Patterns of Advanced Technology Adoption and Manufacturing Performance

An Overview

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Summary

This report on technology adoption patterns and performance characteristics in a sample of several thousand U.S. manufacturing plants sheds new light on the ways in which technology is associated with growth. The report summarizes a more detailed study to be released later that finds patterns of technology adoption to be enormously diverse. Nonetheless, dispersion of advanced technologies appears to follow a recognizable progression: the most frequently adopted complex technology combinations are often comprised of more common simpler combinations. The study also suggests that specific technologies and technology combinations have varying degrees of association with plant-level job creation, productivity, and earnings. Moreover, the association between technology and plant performance is related to the characteristics of the plant itself. Plants with integrated fabrication and assembly operations appear to use technologies more effectively than plants engaged in only fabrication or assembly.

Introduction

Until recently, evidence for the contributions of technology to jobs, productivity, and earnings at the industry, firm, and plant levels had been largely anecdotal or based on relatively small-sample surveys. However, a large data set collected at the plant level in the 1988 Survey of Manufacturing Technology (SMT) now provides information on how 17 specific advanced technologies (Table 1) are used in approximately 10,000 plants in five manufacturing industry groups: Fabricated metal products, Industrial and commercial machinery and computer equipment, Electronic and other electric equipment and components except computer equipment, Transportation equipment, and Instruments and related products (SIC 34-38). Researchers at the Census Bureau's Center for Economic Studies (CES) have augmented these technology adoption data with the plant performance data for 1982 and 1987 from CES's Longitudinal Research Database.[1] The resulting matched data for nearly 7,000 plants are the basis of the present study.[2]

In the past, CES researchers have used these data to analyze relationships between technology use and plant performance. In general, their studies take the number of technologies adopted by a plant as a measure of the plant's technological sophistication. This method, however, obscures the diversity in technology adoption patterns and precludes analysis of the effects of specific technology combinations on plant performance.

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[1]The 1988 SMT sampled more than 10,000 manufacturing plants with more than 20 employees in the five selected manufacturing industry groups. This entire sample is used for the analysis of technology adoption patterns. The five groups account for more than 40 percent of the U.S. manufacturing contribution to GDP and employment share. Plant performance data used in this study are from the Longitudinal Research Database (LRD) compiled from various Censuses of Manufactures and Annual Surveys of Manufactures. Researchers at the Center for Economic Studies matched the 1988 SMT data to corresponding plant data contained in the LRD for 1982 and 1987 for two subsamples of nearly 7,000 plants. These plants are the focus of the present study.

[2]The study employs regression analysis to explore the statistical associations between frequently adopted technology combinations and plant performance. The analysis controls for other observable plant characteristics to isolate the association between technology adoptions and plant performance.

The dependent variables in 1987 level regressions were expressed as logarithms of the variables; whereas the dependent variables in the growth rate regressions were expressed as the difference in the logarithms of the 1987 and 1982 level. Two different subsamples of approximately the same size were used in these two types of analysis.

The explanatory variables are represented by a set of indicator or dummy variables, each identifying whether a specific combination of technologies was adopted by the plant. Specifically, dummy variables were included for the ten most common technology combinations within each technology count class (i.e., the plants that adopted exactly one, two, three, four, five, and six technologies). In addition, for each technology count class a dummy variable was included that represented all of the other less frequently adopted technology combinations. Finally, we included a single dummy variable to indicate whether the plant adopted any combination of seven or more technologies. The regressions also control for other plant characteristics, including size, age, multi-unit status, capital/labor ratio, census region, and four-digit SIC industry. Thus, the coefficient estimates for the technology dummy variables can be interpreted as the difference in the level or growth rates of the dependent variable associated with the adoption of a particular technology or technology combination, when compared with the reference group, which is defined as the plants that did not adopt any of the SMT technologies.

