivity growth during the period. Haltiwanger (1997) finds that net entry accounts for about 18 percent of productivity change in the average U.S manufacturing industry over the 1977-87 period, a time period which included a large recession and significant restructuring of the sector.

net increase in the number of producers has been substantial in most Taiwan industries and, as a result, new firms tend to account for a much larger share of industry output than in other countries.

A second, but related, explanation focuses on the size difference between entering and continuing firms. In Taiwan, the vast majority of firms are small or medium enterprises (SME). In the industries studied here, 66.6 percent of all manufacturing firms have fewer than 10 employees and only 6.95 percent have more than 50 employees. In contrast, in the U.S., 16.9 percent of manufacturing *plants* have at least 50 employees.[23] The size differences between entering and incumbent firms is also more substantial in the United States. Dunne, Roberts, and Samuelson (1988, Table 3) find that entering firms, on average, are .28 the size of incumbents in the same industry. In our Taiwanese industries, the average output of entrants is .41 of the average size of incumbents. As a result, even if the entry rates were similar across countries, the entering firms in Taiwan would account for a larger share of industry output because they are closer in size to the incumbents.

Are there reasons to expect the productivity of entering firms to rise along with the productivity of incumbents over time? Anecdotal and case study evidence in Taiwan suggests that new independent firms are often spin offs from existing firms, particularly foreign-owned firms, and are run by individuals with overseas experience in U.S. firms or universities (Levy, 1991; Wade, 1990). This evidence is consistent with reports of the reverse brain drain of recent years in Taiwan. The government has been very successful in inducing the return of Taiwanese nationals who are trained overseas, to start their own businesses (Gee and Kuo, 1998). In addition, high technology public enterprises such as the Industrial Technology Research Institute explicitly encourage their trainees and graduates to start up new companies with the promise of continued government assistance. Consequently, many of the start-up firms, especially in the electronics industry, in the 1980's entered the industry with state-of-the-art innovation capabilities and were able to compete with incumbent firms (Hobday, 1995).

[23] U.S. Bureau of the Census. 1992 Census of Manufactures, Subject Series, General Summary, Table 1-4.

VII. Summary and Conclusions

In this paper we use micro panel data for Taiwan's manufacturing sector to measure firm total factor productivity, to study the movement of the productivity distribution over time, to examine if patterns of firm turnover are related to productivity differences, and to measure the contribution of firm turnover to industry productivity growth.

A broad conclusion from our examination of the data is that there are significant differences in *TFP* across firms and that these differences are reflected in turnover patterns. Cohorts of new firms have lower average productivity than incumbents but are themselves a heterogeneous group. On average, the more productive members of the group survive and, in many cases, their productivity converges to the productivity level of incumbents. Firms that will exit in the future are also less productive, on average, than survivors. These patterns are generally consistent with the view that the markets sort out high productivity from low productivity firms.

We also find evidence of total factor productivity growth at modest levels (two percent per year) for a number of manufacturing industries over the decade of the 80's. In most industries, the productivity improvements are widespread across the whole distribution of firms, suggesting that it may be less related to individual firm actions than it is to common improvements in worker quality and infrastructure, two areas in which the Taiwanese government has invested heavily over a sustained period of time. One implication of this general shift in the firm-level productivity distribution is that entering firms also shared in the higher productivity so that the turnover of firms through entry and exit made a significant positive contribution to industry productivity growth. Productivity growth of incumbent firms also was a significant source of industry productivity growth. Pack (1992a) maintains that it is the high level of education of the labor force and first class social overhead capital in Taiwan that help create a large stock of entrepreneurs able to start new firms that are capable of sharing in and contributing to industry productivity growth.

While heterogeneity in productivity is a common finding in plant or firm-level micro data, the easy entry and exit of firms is necessary if these micro differences are to be exploited in a way that contributes to aggregate productivity growth. This combination of heterogeneity in productivity and easy entry and exit of firms is found to characterize the manufacturing sector in Taiwan. The concentration of production in less capital-intensive industries and the heavy use of subcontractors both reduce the sunk investment needed to start a new firm and thus speed turnover. The ability of small firms to adjust rapidly to changing product markets in goods as diverse as footwear and personal computers (Levy, 1988) also contributes to reallocation.

Obstacles to free entry and exit slow this reallocation process and are likely to slow productivity growth. For example, Hopenhayn and Rogerson (1993) study the welfare cost of policies, such as taxes on job destruction, that are designed to reduce employment turnover. They find that these policies reduce employment, lower the average productivity of incumbent firms, and have substantial welfare costs. The manufacturing sector of many developing countries is often subject to heavy government regulations, much of it biased in favor of large, incumbent firms (Tybout, 2000). Subsidizing inefficient producers has static efficiency costs but, if this also raises entry costs and slows the turnover process, it can generate dynamic efficiency losses by preventing the reallocation of resources to more productive new firms. In contrast to this, the high rates of producer turnover in the manufacturing sector in Taiwan may contribute to aggregate productivity improvements as firms rapidly exploit micro-level differences in productivity and replace less efficient firms with more efficient ones.

