Flexible Technology and Firm Size

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ABSTRACT. This paper provides the first empirical examination of the relationship between the application of flexible technologies and the firm-size distribution. In particular, we test the hypothesis that implementation of flexible technologies has tended to promote small firms more than large firms. Based on a sample of 36 engineering industries and using two distinct time periods between 1976 and 1986 and two different measures of what constitutes a small firm, we find that the application of certain flexible technologies, such as numerically controlled machines, has led to an increased presence of small firms, while the use of other flexible technologies, such as programmable robots, is associated with a decreased presence of small firms over time.

I. Introduction

Recent theoretical developments have demonstrated that certain characteristics of technology are decisive determinants of market structure, and in particular the size distribution of firms (Dasgupta and Stiglitz, 1980; and Dasgupta, 1986). While this literature offers no a priori prediction about which specific characteristics of technology determine market structure, Mills and Schumann (1985) suggest that the flexibility of technology is a key determinant of the size distribution of firms. In fact, throughout most of this century industrial technology favored mass production, or the application of special purpose machines to produce standardized products. Inherent in this technology is inflexibility. However, more recently manufacturing technology ". . . has been revolutionized by the cost reduction of small-scale production relative to large-scale and the degree of flexibility offered by the technology" (Carlsson, 1984, p. 91). Piore and Sabel (1984) suggest that the emergence of this new flexible technology represents, in fact, an "industrial divide" where firms and society are confronted with a choice of technological modes. In referring to the Italian example, where an increased reliance on small-scale production has resulted from underlying technological and institutional changes, Piore and Sabel (1983) argue that flexible production will tend to promote the relative viability of small firms. However, such arguments have been strongly contested.[1] Mensch (1977), for example, suggests that the new technologies will be used to rationalize the production process, and lead to the substitution of capital for labor, thus resulting in even greater economies of scale.[2] The purpose of this paper is to examine the effect which adoption of flexible technologies has had on the size distribution of firms and, in particular, on the change in the presence of small firms.

Despite the growing evidence documenting the increased importance of small firms in the economy,[3] considerable disagreement still remains regarding both the extent of the shift in the size distribution of firms, as well as the contribution of technology in serving as a catalyst. Thus, we provide the first empirical test of the Piore-Sabel (1983 and 1984) thesis that the application of flexible-production technology has tended to shift the firm-size distribution towards smaller-sized firms.

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In the second section of this paper we examine the emergence of flexible-production technology along with the evolution of small firms in the engineering industries, which have the most intensive use of machine tools in manufacturing. After developing the model in the third section, we test the hypothesis that the change in the share of sales accounted for by small firms is positively related to the application of flexible technology in the fourth section. Finally, in the last section a conclusion and summary are provided. Based on two different measurs of small firms and two distinct time periods, we find that the implementation of certain flexible technologies, such as numerically controlled machine tools, has tended to promote an increased small-firm share of sales, while the opposite is found for programmable robots. Thus, we conclude that there is substantial evidence supporting the hypothesis that at least certain flexible technologies have promoted the viability of small firms.

II. The emergence of flexible technologies and small firms

Machine tools have been an integral component determining the mode of technology used ever since the industrial revolution. Until the end of the last century a mjaor limitation of their applicability was an inadequate source of power. However, with the development of the electric motor in 1892 as a power source for individual machine tools, and with the widespread electrification throughout U.S. manufacturing at the turn of the century, this problem was alleviated. By the end of the 1920s a major new technology was introduced in the machine tool industry — the transfer machine or station-type machine (ST). Transfer machines consist of a number of smaller machines or work stations, each used for a separate operation such as drilling or milling, and organized to work together in such a fashion that a workpiece is automatically put in place at one work station and then transferred automatically to the next work station. Transfer machines were at the core of the increased reliance on mass production that emerged following the Second World War. The first large-scale application of automation was at the Ford Engine plant in Brook Park, Ohio. Ford tied together several large transfer machines into a continuous system of automatic assembly machines (AA). This system became known as "Detroit automation" or "Fordism". While the development of automation continued into the early 1970s, the most important aspect of technological progress in the last thirty years appeared in an entirely different direction — the development of numerical controls (Carlsson, 1984).

With the advent of numerical controls in the late 1940s, the potential emerged for reversing the 150-year technological trend in machine tools favoring large-sclae production. Numerically controlled (NC) machines occupy an intermediate position between transfer machines and conventional hand-operated machines. Since the 1970s there has been an increased emphasis on manufacturing larger and faster NC machines, thereby enhancing their competitiveness *vis-à-vis* transfer machines. A computerized system consisting of several numerically controlled machines, a programmable robotic material handling system (PR), a tool changing system, and a central control system comprises a flexible manufacturing system (FMS). A FMS serves the same purpose as a conventional automated production system, except that it can be more easily reprogrammed and made compatible with computer-aided design (CAD) and computer-aided manufacturing (CAM), rendering the overall system of production substantially more flexible than transfer machines. Subsequently, the cost of small-volume production of complex parts has been reduced much more than that of large-volume production of standardized products. Such systems represent an enormous advantage for small-scale production (Dosi, 1988).

