A note on the diffusion of flexible manufacturing systems technology

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Link, Albert N., and Kapur, Puneet. "A Note on the Diffusion of FMS Technology," *Economics Letters*, 1994, 46(4): 369-374. https://doi.org/10.1016/0165-1765(94)90157-0

Abstract:

This paper examines the pattern of diffusion of flexible manufacturing systems (FMS) technology across firms in the U.S. tooling and machining industry. Evidence is presented regarding the importance of compatibility standards in determining the timing of adoptions of FMS technology.

Keywords: tooling and machining | flexible manufacturing systems (FMS) | compatibility standards

Article:

1. Introduction

Innovation has long been recognized for providing benefits to society far beyond those that accrue to any particular participant in the private sector. However, for those benefits to be realized, innovations embodied in new technology must be adopted and utilized in a timely manner. U.S. firms have been much slower than their world counterparts in adopting and utilizing new technology, especially technology that was developed domestically.

Myriad firm-related explanations (e.g. short-sighted management practices, waning profit margins) for this phenomenon have been set forth in the economics, management, and policy literatures.[1] Surprisingly, however, these studies have systematically ignored the economic environment surrounding the technology, and how that environment affects the adoption and utilization of new technology. The environmental factor considered herein relates to compatibility standards.

The purpose of this paper is to examine the pattern of diffusion of flexible manufacturing systems (FMS) technology across firms in the U.S. tooling and machining industry, and to relate this pattern to the historic promulgation of relevant compatibility or interface standards.[2]

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[1] Excellent reviews of the diffusion and adoption of new technology literature are in Stoneman (1983), Baldwin and Scott (1987), Davies (1979), Nooteboom (1993), and Preece (1989).

[2] A flexible manufacturing system (FMS) is a computer-controlled grouping of work stations and material-handling devices designed to adapt automatically to design, model, or style changes. See U.S. Department of Commerce, International Trade Administration (1985). For a brief history of the concept of an FMS, see Luggen (1991).

2. The diffusion of FMS technology in the tooling and machining industry

The U.S. tooling and machining industry is comprised of relatively small companies.[3] Of the 28,862 enterprises in Standard Industrial Classifications (SICs) 3544 and 3594, 65.8% had less than 10 employees in 1987; 18.6% had 10-19, 11.9% had 20-49, 2.8% had 50-99, 0.8% had 100-249, and 0.1 % had 250 or more employees.[4] Although these enterprises are small, their output is at the core of the U.S. industrial economy because of its relationship to fundamental aspects of manufacturing. In addition, this industry merits investigation because of the potential application of elements of FMS technology to alleviate financial and competitive pressures and to assist enterprises to adjust to a decreasing supply of highly skilled labor.[5]

To obtain a sample of tooling and machining enterprises from which to gather data on the adoption of FMS technology, a mail survey was sent to 300 of the approximately 3000 members of the National Tooling and Machining Association (NTMA). These 300 members were selected with the assistance of the NTMA so as to obtain a sample that was representative of the size distribution of its membership. One hundred and forty-one enterprises completed the mail survey and/ or follow-up telephone interview.[6] The size distribution of this sub-sample of 141 enterprises follows a similar pattern as that of the population of 28,862. Sixty-one percent of the sample had less than 10 employees in 1987; 19.8% had 10-19, 12.8% had 20-49, 4.3% had 50-99, 1.4% had 100-249, and 0.7% had 250 or more employees.

The relevant test statistic to compare the size distribution of the population, as defined by SICs 3544 and 3594, with the size distribution of the sample is $\Sigma_k\{(N_k n/N - n_k)^2/N_k n/N\} \sim \chi^2_{k-1}$, for *N* referring to the population, *n* to the sample, and *k* indexing each of the six size groups. The value of the test statistic is 7.68, which falls within the 0.95 acceptance region.

Each of the sample enterprises was asked the year it first adopted an element of an FMS. In all cases the first element adopted was a numerically-controlled (NC) and/or computer numerically-controlled (CNC) machine tool. Table 1 shows the cumulative number of adopters (*m*) of a NC and/or CNC machine tool as a percent of the total sample of potential adopters (n = 141).