Data Appendix

The data used in this paper are drawn from the Industrial and Commercial Census collected by the Statistical Bureau of Taiwan's Executive Yuan in 1981, 1986 and 1991. The census collects detailed data on each manufacturing firm. There are more than 88,000 firms in the 1981 census and over 100,000 manufacturing firms in 1986 and 1991. These are the micro data which, when aggregated to the industry level, are published in the *Report on Industrial and Commercial Census, Taiwan-Fukien Area, The Republic of China (Volume 3: Manufacturing)* by the Directorate-General of Budget, Accounting and Statistics, Executive Yuan. The firm observations not only provide complete cross-sectional coverage of the manufacturing firms in each year but are matched across the censuses so that individual firms can be followed over time, allowing measurement of firm turnover and firm growth.

There are two limitations associated with measuring firm entry and exit from census data. The first is due to the five-year period between censuses, which means that firms that enter and then exit between the years are never observed. This leads to underestimation of the amount of entry and exit. The second problem occurs when firms change ownership or location between census years. In this case they will be classified as an exit after one census and an entrant in the next census and this will lead to overestimation of the true extent of entry and exit. With the information collected in the census it is not possible for us to determine the extent of ownership or address changes. Finally, occasionally firms switch the two-digit industry in which they are classified as a result of either coding errors or changes in the mix of products they manufacture. Because our focus is on the role of entry and exit at the industry level we have treated the firms as exiting from the original industry and entering the new two-digit industry.

All three Industrial Censuses provide information on the output and input variables that are necessary to measure total factor productivity at the firm-level: sales, employment, book value of the capital stock, and expenditures on labor and different types of intermediate inputs.[24] Firm output is defined as total firm sales deflated by a wholesale price index defined at the two-digit industry level. There are two weaknesses to this measure. First, we are not able to measure the firm's inventories of final output in each census year so we are not able to distinguish firm sales from firm production in the year. The latter is preferable in productivity studies. The second weakness is that there is no information on firm-level output prices to use in deflating firm sales. While this is a limitation of virtually all productivity studies, it does create the possibility that *TFP* estimates at the firm level will be biased in a way that is related to firm size. If large firms have lower (higher) output prices than small firms, then the use of a common industry price deflator will underestimate (overestimate) the real output of large producers and overestimate (underestimate) the output of small firms, leading to a systematic bias in firm *TFP* across the firm size distribution. In a separate project (Aw, Batra, and Roberts (2001)) we have been able to analyze firm-level output prices for Taiwan's electronics producers and, while prices do vary across firms, we have found no systematic relationship between output price and firm size or the output market, export versus domestic, in which the output is sold.

We model each firm as using four inputs in production: labor, capital, materials, and subcontracting services. The labor input is measured as the number of production plus non-production workers. We do not have information on the mix of worker skills in the firm and so are not able to account for improvements in labor quality over time. Total payments to labor are measured as total salaries to both groups. We do not have data on non-wage benefits paid by the firm.

The measure of capital input is the book value of capital stock of the firm. To attempt to control for price level changes in new capital goods that will cause the book value of firms to change over time as they invest in new equipment, we deflate the change in each firm's book value by a price index for new capital goods. For example, to convert the firm capital values in 1991 to the same basis as reported in

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[24] The type of data collected in the Taiwan manufacturing census is very similar to what is collected in the United States (see Baily, Hulten, and Campbell (1992) for its use in productivity measurement) or in the developing countries analyzed in Roberts (1996) and Tybout (1996).

1986, we calculate the change in each firm's reported book value between 1986 and 1991, deflate this using an industry-specific price index for new capital goods and then add this deflated value to the firms reported book value in 1986. While much cruder than constructing perpetual inventory capital stocks, this procedure does recognize both the level differences in the firms' capital, which are important in the cross-section, and the fact that latter additions to each firm's capital stock partly reflect general price level increases. A similar procedure is used to scale the 1981 book values to the 1986 basis. Finally we note that price changes for new capital goods are generally small, averaging less than one percent per year for most industries, so that comparisons of book values over time probably do not greatly distort the growth in capital stocks. The firm's expenditure share on capital is calculated as the residual after subtracting the expenditure on labor, material inputs, and subcontracting from the firm's sales.