According to Piore and Sabel (1984), the implementation of this new technology may result in a shift in the firm-size distribution towards an increased presence of small firms.[4] They argue that the flexible-production firm thrives on the same factors that are debilitating to firms applying mass-production technologies. Rather than trying to control the path and direction of technological change, as is customary for mass-production firms, the flexible-production firm needs to create new market niches by continuously innovating and redesigning the product to serve changing consumer tastes. By contrast, the mass-production firm modifies products and develops new processes mainly as a means for reducing costs but not as a vehicle for anticipating new demand (Piore and Sabel, 1984).[5]

In fact, small firms have accounted for an increased share of sales over time in the engineering industries — non-electrical machinery, electrical machinery, transportation equipment, and instruments — where the application of mass-production technology was historically the norm and large-scale firms tended to dominate the industry.[6] As shown in Table I, firms with fewer than 100 employees in the 36 engineering industries included in our sample accounted for 15.6 percent of total sales in 1976. This was just slightly above the average for all U.S. manufacturing industries of 14.9 percent. The share of sales accounted for by small firms in the engineering industries subsequently increased, and accounted for 22.5 percent of total sales in 1986. The increase in the presence of firms with fewer than 500 employees during this time period was even more dramatic, rising from a share of 30.1 percent of sales in 1976 to 39.7 percent of sales in 1986.[7] Of course, this increased importance of small firms in the engineering industries during the last decade cannot necessarily be attributed to the diffusion of flexible technologies.[8] a more formal statistical test is performed in the next section.

In fact, there is some evidence that a similar transformation is occurring in several other industries as well. For example, Shepherd (1982) found a substantial increase in the scope of competition within four-digit standard industrial classification (SIC) industries between 1958 and 1980, reversing the trend of decreasing competition between 1939 and 1958. Although Shepherd attributes this increase in competition largely to government policy — antitrust and deregulation — he does acknowledge that a decrease in the minimum efficient scale (MES) arising from the application of NC machines has played an important role in this transformation. Thus, while Shepherd (1982, p. 620) asserts that, "[T]he U.S. economy is now an enormous test case for the functioning of competition in a large-scale industrial economy," he is perhaps understating the source of at least some of that increase in competition, namely the diffusion of flexible manufacturing technologies, and NC machines in particular, which may be reshaping the structure of markets in manufacturing industries. Such a shift would be consistent with the thesis of Piore (1986, p. 22) that, "We have entered an era in which we are much more dependent on creative entrepreneurial activity than we were in the past. Individual firms can prosper and survive through innovation and independent initiative in the international economy. The new technology does lend itself to business strategies which move from niche to niche in the market place through continual inventiveness in product design or by attention to quality and fashion. The result is that business is less dependent upon a unified national economy or upon the disciplined role in closely coordinated production activities which mass production entails."

TABLE I
Mean share of total sales accounted for by small firms in the engineering industries (standard deviations listed in parentheses)[a]

Small-firm measure	Year 1976 (%)	1982 (%)	1984 (%)	1986 (%)
Fewer than 100 Employees	15.6 (12.7)	17.2 (13.2)	21.4 (20.2)	22.5 (20.8)
Fewer than 500 Employees	30.1 (21.7)	30.2 (19.4)	36.8 (30.6)	39.7 (33.0)

[a] See Appendix A for a list of the industries included.

III. The model

In their 1989a paper, Acs and Audretsch followed the theory posited by Dasgupta and Stiglitz (1980), among others, that specific characteristics of technology and knowledge *determine* the size distribution of firms. They found that the small-firm share of industry sales in any given period t is determined by factors representing the states of technology (T) and knowledge (K), along with the extent of what we termed structural barriers to entry (BE), so that

$$SFP_t = f(T_t, K_t, BE_t). \qquad (1)$$

Using the standard linear assumption for tractability leads to a cross-section regression model

$$SFP_1 = \beta_0 + \beta_1 T_1 + \beta_2 K_1 + \beta_3 BE_1 + \mu_1. \quad (2)$$

An implication of Dasgupta and Stiglitz's theory is that an industry firm-size distribution would remain constant over time as long as these basic underlying determinants remain invariant. That is, the small-firm presence (SFP) would not be expected to change unless there was a change in T_1, K_1, or BE_1. In such a case, the change in the industry firm-size distribution, or in our case the SFP, between periods 1 and 2 is given by

$$\begin{aligned} SFP_2 - SFP_1 = \beta_0 &+ \beta_1(T_2-T_1) \\ &+ \beta_2 (K_2-K_1) \\ &+ \beta_3(BE_2-BE_1) \\ &+ \mu_2-\mu_1. \end{aligned} \quad (3)$$

As discussed in the previous section, Piore and Sable (1983), Carlsson (1984 and 1989a), Dosi (1988) and others have argued that, in fact, technology has evolved in such a way as to shift the firm-size distribution to promote the growth of small firms relative to that of large firms. In particular, the flexible-manufacturing system and the implementation of numerically controlled machines and programmable robots represent this new technology. Although the inventions for this new technology were generally made several decades ago, the diffusion has only generally taken place within the last decade. Thus, if the technological states T_1 and T_2 are represented by the application of numerically controlled machines and programmable robots for the years 1976 and 1986, T_1 would virtually be zero, since their use was still trivial in the U.S. in 1976 (Carlsson, 1984).

To test the hypothesis that the implementation of flexible production technology has tended to reduce the inherent size disadvantage of small firms, we estimate

$$\begin{aligned} SFC = \beta_0 &+ \beta_1 SAA + \beta_2 SPR + \beta_3 SMP \\ &+ \beta_4 SST + \beta_5 SNC + \beta_6 RD/S \\ &+ \beta_7 SKILL + \beta_8 K/L + \mu, \end{aligned} \quad (4)$$

where SFC is defined as the change in the share of sales accounted for by small firms or $SFC = SFP_2 - SFP_1$. To test for robustness of results, two different time periods are used, 1982—1986, and 1976—1986. Comparing the results for these two different time periods enables us to find out whether the model varies substantially over different phases of the business cycle.[9] Similarly, two distinct measures of a small firm are used — firms with fewer than 100 employees, and firms with fewer than 500 employees. Since there is no widely accepted definition of the size boundary for small firms, using these two measures also provides a test of robustness.