To quantify the speed of adoption of this technology over time, a logistic diffusion model was estimated, and the regression results are:[7]

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[3] Tooling (SIC 3544) includes establishments that produce special tools and fixtures used with machine tools, hammers, die-casting machines, and presses. Machining (SIC 35995 within SIC 3599) includes machine shops doing contracted work for others.
[4] See U.S. Department of Commerce, Bureau of the Census (1987, pp. 35C-20 and 35H-13).
[5] See U.S. Department of Commerce, International Trade Administration (1985).
[6] Complete documentation of the sample selection process and process of re-interviewing enterprises to ensure representativeness is available upon request from the authors.
[7] The results presented in Eq. (1) are not based on weighted observations in the tradition of Berkson (1953). While Griliches' (1957) study was also not based on weighted observations, the studies by Mansfield (1961, 1963) and others have been. Criticisms of Mansfield's general methodology are in Stoneman (1983), Davies (1979), and Thirtle and Ruttan (1987). Eq. (1) herein should be viewed only as a descriptive model of industry diffusion. that is as a means to represent the extent to which the diffusion of FMS technology has followed a logistic or S-shaped pattern over time. An alternative approach, which was beyond the intended purpose of this paper, would be to develop an economic model of technology adoption, that is to model the binary choice problem of whether to adopt FMS

$$\log\{m/(n-m)\}_t = -394.60 + 0.198\, year\ ,$$
$$(-26.75)(26.63)$$

$R^2 = 0.978$,
t-statistics in parentheses (1)

This estimated diffusion coefficient, which is an instantaneous rate of growth parameter, implies that FMS technology has diffused throughout the tooling and machining industry at the annual rate of 21. 9%. Others have reported similar diffusion rates for related technologies.[8]

Table 1. Cumulative adoption of FMS technology over time

Year	*m/n*
1968	0.014
1969	0.021
1970	0.021
1971	0.021
1972	0.021
1973	0.043
1974	0.043
1975	0.043
1976	0.050
1977	0.071
1978	0.085
1979	0.092
1980	0.106
1981	0.113
1982	0.142
1983	0.156
1984	0.255
1985	0.305
1986	0.348
1987	0.390
1988	0.440
1989	0.504
1990	0.546

3. Interface standards and the diffusion of FMS technology

An inspection of the data in Table 1 suggests that the proportion of the sample of enterprises that adopted a NC and/ or CNC machine tool increased noticeably after 1983. Seventy-seven of the 141 enterprises adopted FMS technology between 1968 and 1990; 55 adopted it after 1983. In fact, there were 14 adopters in 1984, the largest number of adopters for any one year. Not by

technology and if so, when. In that context, which is somewhat similar to the Mansfield approach, the resulting dependent variable would be the individual firm's probability of adoption. If, as is common with such data, one aggregates and transforms the dependent variable to the log-odds of adopting, then the economic model could be estimated using weighted least squares, with the weights being the inverse of $nP(1-P)$. where n is the number of individual decisions associated with each observation and P the proportion of decisions to adopt per time period.

[8] See, for example, Globerman (1975) and Romeo (1975).

coincidence, all nine of the critical compatibility standards related to numerical controls had been promulgated by 1984.

Compatibility standards define the physical and/ or functional interface between two pieces of equipment that work together as part of, say, an automated manufacturing process. Without this compatibility function, equipment users must either purchase all components of a system from a single vendor (not possible with FMS technology), or modify the components to achieve compatibility. In either case, the user is likely to pay a higher price, and this higher capital cost will slow the market penetration of the new technology.

Standards have developed to facilitate the operations of numerically-controlled machine tools over two time periods. In the late 1950s and early 1960s standards related to numerical controls were aimed at variety reduction; in the 1970s and early 1980s these standards focused on component interfacing. Each standard is described and dated in Table 2.

To estimate the statistical influence of the promulgation of these compatibility standards on the diffusion of FMS technology, the above regression model was modified to include a binary variable for the post-1983 period ($D = 1$) when all aspects of the operation of a numerically-controlled machine tool were standardized. The regression results are:

$$\log\{m/(n-m)\}_t = \underset{(-29.63)}{-322.20} - \underset{(-2.66)}{91.9D} + \underset{(29.40)}{0.162\text{year}} + \underset{(2.67)}{0.047D \cdot \text{year}}$$

$R^2 = 0.996$,
t-statistics in parentheses (2)

The estimated annual rate of diffusion of FMS technology was 17.6% during the 1968-1983 period, and it was 23.2% during the 1984-1990 period. The population of compatibility standards appears to have increased the annual rate of diffusion of FMS technology by 31.8%.