The material input includes the raw materials, fuel, and electricity used by the firm. Expenditures on these categories are converted to 1986 dollars. Raw material expenditures are deflated by a general producer price index which covers both manufacturing and nonmanufacturing output in the country. Fuel and electricity expenditures are deflated by an energy price index. These deflators are the same for all industries. The subcontracting input is included as a separate factor because, while small as a share of a typical firm's total cost, it has risen in importance over the time period we study. This input is not used by all firms, although it has become more widely used over time, and failing to account for it would mean that we systematically underestimate the inputs used by firms that hired subcontractors relative to those that did everything internally. This would lead us to overestimate *TFP* for firms that used subcontractors relative to those that did not. In the census data a firm that out-sources some of the production steps to a subcontractor generally transfers material inputs to the subcontractor. The value of these transferred material inputs are not reported separately but are included with the hiring firm's expenditure on materials. The hiring firm also reports its payments to subcontractors, which effectively represents the cost to the hiring firm of using the labor and equipment services of the subcontractors as well as the latters' expenses for fuel and electricity. To construct a subcontracting input we deflate the firm's payments to subcontractors by the output price of the industry in which the firm operates. If we had information on the precise step of the production process in which the subcontractor was involved and more disaggregated price deflators it might be possible to use a more accurate price deflator for the subcontracting input. Neither of these pieces of information is available. Our correction, however, attempts to recognize that the inputs of firms which subcontract some of the production steps to others need to be increased, and thus their *TFP* reduced, relative to the firms that do not subcontract.[25]

[25] The firms which engage in subcontracting are not included in the set of firms whose productivity we study. The census data reports a zero value of sales for these firms. Also, most of the material inputs they use are not reported by the subcontracting firm but instead are reported as material purchases by the firm that hires the subcontractor. Thus there is no way to construct productivity measures for subcontractors that are comparable to the measures we construct for the firms we analyze.

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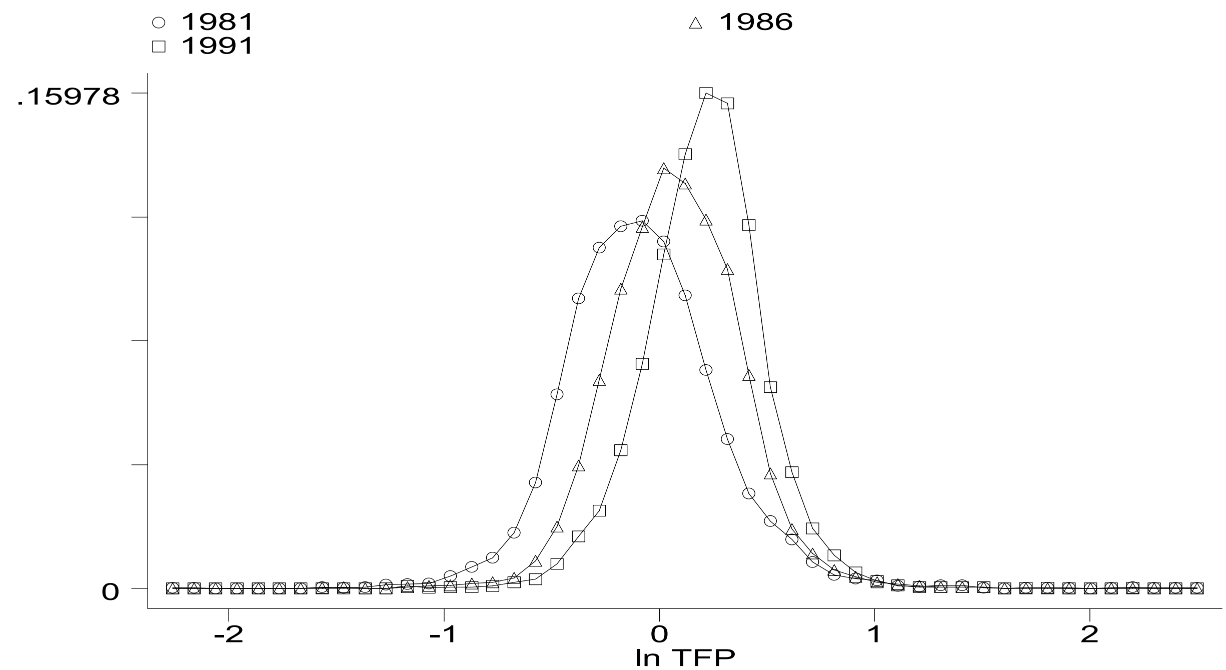
Table 1