The first five explanatory variables are specific measures of technologies used in the production process. The first one, SAA, represents the share (%) of the total number of machines in the industry accounted for by automatic assembly machines in 1983. The greater the extent to which a production process relies upon a highly mechanized production of commodity-like goods, the greater will be the share of total machines accounted for by assembly machines. As Table 2 shows, an average of 0.72 percent of all machines in 1983 were assembly machines. Since SAA reflects a mass-production technology, it should be negatively related to SFC.

SPR represents the share (%) of the total number of machines accounted for by programmable robots in 1983. Using programmable robots rather than mechanical devices to connect various machines to each other enhances the flexibility of numerical machine tools. However, as Table II shows, the mean share of machine tools accounted for by programmable robots in the 36 engineering industries was only considerably less than one percent. Although they were not extensively used in 1983, they may become increasingly important in the future.

The share (%) of the total number of machines accounted for by mechanical presses in 1983 is represented by SMP. As Table II shows, mechanical presses were the most prevalent type of machine used in the engineering industries, accounting for an average of 6.65 percent of all machines used. Since mechanical presses are used predominantly for mass production, β_4 is expected to be negative. SST represents the share (%) of the total number of machines accounted for by transfer or station-type machines in 1983. A transfer machine typically consists of several smaller machines or work stations. These, in turn, each have

TABLE II
Variable definitions, means and standard deviations[a]

Variable	Definition	Mean	Standard deviation
SAA	Share of total number of machines accounted for by automatic assembly machines (%), 1983	0.72	0.67
SPR	Share of total number of machines accounted for by programmable robots (%), 1983	0.07	0.06
SMP	Share of total number of machines accounted for by mechanical presses (%), 1983	6.65	6.05
SST	Share of total number of machines accounted for station-type (transfer) machines (%), 1983	0.45	0.55
SNC	Share of total number of machines accounted for by numerically controlled machine tools (%), 1983	3.64	2.34
K/L	Capital-labor ratio, defined as total capital stock divided by total employment (thousands of dollars), 1977	13.00	10.37
RD/S	Total R&D expenditures divided by sales, 1982	0.04	0.06
SKILL	The share of total employment accounted for by non-production employees, 1982	0.34	0.11
SF18286	Change in share of sales (%) accounted for by firms with fewer than 100 employees, 1982—1986	5.34	15.52
SF17684	Change in share of sales (%) accounted for by firms with fewer than 100 employees, 1976—1984	5.81	14.82
SF17686	Change in share of sales (%) accounted for by firms with fewer than 100 employees, 1976—1986	6.93	16.34
SF28286	Change in share of sales (%) accounted for by firms with fewer than 500 employees, 1982—1986	9.50	27.01
SF27684	Change in share of sales (%) accounted for by firms with fewer than 500 employees, 1976—1984	6.71	28.50
SF27686	Change in share of sales (%) accounted for by firms with fewer than 500 employees, 1976—1986	9.68	33.43

[a] Based on the sample of 36 observations (see Appendix A).

their own specific function, such as drilling or milling, but are organized and connected via mechanical materials handling devices. The transfer machine, therefore, represents the most extensive use of mass-production technology. As shown in Table II, and average of less than one percent of all machine tools in the engineering industries consisted of transfer machines. Since transfer machines are related to the extent of mass production, SST is expected to exert a negative effect on the expansion of the share of sales accounted for by small firms.

The share (%) of the total number of machines accounted for by numerically controlled machine tools is represented by SNC. Table II shows that in 1983 machine tools accounted for an average of 3.64 percent of the total number of machine tools in the engineering industries. As described in the previous section, the application of numerically controlled machine tools is conducive to flexible production, and therefore batch production and short production runs. It is hypothesized that the application of numerically controlled machine tools should promote the relative expansion of small firms, and therefore a positive relationship between SNC and SFC is expected.

It should be recognized that these five different types of machine tools cannot at all be considered to be homogeneous. That is, one AA is not the equivalent of one PR or one MP. Rather, these are very heterogeneous measures which cannot be readily compared to determine which type of machine tool is most prevalent in any given industry. The usefulness of these measures is only in comparing the application of any given type of machine tool across different industries.

To represent changes in knowledge in the industry, the 1982 R&D/sales ratio (RD/S) and a measure of skilled labor (SKILL), defined as the share of total employment accounted for by non-production employees in 1982, are included as explanatory variables. However, these two variables may affect the relative small-firm growth differently. While industries in which the evolution of kowledge has been more dependent upon R&D have tended to present a barrier for the viability of small firms (Acs and Audretsch, 1989b), Winter (1984) has argued that smaller firms are more likely to prosper in industries in which the evolution of knowledge emanates more from skilled labor and high levels of human capital. We found support for Winter's hypothesis that small-firm innovation emantates from a different technological regime than does large-firm innovation (Acs and Audretsch, 1987 and 1988). In particular, we found that in industries where skilled labor plays a relatively important role small firms tend to have the innovative advantage. In such industries the evolutionof knowledge is more likely to emanate from high levels of human capital, resulting in a firm-size distribution more favorable to small firms.