Table 2. Compatibility standards related to numerical controls

Standard	Year adopted	Description
EIA RS-408	1973	Interface between tape reader and controller
ANSI X-3.37	1974	Formalized the APT standard of 1957 for adapting design data
EIA RS-431	1978	interface between controller and numerically-controlled machine
EIA RS-447	1978	Standardized operational commands and data formats for the numerically-controlled machine
EIA RS-441	1979	Standardization of the functional interface between the operator of the machine tool and the controller
EIA RS-474	1982	Flexible disk format for numerically-controlled equipment information interchanges
EIA RS-491	1982	Interface between a numerically-controlled unit and peripheral equipment
EIA RS-484	1983	Electrical and mechanical interface standard between the direct numerically-controlled system and the equipment
EIA RS-494	1983	Standard related to binary input formats

4. Concluding statement

The existence of compatibility standards is an important factor in determining the timing of adoption of FMS technology by enterprises in the tooling and machining industry. Public policy in the United States continues to be initiated with an intent of stimulating the adoption of new technology (e.g. the Technology Transfer Act of 1984, the MTC and STEP programs in the Technology Competitiveness Act of 1988, and the American Preeminence Act of 1992).[9] However, a profit-oriented enterprise will evaluate the decision to adopt a new technology by comparing the expected benefits from the technology with the expected costs. Industry-wide interface standards significantly reduce the economic cost associated with utilizing a new technology. Perhaps future policy initiatives designed to increase the speed of technology adoption should emphasize standards as part of the technology infrastructure supported by the public sector.

Acknowledgements

This research was funded by the U.S. Small Business Administration under SBA-4122-OA-89 and the National Science Foundation under SRS-9012402. The assistance of Matthew B. Coffey, President of the National Tooling and Machining Association, was invaluable in the collection of the primary data used in this study.

References

Baldwin, William L. and John T. Scott, 1987. Market structure and technological change (Harwood Academic Publishers, London).

Berkson, Joseph, 1953, A statistically precise and relatively simple method of estimating the bio-assay with quantal response, based on the logistic function, Journal of the American Statistical Association 48, 565-599.

David, Paul A. and Shane Greenstein, 1990, The economics of compatibility standards: An introduction to recent research, Economics of Innovation and New Technology 1, 3-41.

Davies, Stephen, 1979, The diffusion of process innovations (Cambridge University Press, Cambridge).

Globerman, Stephen, 1975, Technological diffusion in the Canadian tool and die industry, Review of Economics and Statistics 57, 428-434.

Griliches, Zvi. 1957, Hybrid corn: An exploration in the economics of technological change, Econometrica 25, 501-522.

Leyden, Dennis P. and Albert N. Link, 1992, Government's role in innovation (Kluwer Academic Press, Norwell, MA).

Luggen, William W., 1991, Flexible manufacturing cells and systems (Prentice-Hall, Englewood Cliffs, NJ).

Mansfield, Edwin, 1961, Technical change and the rate of imitation, Econometrica 2, 741-766.

[9] See, for example, Leyden and Link (1992).

Mansfield, Edwin, 1963, Intrafirm rates of diffusion of an innovation, Review of Economics and Statistics 45, 348-359.

Nooteboom, Bart, 1993, Adoption, firm size and risk of implementation, Economics of Innovation and New Technology 2, 203-216.

Preece, David A., 1989, Managing the adoption of new technology (Routledge, New York).

Romeo, Anthony A., 1975, Interindustry and interfirm differences in the rate of diffusion of an innovation, Review of Economics and Statistics 57, 311-319.

Stoneman, Paul, 1983, The economic analysis of technological change (Oxford University Press, Oxford).

Tassey, Gregory, 1992, Technology infrastructure and competitive position (Kluwer Academic Publishers, Norwell, MA).

Thirtle, Colin G. and Vernon W. Ruttan, 1987, The role of demand and supply in the generation and diffusion of technical change (Harwood Academic Publishers, Chur).

U.S. Department of Commerce, Bureau of the Census, 1987, Census of manufacturers (Washington, DC).

U.S. Department of Commerce, International Trade Administration, 1985, A competitive assessment of the flexible manufacturing systems industry (Washington, DC).