Table 1: Technologies Surveyed in the 1988 Survey of Manufacturing Technologies, By Major Technology Group

Group 1: Computer Aided Design and Related Technologies

1. Computer-aided design and/or computer-aided engineering (CAD)
2. CAD output used to control manufacturing machines (computer-aided design/computer-aided manufacturing (CAM))
3. Digital representation of CAD output used in procurement activities (DCAM)

Group 2: Flexible Manufacturing

4. Flexible manufacturing cells (FMC) or systems (FMS)
5. Numerically or computer numerically controlled machines (NC)
6. Materials working lasers (MWL)

Group 3: Robotics

7. Pick and place robots (PPR)
8. Other robots (OR)

Group 4: Automated Materials Handling

9. Automatic storage and retrieval systems (AS/RS)
10. Automatic guided vehicle system (AGVS)

Group 5: Automated Sensors

11. Automatic sensor-based inspection and/or test equipment performed on incoming or in process materials (ASIP)
12. Automatic sensor-based inspection and/or test equipment performed on final product (ASIF)

Group 6: Communications Networks

13. Local area network for technical data (LANT)
14. Local area network for factory use (LANF)
15. Intercompany computer network linking plant to subcontractors, suppliers, and/or customers (WAN)

Group 7: Programmable Manufacturing Control

16. Programmable logic controllers (PLC)
17. Computer(s) used for control on the factory floor (CC)

Source: Bureau of the Census, ESA, U.S. Department of Commerce

In contrast, this paper develops a richer picture of the relationships between specific technologies and technology combinations and various measures of plant performance, including the rate of job creation and the levels and rates of change in productivity and earnings. The paper has three goals: (1) to examine the patterns of technology adoption among manufacturing plants, (2) to show how the association of technology combinations with plant performance differs based on actual combinations adopted (i.e., to move beyond previous analyses based only on technology counts), and (3) to show that the effect of technology on performance depends in part on plant characteristics—especially on whether plants engage in both fabrication and assembly operations, only fabrication, or only assembly.

I. Diversity in Adoption Patterns[3]

Technology adoption patterns of manufacturing plants exhibit enormous diversity, even within the same industry or the same production process.

- The most frequently used stand-alone technologies or technology combinations, which are Computer Aided Design (CAD), Numerical Control tools (NC), and the combination of these two technologies, are each adopted by only 2 to 4 percent of the overall sample of approximately 10,000 plants.

- Plants that use any one of the 13 most frequently adopted technology combinations together account for about 19 percent of all sampled plants. About 18 percent of plants adopt technology combinations found only in one or two plants.

- Differences among industries and types of operation (i.e., fabrication, assembly, or both in combination) cannot explain this enormous diversity of technology adoption patterns. Diversity in patterns of technology adoption is also found within each industry and within each type of operation in a given industry.

Despite the diversity of technology adoption patterns, there are clear linkages among the most frequently adopted technologies and technology combinations.

- The pattern of combination in some cases suggests a "natural" progression or technology "ladder" that plants follow when they expand their acquisition of technologies. Among the more frequently used simple and complex technology combinations, the simple combinations are often subsets of more complex combinations.

- The 5 most frequently adopted stand-alone (single) technologies are CAD, NC, Programmable Logic Controllers (PLC), Computers used for Control on the factory floor (CC), and Wide-Area Networks (WAN) or intercompany computer networks.

- The three most frequently adopted pairs of technology combinations—CAD and NC, NC and PLC, and PLC and CC—are composed of four of the five most frequently adopted stand-alone technologies.

- The most frequently adopted combination of three technologies is CAD, NC, and CAD output used to control manufacturing machines (i.e., CAD/CAM). This technology combination includes a combination of one of the most frequently

[3] The following discussion summarizes conclusions fully reported in the authors' forthcoming paper.

adopted pairs of technologies mentioned above (i.e., CAD and NC) and CAD/CAM technology.

- The most frequently adopted combination of four technologies is the combination of CAD, NC, PLC, and CC, a combination of two of the frequently adopted pairs of technologies—the pair of CAD and NC, and the pair of PLC and CC.

II. Technology Combinations and Plant Performance

Specific technology combinations generally have differing degrees of association with plant performance.

- Simply using the number of technologies adopted by the plant as a measure of technological sophistication obscures significant differences in the relationships between specific technology combinations and plant performance. As the regression results summarized below show, this finding holds true for all measures of plant performance examined. (See footnote 2 for detailed specification.)