White (1982) and Acs and Audretsch (1989a) have both determined that the presence of small firms is impeded in industries which are high in capital intensity. In such industries the barriers to entry and expansion facing small firms may be too great to afford anything other than a nominal role for small firms. To control for such barriers, we included the capital-labor ratio (K/L), defined as the total capital stock divided by total employment (thousands of dollars). K/L is expeced to exert a negative effect on the change in the share of sales accounted for by small firms (relative small-firm growth) over any given period of time, since a high level of capital intensity represents industries in which there exist substantial barriers to small-firm entry and expansion. It should be noted that Equation 3 implies that the change in the capital-labor ratio between the two periods would be more appropriate that the level of capital intensity in one year in estimating the change in the small-firm presence. In fact, the capital-labor ratio has not significantly changed in most industries over this period. Thus, the observed changes in relative small-firm growth cannot be attributable to changes in capital intensity during the relevant period. We include K/L as an explanatory variable only to test whether, for a given application of numerically controlled machines or programmable robots in an industry, capital-intensity exerts a negative influence on small-firm relative growth. However, the implication from Equation 3 is that while capital-intensity may determine the share of sales accounted for by small firms in a single year, only changes in K/L should be related to changes in the small-firm presence over time. Finally, μ represents stochastic disturbance. (Further explanations and data sources are avaialble from the authors.)

It should be recognized that while SAA, SMP, and SST are types of technology generally associated with mass production, they are not at all interchangeable measures. That is, as Table III shows, the correlation between SAA and SST is virtually zero, while that between SMP and SST is actually negative (−0.10). These measures clearly represent distinct types of technologies associated with mass production which are not necessarily used in conjunction with each other. For example, mechanical presses are typically used in metal-forming industries, while transfer machines tend to be used in metal-cutting industries. Similarly, although they both measure the extent of flexible production, SNC and SPR should not be considered to be substitute measures of the same phe-

TABLE III
Correlation matrix for production process variables

	SNC	SPR	SST	SAA	SMP
SNC	1.00	–	–	–	–
SPR	0.27	1.00	–	–	–
SST	−0.04	0.11	1.00	–	–
SAA	−0.38	0.25	−0.01	1.00	–
SMP	−0.59	−0.16	−0.10	0.37	1.00

nomenon. As the low correlation of 0.27 between SNC and SPR indicates, numerically controlled machine tools and programmable robots are clearly two very distinct types of technology, which have not been applied consistently across the engineering industries.

IV. Empirical results

Using the 36 engineering industries, the regression model was estimated for the dependent variable defined as the change in the share of sales accounted for by firms with fewer than 100 employees between 1982 and 1986 (SF18286), and the results are shown in Table IV, Some, but not all of the production process variables are significantly related to the change in the small-firm presence over this period. As expected, the relative presence of small firms has tended to increase in industries with a relatively extensive application of numerically controlled machine tools (SNC). Small firms have been less successful in industries in which transfer machines play an important role, as indicated by the negative coefficient of SST. The other two measures of mass-production technology, SAA and SMP, are both statistically insignificant, suggesting that the relative presence of small firms has remained stable in industries where these technologies are important. The negative coefficient of SPR implies that the application of programmable robots tends to reduce the share of sales accounted for by small firms. The coefficients are both negative for capital-intensity (K/L) and the R&D-sales ratio (RD/S), although only the coefficient of RD/S can be considered to be statistically significant. This is consistent with the

TABLE IV
Regression results for change in share of sales accounted for by small firms, 1982—1986 (standard errors listed in parentheses)[a]

	(1) OLS	(2) OLS	(3) OLS	(4) LOGIT	(5) LOGIT
SAA	−0.440	—	—	−0.009	—
	(0.426)			(0.009)	
SPR	−7.333	−8.474	—	−0.154	−0.193
	(4.482)[b]	(4.875)[c]		(0.096)[b]	(0.088)[c]
SMP	0.030	1.680	—	0.010	−0.030
	(5.230)	(5.300)		(0.110)	(0.110)
SST	−0.785	−0.828	−0.758	−0.016	−0.016
	(0.463)[b]	(0.492)[b]	(0.443)[c]	(0.010)[b]	(0.010)[b]
SNC	0.220	0.279	0.281	0.005	0.006
	(0.140)[b]	(0.147)[c]	(0.111)[c]	(0.003)[b]	(0.003)[c]
K/L	−0.063	−0.011	−0.036	−0.002	−0.001
	(0.247)	(0.250)	(0.233)	(0.005)	(0.005)
RD/S	−85.952	−75.332	−86.049	−1.834	−1.862
	(42.193)[c]	(59.189)	(41.290)[c]	(0.906)[c]	(0.906)[c]
SKILL	—	−14.302	—	—	—
		(48.743)			
Intercept	13.437	14.006	8.945	0.279	0.271
	(8.716)[b]	(14.705)	(5.721)[b]	(0.187)	(0.177)
R^2	0.370	0.342	0.340	0.354	0.33
F	2.230[c]	2.083[b]	3.076[c]	2.194[b]	2.39[c]

[a] A small firm is defined as a firm with fewer than 100 employees. The coefficients and standard errors of SMP have been multiplied by 100 for presentation purposes.
[b] Statistically significant at the 90 percent level of confidence, one-tailed test.
[c] Statistically significant at the 95 percent level of confidence, one-tailed test.

previous findings in other studies that these are entry barriers which tend to impede the existence and entry of small firms.

Including the skill measure in Equation 2 results in statistically insignificant coefficients for both RD/S and SKILL. As the simple correlation of 0.74 between RD/S and SKILL reflects, this is most likely the result of multicollinearity. Thus, in the remaining regressions in Table IV, only RD/S is retained. In Equation 3 APR and SMP are omitted. SNC continues to exert a positive influence, and SST a negative influence on the change in the small-firm presence. The F-ratio is the greatest in Equation 3 where only one measure of flexible production (SNC) and one measure of mass-production technology (SST) is included in the model.