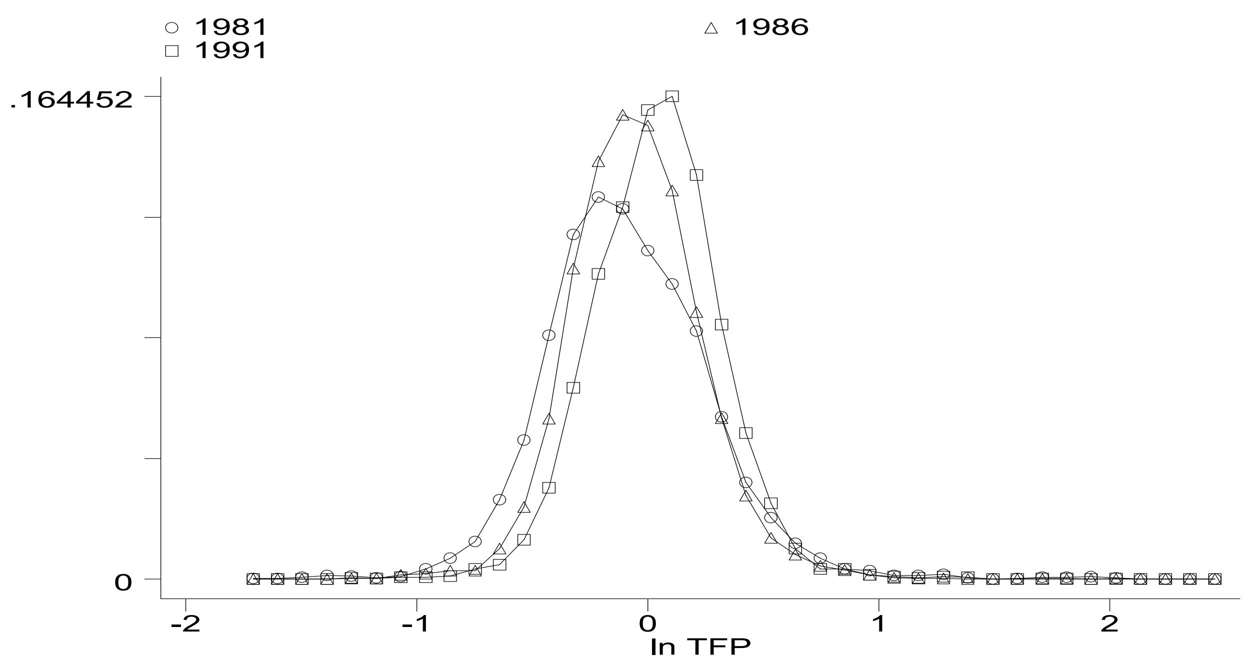
Contribution of Entry and Exit Cohorts to Industry Output and Firm Numbers

Industry / Entry Cohort	Production - 1991		Industry/Exit Cohort	Production - 1981	
	Share of Number of Firms	Share of the Value of Production		Share of the Number of Firms	Share of the Value of Production
Textiles			Textiles		
1986 Entry Cohort	.238	.242	1986 Exit Cohort	.609	.422
1991 Entry Cohort	.594	.334	1991 Exit Cohort	.178	.211
Clothing			Clothing		
1986 Entry Cohort	.221	.234	1986 Exit Cohort	.737	.502
1991 Entry Cohort	.635	.455	1991 Exit Cohort	.138	.161
Chemicals			Chemicals		
1986 Entry Cohort	.198	.292	1986 Exit Cohort	.564	.223
1991 Entry Cohort	.640	.401	1991 Exit Cohort	.142	.361
Plastics			Plastics		
1986 Entry Cohort	.215	.200	1986 Exit Cohort	.622	.362
1991 Entry Cohort	.648	.332	1991 Exit Cohort	.161	.233
Basic Metals			Basic Metals		
1986 Entry Cohort	.162	.233	1986 Exit Cohort	.671	.376
1991 Entry Cohort	.743	.377	1991 Exit Cohort	.149	.122
Fabricated Metals			Fabricated Metals		
1986 Entry Cohort	.217	.277	1986 Exit Cohort	.424	.386
1991 Entry Cohort	.666	.510	1991 Exit Cohort	.284	.252
Non Electrical Machinery			Non Electrical Machinery		
1986 Entry Cohort	.193	.240	1986 Exit Cohort	.611	.473
1991 Entry Cohort	.666	.473	1991 Exit Cohort	.161	.127
Electrical Machinery			Electrical Machinery		
1986 Entry Cohort	.200	.270	1986 Exit Cohort	.588	.300
1991 Entry Cohort	.686	.310	1991 Exit Cohort	.160	.149
Transportation Equipment			Transportation Equipment		
1986 Entry Cohort			1986 Exit Cohort		
1991 Entry Cohort	.201	.264	1991 Exit Cohort	.620	.223
	.669	.245		.157	.156