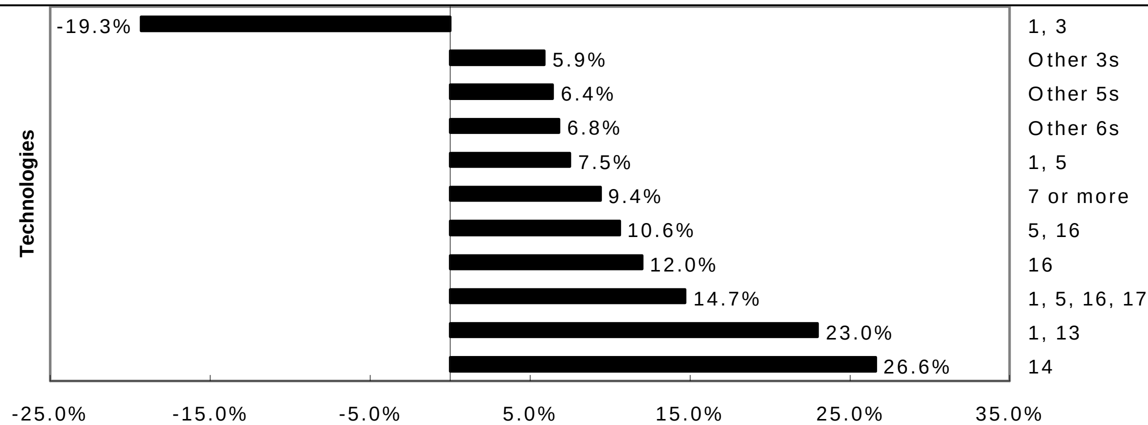
Adoptions of most technology combinations are positively associated with overall job growth and productivity levels.

- More than 80 percent of technology categories adopted are associated with plants with a relatively higher rate of job growth and a higher level of labor productivity than plants that do not adopt any SMT technologies. (See footnote 2 for the definition of these categories or technology dummy variables.) The relationships between technology adoption and the rate of productivity growth tend to be positive, but are often weak. These general findings are consistent with those reported in earlier studies.

- Figure 1 shows the eleven technologies and technology combinations adopted by establishments with the highest rates of employment growth between 1982 and 1987. Statistically, these plants have a much different rate of job growth than the plants that did not adopt any of the SMT technologies.

- Local-Area Network (LAN) technologies, either combined with CAD for the exchange of technical data or adopted alone for factory use, are associated with about a 25 percentage point faster rate of job growth from 1982 to 1987 than plants adopting none of the SMT technologies. (Figure 1) Other more complex technology combinations, many of which include LAN technologies, are also associated with higher rates of job growth.

Figure 1
Relative Employment Growth



Notes: Definitions of Technology Combinations:

1 Computer aided design (CAD)
3 Digital representation of CAD output
5 Numerically controlled machines
13 Local area networks for technical data
14 Local area networks for factory use
15 Intercompany computer network linking plants to suppliers and others
16 Programmable logic controllers
17 Computers used for control on factory floor
Other - other less frequently used combinations of two, three, four, five, or six technologies of the 17 technologies available

Percentages are relative to otherwise similar plants adopting no SMT technologies.

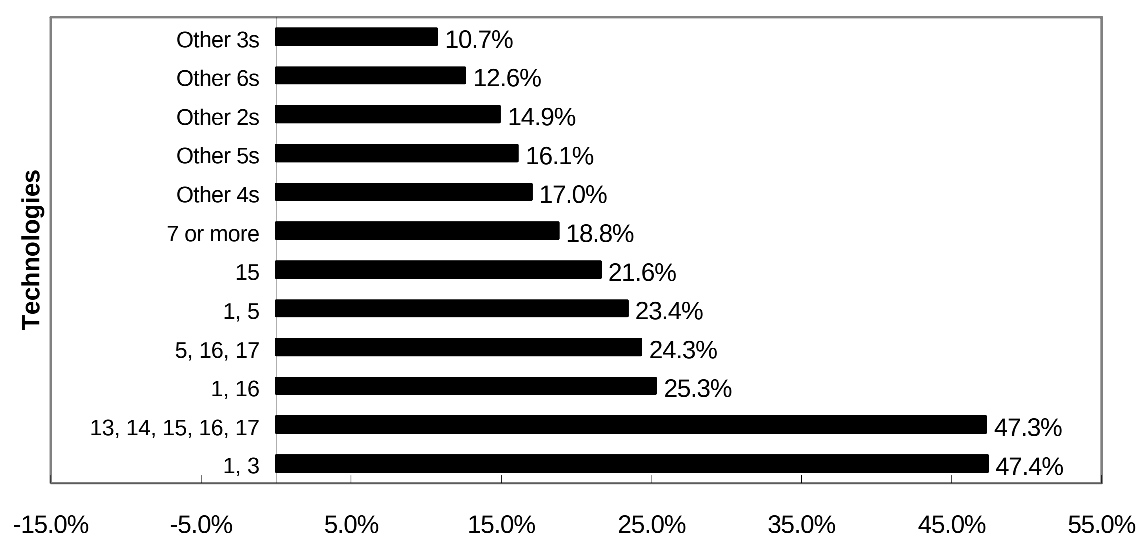
Source: Bureau of the Census, ESA, U.S. Department of Commerce