One statistical concern with the estimation is that the dependent variable, the difference between the share of sales accounted for by small firms in 1986 and 1982, is by definition bounded by 100 and −100. Judge *et al.* (1980) note that under such conditions ordinary least squares estimation could produce inefficient variances of the estimated coefficients and therefore unreliable t-statistics, rendering the necessary hypothesis tests also unreliable. By first transforming the dependent variable to vary between zero and one,[10] we then correct for this potential inefficiency by using a logit transformation, where the transformed dependent variable (SFC*) is again transformed from SFC* to ln (SFC*/1-SFC*)). As shown in Equations 4 and 5, the logit transformation has virtually no effect on the results. In terms of coefficient signs and significance, the results yielded in Equation 4 are identical to those in Equation 1. In fact, the results were identicall regardless of whether the OLS or logit method of estimation was used for all of the equations in Table IV.

It is possible that the inferences made from Table IV are sensitive to both the small-firm measure and the time period used. To provide a sensitivity analysis, both the small-firm measure and the time period vary in Table V.[11] In the first two equations the small-firm measure remains as enterprises with fewer than 100 employees, but an alternative time period for the change in the relative small-firm presence is used. In Equation 1 the time period 1982 to 1986 is again used for comparison, and in Equation 2 the time period is for 1976 to 1986. For both of these time periods SNC is positively related and SST, SPR, and RD/S negatively related to the change in the relative small-firm presence.

An alternative measure of small firms, enterprises with fewer than 500 employees is substituted and compared for both time periods in Equations 3 and 4. Although the results are generally the same as for the first measure of small firms, SNC appears to have had a greater impact on firms with fewer than 100 employees than on firms with between 100 and 499 employees. Not only are the t-ratios of the coefficient of SNC considerably smaller in Equations 3 and 4, but in the last equation it cannot even be considered to be statistically significant. Similarly, the coefficients for SST are significantly negative in Equations 1 and 2, whereas they are insignificant (although still negative) in Equations 3 and 4. This would suggest that the implementation of transfer machines tends to inhibit the relative expansion of small firms. However, in general the results appear to be remarkably robust with respect to the time period and the measure of small firms used.

The results from Table IV and V clearly indicate that the type of technology used in an industry is related to changes in the firm-size distribution. In particular it appears that while the application of certain flexible technologies, such as numerically controlled machines, has tended to be a catalyst for the presence of small firms, other types of flexible technologies such as programmable robots may tend to inhibit small firms. The observed negative relationship between SPR and the change in the small-firm presence may reflect the relatively high cost of programmable robots (exceeding $100,000), which perhaps has tended to restrict their use to larger firms.

What Tables IV and V do not reveal is whether the tendency for numerically controlled machines to promote and programmable robots to hinder the viability of small firms is a relatively recent or established phenomenon. To examine this issue, we consider the relationship between the production process variables and the static small-firm share of sales (rather than change in the share of sales over time as in Table IV and V). If, for example, the positive influence of NC machines on small firms is a fairly established phenomenon,

TABLE V
Regression results for change in sales for varying definition of small firms and over alternative periods
(standard errors listed in parentheses)

	Definition of small firm			
	Fewer than 100 employees		Fewer than 500 employees	
	(1) 1982–1986	(2) 1976–1986	(3) 1982–1986	(4) 1976–1986
SPR	−9.217	−10.768	−17.539	−20.368
	(4.099)[b]	(4.376)[b]	(7.501)[b]	(9.065)[b]
SMP	−0.013	−0.026	−0.011	−0.033
	(0.051)	(0.054)	(0.093)	(0.112)
SST	−0.786	−0.708	−0.916	−0.718
	(0.463)[a]	(0.495)[b]	(0.848)	(1.024)
SNC	0.262	0.214	0.355	0.302
	(0.134)[b]	(0.143)[a]	(0.245)[a]	(0.296)
K/L	−0.210	0.007	−0.171	−0.047
	(0.244)	(0.261)	(0.447)	(0.540)
RD/S	−87.296	−84.743	−119.950	−224.730
	(42.222)[b]	(45.077)[b]	(77.261)[a]	(93.374)[b]
Intercept	10.458	15.079	20.795	27.926
	(8.234)	(8.791)[b]	(15.067)[a]	(18.210)[a]
R^2	0.340	0.322	0.271	0.305
F	2.495[b]	2.300[b]	1.800	2.123[a]

[a] Statistically significant at the 90 percent level of confidence, one-tailed test.
[b] Statistically significant at the 95 percent level of confidence, one-tailed test.

SNC would be expected to be positively associated with the small-firm share of sales, at least for recent years. However, if the phenomenon is a more recent development, it is conceivable that no relationship can be found between SNC and the small-firm share of sales, despite the existence of a positive relationship between SNC and the change in the small-firm share of sales over time. We expect this latter case to be true because the application of NC machines only became substantial in the U.S. in the later 1970s (Carlsson, 1989a).