Figure 1: Kernel Density Estimates for *ln TFP*

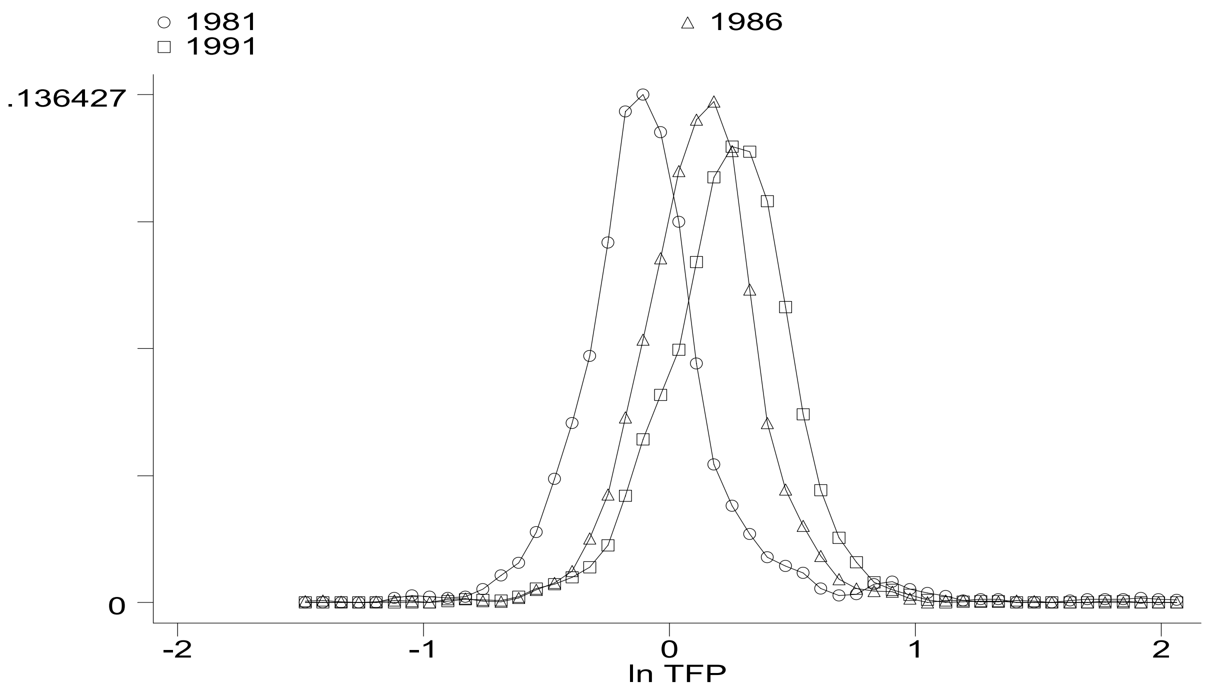


Textiles

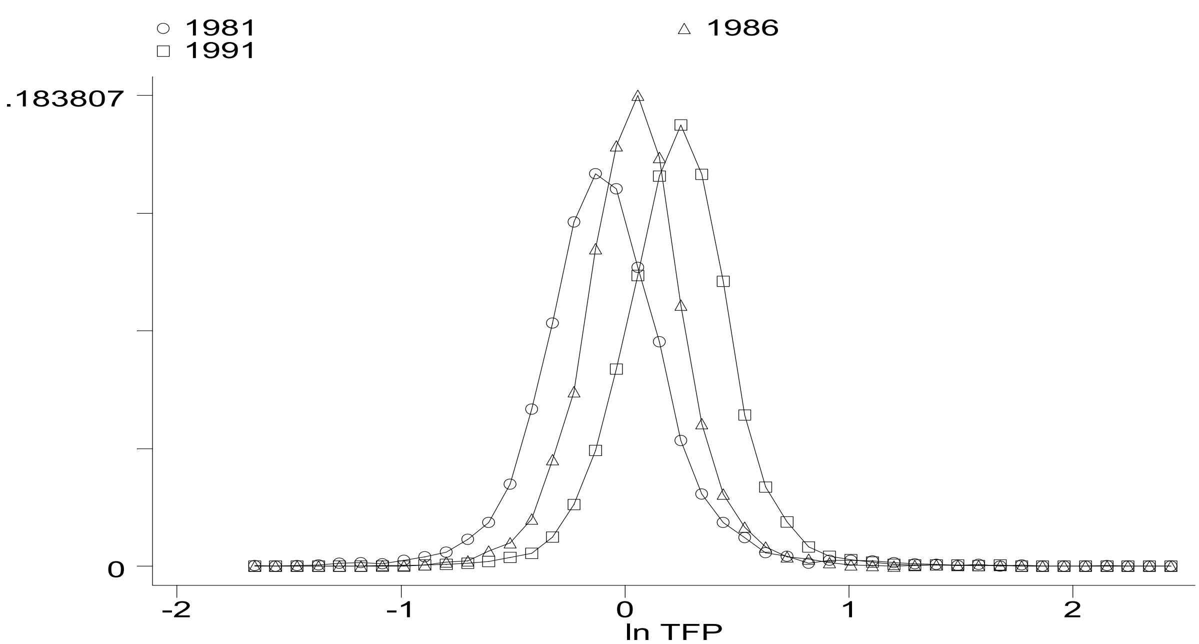


Clothing

Figure 1 (cont.): Kernel Density Estimates for ln TFP



Chemicals



Electrical Machinery and Electronics

Figure 2: Firm groups based on year, entry cohort, and transition status

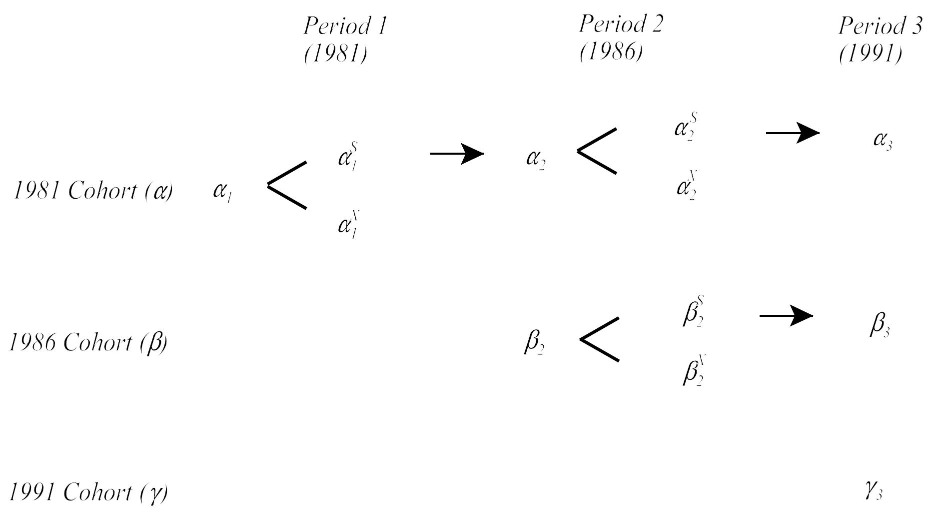


Table 2

Percentiles of the Cross-Sectional Distribution of lnTFP

	1981	1986	1991
Textiles - number of firms	2,313	3,236	3,509
25th percentile	-.249	-.047	.090
Median	-.077	.109	.252
75th percentile	.116	.275	.396
Clothing - number of firms	1,745	1,956	2,023
25th percentile	-.264	-.176	-.090
Median	-.078	-.026	.079
75th percentile	.129	.138	.241
Chemicals - number of firms	462	796	988
25th percentile	-.207	.020	.120
Median	-.086	.154	.275
75th percentile	.051	.278	.413
Plastics - number of firms	4,571	6,573	8,925
25th percentile	-.215	-.061	-.030
Median	-.069	.073	.121
75th percentile	.094	.209	.264
Basic Metals - number of firms	1,269	1,961	3,323
25th percentile	-.237	-.045	-.042
Median	-.101	.067	.105
75th percentile	.035	.182	.235
Fabricated Metals - number of firms	6,348	14,544	19,537
25th percentile	-.223	-.151	-.105
Median	-.075	-.018	.042
75th percentile	.078	.121	.187
Non Electrical Machinery - number of firms	4,894	6,610	9,618
25th percentile	-.204	-.108	-.104
Median	-.062	.028	.049
75th percentile	.083	.164	.191
Electrical Machinery & Electronics - number of firms	3,150	5,321	8,006
25th percentile	-.214	-.061	.119
Median	-.070	.068	.268
75th percentile	.077	.202	.410
Transportation Equipment - number of firms	1,585	2,338	3,227
25th percentile	-.208	-.215	-.298
Median	-.065	-.078	-.140
75th percentile	.087	.040	.012

Table 3

Average Total Factor Productivity by Cohort/Year/Exit Status
(standard errors in parentheses)