- Employment at plants that adopted the combination of CAD, NC, PLC, and CC technologies grew nearly 15 percentage points faster than plants that did not use any of the SMT technologies between 1982 and 1987. In fact, even plants that adopted PLC technology alone or in combination with NC also exhibited a more than 10 percentage point faster rate of employment growth.

- Plants that adopted the combination of CAD and digital representation of CAD output used in procurement activities experienced slower job growth by nearly 20 percentage points. Plants that adopted this particular technology combination experienced a very fast rate of productivity growth, but a substantial decline of production worker jobs, and a much slower increase of non-production worker earnings over the 1982-87 period.

- Figure 2 shows the twelve technologies or technology combinations adopted by establishments with the highest *levels* of productivity in 1987. The figure indicates that the combination of CAD and CAD output used for procurement and the combination of technologies of LAN for technical data and for factory use, WAN, PLC, and CC are associated with nearly 50 percent higher productivity levels than similar plants that adopted none of the SMT technologies. These plants also experienced a much higher rate of productivity *growth* over the 1982 to 1987 period.

Figure 2
Relative Productivity Level



Notes: Definitions of Technology Combinations: (see Figure 1). Percentages are relative to otherwise similar plants adopting no SMT technologies.

Source: Bureau of the Census, ESA, U.S. Department of Commerce

- Plants that adopted WAN or intercompany computer network, CAD with PLC or NC, and the combination of NC, PLC, and CC are associated with 20 to 25 percent higher productivity than otherwise similar plants that did not use any of the SMT technologies.

There are sharp differences in how technology combinations are associated with growth on employment of production and non-production workers.

- Most technology combinations are positively associated with employment growth for both production and non-production workers, but the associations are stronger for production workers than for non-production workers.

- Production worker employment growth is 35 percentage points higher in plants that adopted LAN on the factory floor than in plants that adopted none of the SMT technologies. It is 32 percentage points higher in plants that adopted the combination of CAD and LAN for technical data.

- Non-production worker employment growth is weakly associated with most technology combinations, but there are some significant exceptions. For example, plants that adopted the flexible manufacturing cells (FMC) or systems (FMS) technology had a much lower rate of employment growth for non-production workers, relative to plants that adopt no SMT technologies, possibly because this technology is a substitute for non-production workers. (Non-production workers in these plants increased their earnings relatively faster than workers in other plants.)

There are also sharp differences in how technology combinations are associated with earnings of production and non-production workers.

- About 60-80 percent of the technology categories are associated with higher earnings levels for both production and non-production workers, but production workers benefited the most. For example, production workers at plants that adopted the WAN technology, the combination of CAD and PLC, and the combination of NC, PLC, and CC, earned 10 percent more than their counterparts at plants that adopted none of the SMT technologies.

- Non-production worker earnings are only weakly related to the adoption of the SMT technologies. Non-production workers at some plants, particularly those that adopted technologies other than CAD, earned significantly less than their counterparts at similar plants that adopted none of the SMT technologies. This is plausible because relatively fewer highly-paid non-production workers in managerial or professional occupations, such as design engineers, work at "CAD-less" plants.

III. Impact of Technology and Plant Characteristics

The relationships between technologies and plant performance is better for plants that integrate fabrication with assembly operations than for plants that engage in only fabrication or only assembly.

- Plants that engage in both fabrication and assembly appear to make better use of advanced technologies than those that engage in only one or the other function. For example, plants with integrated operations that adopted a complex technology combination (involving 7 or more technologies) generally had higher labor productivity and production worker earnings levels in 1987 and production worker earnings growth over the 1982-87 period.

- These findings support the hypothesis that improving management by integrating different functions complements the adoption of advanced technologies. Plants that engage in both fabrication and assembly are also apt to integrate other functions, for example, marketing, design, and manufacturing. So the finding may also reflect this integration.