White (1982) and Acs and Audretsch (1989b) have found that the static presence of small firms is largely determined by capital-intensity, the extent of skilled labor, R&D-intensity, the degree of concentration, and the extent to which the industry is unionized. Thus, in estimating the small-firm share of sales in any given year, we include the four-firm concentration ratio (CR) and the percentage of employees in the industry belonging to a union in 1985 (UNION) in the basic model given in Equation 1.[12] Since the small-firm share of total industry sales varies between zero and 100 by definition, the logit transformation procedure explained above is utilized. Table VI lists the regression results for the share of sales accounted for by small firms, using both two different measures of a small firm and two different time periods.[13] As found by Acs and Audretsch (1989a) and White (1982), K/L, CR, SKILL, UNION, and RD/S are all negatively related to the static small-firm presence, regardless of the small-firm measure or time period used. Most interesting is that SNC has no statistical relationship to the presence of small firms in any given year. In fact, of the production process variables, only SAA has an influence (negative) on the small-firm presence. Thus, these results imply that the implementation of numerically controlled machine tools is not related to the extent to which

TABLE VI
Regression results for share of sales accounted for by small firms, 1984 and 1986 (standard errors listed in parentheses)[a]

	Definition of small firm					
	Fewer than 100 employees				Fewer than 500 employees	
	(1) 1984	(2) 1984	(3) 1986	(4) 1986	(5) 1984	(6) 1984
SAA	–	−0.066 (0.034)[c]	–	−0.074 (0.028)[c]	–	−0.036 (0.031)
SPR	−0.374 (0.362)	–	−0.394 (0.333)	–	−0.516 (0.421)	–
SST	0.043 (0.042)	–	0.028 (0.039)	–	0.017 (0.038)	–
SMP	0.210 (0.430)	0.160 (0.450)	0.120 (0.400)	0.180 (0.360)	−0.020 (0.380)	−0.100 (0.410)
SNC	0.013 (0.011)	0.002 (0.011)	0.003 (0.010)	−0.006 (0.009)	−0.003 (0.010)	−0.008 (0.010)
K/L	−0.020 (0.019)	−0.035 (0.021)[c]	−0.012 (0.017)	−0.030 (0.017)[c]	−0.008 (0.017)	−0.023 (0.019)
CR	−0.060 (0.016)[c]	–	−0.048 (0.015)[c]	–	−0.047 (0.014)[c]	–
SKILL	−4.631 (2.883)	–	−5.074 (2.656)[c]	–	−2.889 (2.555)	–
UNION	−0.025 (0.010)[c]	−0.047 (0.010)[c]	−0.017 (0.010)[c]	−0.036 (0.008)[c]	−0.019 (0.009)[c]	−0.035 (0.009)[c]
RD/S	–	−14.648 (3.541)[c]	–	−14.711 (2.875)[c]	–	−12.007 (3.220)[c]
Intercept	3.256 (1.004)[c]	1.647 (0.859)[c]	2.890 (0.925)[c]	1.454 (0.698)[c]	3.314 (0.890)[c]	1.907 (0.782)[c]
R^2	0.700	0.601	0.675	0.664	0.675	0.544
F	7.885[c]	7.280[c]	7.013[c]	9.550[c]	7.006[c]	5.776[c]

[a] All regressions are estimated using the logit estimation procedure. The coefficients and standard errors of SMP have been multiplied by 100 for presentation purposes.
[b] Statistically significant at the 90 percent level of confidence, one-tailed test.
[c] Statistically significant at the 95 percent level of confidence, one-tailed test.

small firms currently exist, but rather to the extent to which they are expanding relative to large firms. This would suggest that the relationship between the application of numerically controlled machine tools and the shift in the size distribution of firms is a very recent phenomenon.[14]

V. Conclusion

In this paper we have examined how the application of flexible technology has affected the size distribution of firms and, in particular, the change in the presence of small firms. We find that the implementation of numerically controlled machine tools is related to an increased relative presence of small firms over time, while the application of programmable robots is related to a decrease in the share of total industry sales accounted for by small firms. These results would suggest that the exact effect of these new flexible technologies on the firm-size distribution may be, in fact, particular to the specific type of technology used. Not surprisingly, certain measures of mass-production technology, such as the share of the total number of machines accounted for by transfer machines, are negatively related to the change in small-firm presence. These results proved to be quite robust using two different measures of what constitutes a small firm and two different time periods representing different stages of the business cycle.

One important qualification of the results is that the type of technology used in an industry may, in fact, be the result and not just the determinant of the firm-size distribution. This would suggest that the observed positive statistical relationship between the application of numerically controlled machie tools and the change in the small-firm presence could reflect the tendency for small firms, once established in an industry, to select certain flexible technologies and refrain from using mass-production technologies. While an important extension of our findings would be to incorporate technological choice and firm size into a simultaneous model, the simple correlation coefficients of −0.15 between the share of sales accounted for by small-firms (less than 100 employees) in 1976 and the share of the total number of machines accounted for by numerically controlled machine tools in 1983 does not suggest that such machines tended to be used where small firms were particularly prevalent.[15] Rather, as the regression results indicate, in industries in which numerically controlled machines are extensively used, small firms have accounted for an increased share of subsequent sales in the market.

Notes

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[1] For an example see Solo (1985).

[2] For a review of this literature see Campbell (1988), Dosi (1988, pp. 1153—1155), and Carlsson (1989b).

[3] Acs and Audretsch (1987 and 1988), Beasley and Hamilton (1984), Evans (1987), Caves and Pugel (1980), Shepherd (1982), Brock and Evans (1989).

[4] Piore and Sabel (1984) provide a detailed analysis of why the "mass-production system" of production deteriorated in the 1970s in Chapter 7. For a test of the relationship between flexible manufacturing and economic performance at the macro level see Carlsson (1987).

[5] Recent empirical evidence suggests that small firms are as innovative as large firms (Acs and Audretsch, 1987 and 1988).

[6] The entire sample of engineering industries included in our analysis and the method of classifying the industries is available from the authors.

[7] Small firms have always existed in the mass-production system. However, they existed in an environment that was characterized by less technological sophistication. the small firms used more general purpose machinery and craft workers — flexible technologies — that would allow them to respond quickly to changes in demand (Mills and Schumann, 1985, and Piore, 1980).