	α_1^s	α_1^x	α_2^s	α_2^x	α_3	β_2^s	β_2^x	β_3	γ_3
Textiles	-.015	-.082	.143	.141	.257	.125	.091	.274	.222
	(.009)	(.007)*	(.013)*	(.014)*	(.013)*	(.010)*	(.007)*	(.010)*	(.006)*
Clothing	-.026	-.070	-.011	.001	.086	-.012	-.017	.081	.073
	(.013)**	(.008)*	(.019)	(.019)	(.019)*	(.013)	(.009)**	(.013)*	(.008)*
Chemicals	-.052	-.075	.206	.119	.318	.148	.132	.259	.248
	(.018)*	(.015)*	(.022)*	(.031)*	(.022)*	(.018)*	(.012)*	(.018)*	(.010)*
Plastics	-.035	-.070	.090	.104	.132	.077	.060	.143	.106
	(.006)*	(.005)*	(.008)*	(.009)*	(.008)*	(.006)*	(.005)*	(.006)*	(.003)*
Basic Metals	-.053	-.100	.122	.091	.146	.079	.043	.127	.083
	(.012)*	(.008)*	(.016)*	(.017)*	(.016)*	(.010)*	(.007)*	(.010)*	(.005)*
Fabricated Metals	-.062	-.076	-.002	-.016	.018	-.008	-.018	.055	.035
	(.004)*	(.005)*	(.006)	(.006)*	(.006)*	(.004)**	(.003)*	(.004)*	(.002)*
Non Electrical Machinery	-.034	-.076	.054	.030	.052	.038	.013	.056	.039
	(.006)*	(.004)*	(.008)*	(.009)*	(.008)*	(.006)*	(.005)*	(.006)*	(.003)*
Electrical Machinery	-.019	-.102	.119	.077	.299	.076	.050	.285	.251
	(.007)*	(.006)*	(.009)*	(.011)*	(.009)*	(.006)*	(.005)*	(.006)*	(.003)*
Transport Equipment	-.027	-.081	-.059	-.102	-.129	-.075	-.094	-.127	-.157
	(.010)*	(.008)*	(.014)*	(.016)*	(.014)*	(.010)*	(.007)*	(.010)*	(.005)*

* indicates statistically significantly at the .01 significance level.
** indicates statistically significantly at the .05 significance level.

Table 4

Mean Productivity Difference Between Exiting and Surviving Firms by Cohort and Year
(standard errors of the difference in parentheses)

	$\alpha_1^X - \alpha_1^S$	$\alpha_2^X - \alpha_2^S$	$\beta_2^X - \beta_2^S$	F-statistic: No exit differential (a)	F-statistic: Equal exit differential (b)
Textiles	-.067 (.012)*	-.001 (.019)	-.034 (.012)*	13.3*	4.88*
Clothing	-.044 (.015)*	.012 (.026)	-.004 (.016)	2.78**	2.40
Chemicals	-.023 (.023)	-.088 (.037)**	-.015 (.022)	2.34	1.48
Plastics	-.036 (.008)*	.014 (.012)	-.017 (.007)**	9.76*	6.14*
Basic Metals	-.048 (.014)*	-.032 (.023)	-.035 (.013)*	7.03*	.27
Fabricated Metals	-.014 (.006)**	-.014 (.008)	-.010 (.005)**	4.08*	.20
Non Electrical Machinery	-.042 (.007)*	-.025 (.012)**	-.025 (.008)*	16.57*	1.68
Electrical Machinery	-.083 (.009)*	-.042 (.014)*	-.026 (.008)*	35.81*	11.55*
Transport Equipment	-.054 (.013)*	-.043 (.021)**	-.018 (.012)	8.14*	2.1

* indicates statistically significantly at the .01 significance level.
** indicates statistically significantly at the .05 significance level.

(a) Null hypothesis: $\alpha_1^X - \alpha_1^S = \alpha_2^X - \alpha_2^S = \beta_2^X - \beta_2^S = 0$

(b) Null hypothesis: $\alpha_1^X - \alpha_1^S = \alpha_2^X - \alpha_2^S = \beta_2^X - \beta_2^S$

Table 5

Mean Productivity Differences Between Entrants and Incumbent Firms by Cohort and Year
(standard errors of the difference in parentheses)

	$\beta_2 - \alpha_2$	$\gamma_3 - \beta_3$	$\gamma_3 - \alpha_3$	F-statistic: No entry differential (a)	F-statistic: Equal entry differential (b)
Textiles	-.039 (.011)*	-.052 (.011)*	-.035 (.014)*	12.06*	.71
Clothing	-.011 (.015)	-.007 (.015)	-.012 (.020)	.34	.03
Chemicals	-.040 (.020)**	-.011 (.020)	-.071 (.024)*	4.31*	2.26
Plastics	-.030 (.007)*	-.037 (.006)*	-.026 (.009)*	18 .75*	.78
Basic Metals	-.052 (.013)*	-.044 (.011)*	-.063 (.017)*	14.3*	.52
Fabricated Metals	-.005 (.005)	-.020 (.004)*	.017 (.006)*	12.08*	15.15*
Non Electrical Machinery	-.020 (.007)*	-.017 (.006)*	-.013 (.008)	5.75*	.22
Electrical Machinery	-.042 (.008)*	-.034 (.007)*	-.047 (.009)*	23.86*	.86
Transport Equipment	-.009 (.012)	-.030 (.011)*	-.029 (.015)**	3.46**	.90

* indicates statistically significantly at the .01 significance level.
** indicates statistically significantly at the .05 significance level.

(a) Null hypothesis: $\beta_2 - \alpha_2 = \gamma_3 - \beta_3 = \gamma_3 - \alpha_3 = 0$

(b) Null hypothesis: $\beta_2 - \alpha_2 = \gamma_3 - \beta_3 = \gamma_3 - \alpha_3$

Table 7

Mean Productivity Differences Over Time
(standard errors in parentheses)

	Replacement Effect			Productivity Growth of Survivors		
	$\beta_2 - \alpha_1^X$	$\gamma_3 - \alpha_2^X$	$\gamma_3 - \beta_2^X$	$\alpha_2 - \alpha_1^S$	$\alpha_3 - \alpha_2^S$	$\beta_3 - \beta_2^S$
Textiles	.185 (.009)*	.080 (.015)*	.130 (.009)*	.157 (.013)*	.114 (.018)*	.149 (.014)*
Apparel	.054 (.011)*	.072 (.020)*	.090 (.012)*	.021 (.019)	.096 (.027)*	.093 (.019)*
Chemicals	.213 (.018)*	.129 (.032)*	.115 (.016)*	.230 (.025)*	.112 (.030)*	.112 (.025)*
Plastics	.137 (.006)*	.002 (.010)	.046 (.006)*	.131 (.008)*	.042 (.011)*	.066 (.008)*
Basic Metals	.156 (.010)*	-.008 (.018)	.039 (.009)*	.160 (.017)*	.023 (.022)	.048 (.014)*
Fabricated Metals	.062 (.005)*	.051 (.006)*	.053 (.004)*	.053 (.006)*	.020 (.008)*	.063 (.005)*
Non Electrical Machinery	.100 (.006)*	.009 (.009)	.026 (.006)*	.078 (.008)*	-.003 (.011)	.018 (.008)**
Electrical Machinery	.162 (.007)*	.174 (.011)*	.202 (.006)*	.121 (.010)*	.180 (.012)*	.209 (.009)*
Transportation Equipment	-.005 (.010)	-.055 (.017)*	-.064 (.009)*	-.051 (.015)*	-.069 (.019)*	-.052 (.014)*

* indicates statistically significantly at the .01 significance level.

Table 6
Decomposition of Industry Productivity Levels

Industry	Year	Aggregate Level *ln TFP*	Unweighted Mean *ln TFP*	$\sum_f \Delta\theta_{ft}\ \Delta\, ln\ TFP_{ft}$
Textiles	1981 1986 1991	.097 .262 .414	-.056 .114 .239	.153 .148 .175
Clothing	1981 1986 1991	.192 .160 .269	-.058 -.013 .076	.251 .173 .193
Chemicals	1981 1986 1991	.026 .290 .413	-.065 .147 .259	.092 .143 .153
Plastics	1981 1986 1991	.104 .223 .341	-.057 .074 .116	.161 .149 .224
Basic Metals	1981 1986 1991	-.011 .110 .274	-.085 .066 .094	.075 .044 .180
Fabricated Metals	1981 1986 1991	.112 .132 .216	-.068 -.013 .038	.179 .145 .178
Non-Electrical Machinery	1981 1986 1991	.118 .154 .203	-.060 .030 .044	.179 .125 .159
Electrical Machinery	1981 1986 1991	.086 .138 .432	-.068 .070 .263	.153 .068 .169
Transportation Equipment	1981 1986 1991	.168 .035 .129	-.061 -.085 -.148	.229 .119 .277

Table 8

Decomposition of Industry Productivity Growth

Industry/Years	Labor Productivity Growth	TFP Growth	Decomposition of TFP Growth		
			Continuing Firms	Entry vs. Exit	Market Share Reallocation
Textiles					
1981-86	.514	.165	.096	.075	-.006
1986-91	.437	.152	.091	.052	.010
Clothing					
1981-86	.157	-.032	-.023	-.009	-.000
1986-91	.352	.110	.056	.052	.002
Chemicals					
1981-86	.515	.264	.171	.093	.000
1986-91	.194	.122	.059	.057	.007
Plastics					
1981-86	.268	.120	.071	.044	.005
1986-91	.420	.118	.080	.033	.005
Basic Metals					
1981-86	.369	.121	.087	.041	-.008
1986-91	.299	.164	.127	.032	.005
Fabricated Metals					
1981-86	.266	.021	-.008	.028	.001
1986-91	.371	.083	.042	.042	-.001
Non Electrical Machinery					
1981-86	.220	.036	.027	.005	.004
1986-91	.404	.048	.028	.014	.007
Electrical Machinery					
1981-86	.368	.053	.028	.041	-.017
1986-91	.743	.293	.180	.105	.008
Transportation Equipment					
1981-86	-.047	-.133	-.074	-.048	-.011
1986-91	.468	.094	.066	.014	.014