[8] According to some, changes in demand and given changes in technology can lead to biased adoption of FMS, quite possibly more by the large firms, who are trying to lessen their flexibility disadvantages *vis à vis* small firms, than by the small firms (including entrants), who may be too small to bit off the new technologies. However, according to a recent study, investment in NC machines by small firms had been successfully implemented (Dodgson, 1985).

[9] Highfield and Smiley (1987) found that new business starts in the U.S. vary considerably over the business cycle. Since most new starts tend to be small firms, our model could be sensitive to the period used. Thus, we apply these two different periods.

[10] To vary between zero and one, the dependent variable was transformed according to $SFC^* = (SFC + 100)/200$.

[11] Since the OLS and logit results are identical for all equations in Table IV, only the OLS equations are reported since they are easier to interpret intuitively.

[12] For a developed theory on the determinants of the presence of small firms see Acs and Audretsch (1989).

[13] Regressions for 1982 were also estimated and yielded virtually the identical results as in Table V. They are not included for space considerations.

[14] These results are consistent with the findings of Carlsson (1989).

[15] In fact, the negative correlation between the presence of small firms and SNC is even stronger (−0.220) when the 1982 share of sales accounted for by firms with fewer than 100 employees is used. Similarly there is a correlation of −0.124 between SNC and the share of sales accounted for by firms with fewer than 500 employees in 1976 and a correlation of −0.324 for this small-firm share of sales in 1982.

References

Acs, Zoltan J. and David B. Audretsch, 1987, 'Innovation, Market Structure, and Firm size', *Review of Economics and Statistics* **69**, 567—575.

Acs, Zoltan J. and David B. Audretsch, 1988, 'Innovation in Large and Small Firms: An Empirical Analysis', *American Economic Review* **78**, 678—690.

Acs, Zoltan J. and David B. Audretsch, 1989a, 'Entrepreneurial Strategy and the Presence of Small Firms', *Small Business Economics* **1**(3), 193—214.

Acs, Zoltan J. and David B. Audretsch, 1989b, 'Small-Firm Entry in U.S. Manufacturing', *Economica* **55**, 225—256.

Brock, William A. and David S. Evans, 1989, 'Small Business Economics', *Small Business Economics* **1**(1), 7—21

Campbell, Duncan C., 1988, 'Technology, Flexibility of Manufacturing, and Industrial Relations: A Cross-National Review of Literature', Wharton School, Industrial Research Unit, University of Pennsylvania, Philadelphia.

Carlsson, Bo, 1984, 'The Development and Use of Machine Tools in Historical Perspective', *Journal of Economic Behavior and Organization* **5**, 91—114.

Carlsson, Bo. 1987, 'Manufacturing Technology and U.S. Trade Performance', paper presented at the European Association for Research in Industrial Economics (EARIE) Conference, Madrid.

Carlsson, Bo, 1989a, 'The Evolution of Manufacturing Technology and Its Impact on Industrial Structure: An International Study', *Small Business Economics* **1**, 21—38.

Carlsson, Bo, 1989b, 'Flexibility in the Theory of the Firm', *International Journal of Industrial Organization* 7(2), 179—204.

Dasgupta, Partha, 1986, 'The Theory of Technological Competition', in J. E. Stiglitz and G. F. Mathewson (eds.), *New Developments in the Analysis of Market Structure*, Cambridge, MA: The MIT Press.

Dasgupta, Partha and Joseph Stiglitz, 1980, 'Industrial Structure and the Nature of Innovative Activity', *The Economic Journal* **80**, 266—293.

Dodgson, Mark, 1985, *Advanced Manufacturing Technology in the Small Firm*, London: The Technology Change Center.

Dosi, Giovanni, 1988, 'Sources, Procedures, and Microeconomic Effects of Innovation', *Journal of Economic Literature* **XXVI**, 1120—1171.

Evans, David, 1987, 'Tests of Alternative Theories of Firm Growth', *Journal of Political Economy* **95**, 657—674.

Highfield, Richard and Robert Smiley, 1987, 'New Business Starts and Economic Activity: An Empirical Investigation', *International Journal of Industrial Organization* **5**, 51—66.

Judge, George G., E. Griffiths, R. Carter-Hill and Tsoung-Chao-Lee, 1980, *The Theory and Practice of Econometrics*, New York: John Wiley & Sons.

Mensch, Gerhard, 1979, *Stalemate in Technology*, Cambridge, MA: Ballinger.

Mills, David E. and Laurence Schumann, 1985, 'Industry Structure with Fluctuating Demand', *American Economic review* **75**, 758—767.

Piore, Michael J., 1980, 'Technological Foundations of Dualism and Discontinuity', in Suzanne Berger and Michael J. Piore (eds.), *Dualism and Discontinuity in Industrial Societies*, Cambridge, MA: Cambridge University Press.

Piore, Michael J., 1986, 'The Decline of Mass Production and Union Survival in the USA', *Industrial Relations Journal* **17**, 207—213.

Piore, Michael J. and Charles F. Sabel, 1983, 'Italian Small Business Development: Lessons for U.S. Industrial Policy', in John Zysman and Laura Tyson (eds.), *American Industry in International Competition*, Ithaca, NY: Cornell University.

Piore, Michael J. and Charles F. Sabel, 1984, *The Second Industrial Divide: Possibilities for Prosperity*, New York: Basic Books.

Shepherd, William G., 1982, 'Causes of Increased Competition in the U.S. Economy, 1939—1980', *Review of Economics and Statistics* **64**, 613—626.

Solo, Robert, 1985, 'Across the Industrial Divide: A Review Article', *Journal of Economic Issues* **19**, 829—837.

White, Lawrence J., 1982, 'The Determinants of the Relative Importance of Small Business', *Review of Economics and Statistics* **64**, 42—49.

Appendix A
Industries included in the sample

SIC Code	Industry
3410	Metal cans and shipping containers
3420	Cutlery, hand tools, and hardware
3430	Plumbing and heating
3440	Fabricated structural metal products
3450	Screw machine products
3462	Iron and steel forgings
3480	Ordnance and accessories, nec
3510	Engines and turbines
3520	Farm and garden machinery
3530	Construction machinery
3531	Construction machinery
3540	Machine tools
3541	Other metalworking machinery
3552	Special industry machinery and miscellaneous machinery
3560	General industrial machinery
3570	Office and computer machines
3580	Refrigeration and service machinery
3610	Electric distributing equipment
3620	Electrical industrial apparatus
3630	Household appliances
3640	Electrical lighting and wiring equipment
3650	Radio and television receiving equipment
3660	Communication equipment
3670	Electronic components and accessories
3690	Miscellaneous elelctrical equipment and supplies
3710	Motor vehicles and supplies
3720	Aircraft
3721	Aircraft parts
3730	Ship and boat building and repairing
3743	Railroad equipment
3752	Miscellaneous transportation equipment
3760	Guided missiles and space vehicles
3811	Engineering and scientific instruments and measuring devices
3832	Optical instruments and lenses
3840	Medical instruments and supplies
3861	Photographic equipment and supplies
3873	Watches, clocks, and watchcases

Appendix B
Data sources and further explanations

Industry classification

All industries are 3-digit industries according to the standard industrial classificastion (SIC) in SIC sectors 34—38, except

a) SIC 347 (metal services, nec) was excluded since the relevant data could not be obtained.
b) SIC 346 (metal forgings and stampings) and SIC 349 (miscellaneous fabricated metal products) were aggregated into a single industry.
c) SIC 355 (special industrial machinery) and SIC 359 (miscellaneous machiner, except electrical) were aggregated into a single industry.
d) SIC 3751 (motorcycles, bicycles and parts) and SIC 379 (miscellaneous transportation equipment) were aggregated into a single industry.
e) SIC 3811 (engineering and scientific equipment) and SIC 382 (measuring and controlling devices) were aggregated into a single industry.
f) SIC 3832 (optical instruments and lenses) and SIC 3851 (ophthalmic goods) were aggregated into a single industry.
g) SIC 353 (construction and related machinery) was disaggregated into 3530 (construction and related machinery) and 3531 (materials handling machinery and equipment).
h) SIC 354 (metalworking machinery) was disaggregated into 3540 (machine tools) and 3541 (other metalworking machinery, equipment, and accessories).
i) SIC 372 (aircraft and parts) was disaggregated into 3720 (complete aircraft) and 3721 (aircraft engines and parts).

Small-firm and large-firm sales

The sales data by firm size, enabling construction of SF18286, SF17684, SF17686, SF28286, SF27684, SF27686, along with the measures of the small-firm presence used in Table VI are from the U.S. Small Business Administration, Office of Advocacy, Small Business Data Base. Since 1979, the U.S. Small Business Administration has maintained a major microdatabase. The U.S. Enterprise and Establishment Microdata (USEEM) and (USELM) files are a biannual data base which are derived from the DUNS Market Identifier (DMI) file leased from the Dun and Bradstreet Corporation. More detailed description of the data base can be found in Richard Boden and Bruce D. Phillips, "Uses and Limitations of USEEM/USELM Data," Office of Advocacy, U.S. Small Business Administration, Washington, D.C., November 1985.

Production process data

The machinery data used in this paper were obtained from American Machinist, *13th American Machinist Inventory Market Potentials Report* (New York: McGraw-Hill, 1983).

The data for this inventory were gathered by questionnaire from metalworking plants in the 48 contiguous States during the period February to June 1983. Estimation of the numbert of machine tools and related equipment has been based on this survey. The universe of the inventory is the following industries:

SIC 25	Furniture and Fixtures (metal only)
SIC 33	Primary Metals (metalworking only)
SIC 34	Fabricated Metal Products
SIC 35	Machinery (except electrical)
SIC 36	Electrical Machinery
SIC 37	Transportation Equipment
SIC 38	Precision Instruments
SIC 39	Miscellaneous Metal Products.

The AM Inventory covers data in four categories:

1. Number of units of equipment by 173 types.
2. Age of equipment in four categories.
3. Distribution of equipment within 24 geographic areas.
4. Distribution of equipment into four plant-size groups.

The data were obtained for the 3-digit SIC level (except construction and handling machinery, metalworking machinery, aircraft and parts, and motor vehicles and parts; these industries were divided into two groups each). Numerically controlled (NC) machine tools, programmable robots, station-type machines, automatic assembly machines, mechanical presses, and total machinery figures were calculated from the AM Inventory Market Potentials Report for SIC industries 34—38. For more information about this inventory and details of the research method, see the summary of the report published in *American Machinest*, Vol. 127, No. 11 (November 1983), pp. 113—144.

Industry characteristics

The R&D-sales ratio (RD/S) comes from National Science Board, *science Indicators: The 1985 Report* (Washington, D.C.: U.S. Government Printing Office, 1985).

The 1977 capital-labor ratio (K/L) and four-firm concentration ratio (CR) come from the U.S. Department of Commerce, Bureau of the Census, Annual Survey of Manufactures, 1977, *Industry Profiles* (Washington, D.C.: U.S. Government Printing Office, 1981). The measure of skilled labor (SKILL) comes from the 1983 *U.S. Statistical Abstract.* The union participation rates (UNION) are from Richard B. Freeman and James L. Medoff, "New Estimates of Private Sector Unionism in the United states," *Industrial and Labor Relations Review*, January 1979, 32, 143—174.