Chapter 14

External Learning Opportunities and the Diffusion of Process Innovations to Small Firms: The Case of Programmable Automation

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14.1 Introduction

In this chapter, we are concerned with explaining which types of firms have failed to adopt well-known improvements in process technology. This problem has, of course, been the underlying concern of all studies of diffusion *"to rationalize why, if a new technology is superior, it is not taken up by all potential adopters"* (Stoneman, 1983). Drawing on various theoretical perspectives, we identify a number of different barriers to adoption. With data collected from a 1987 nationally representative sample of US establishments in 21 metal-working and machinery manufacturing industries, we then construct a multivariate logistic regression model to empirically test for the effects of these factors on the likelihood of adoption of a particular process innovation, namely programmable automation (PA) machine tools.

A widely accepted tenet of contemporary analyses of the diffusion of innovations is that certain types of organizations are better positioned than others to generate and to adopt innovations (David, 1969 and 1975; Mansfield, 1968; Mansfield *et al.*, 1977; Nabseth and Ray, 1974; Stoneman, 1980; Utterback, 1988). With respect to process innovations in particular, economic research on technology diffusion has demonstrated the importance of differences, or *heterogeneity* in what Dosi (1989) has termed the *incentive structures* of firms to explain why some firms are quick to adopt a process innovation while others fail to do so. For example, some firms are price leaders in labor markets, willing to pay a premium in order to attract the best quality labor; other firms are willing to accept somewhat lower quality labor in order to keep their wages at or below the average paid by their competitors. Unless the expected labor savings from a new technology are greater than the capital costs of purchasing the equipment, a firm is apt to delay making that investment (Metcalfe, 1990; Salter, 1960). Thus, at any one point in time, high-wage firms are apt to have a greater incentive than low-wage firms to adopt a labor-saving technology. Moreover, there may be some minimum threshold scale (i.e., volume of output), below which the labor savings are too small for it to be profitable for the small firm to invest (David, 1975). In addition, there may be scale requirements that make it technically infeasible for small firms to adopt it. For example, Mansfield (1968) found that for certain innovations, there is a minimum scale at which a technology can be profitably used in particular industries. Hence, where the scale of investment necessary for a new process technology is very large, it can only be undertaken by large firms; small firms will simply lack the financial resources or size of revenue stream to make such an investment. From this body of research, we learn that the failure of small firms to adopt an innovation may be attributable to the heterogeneity of firms with respect to relative factor prices (of labor and technology), profitability, and the lumpiness of capital investment.

A second stream of research on the economics of innovation emphasizes differences in firms' technological and organizational competencies, which develop or accumulate over time (Cohen and Levinthal, 1990; Dosi, 1988; Freeman, 1988; Nelson and Winter, 1977 and 1982; Rosenberg, 1972 and 1982). In this line of inquiry, the problem of imperfect information for learning about new technologies and the importance of accumulated knowledge and expertise are given prominence in explaining why some firms are more likely to adopt a new technology or to be sources of innovation themselves. Since information about the possible uses and relevance of a new technology to the firm is difficult to assess (Rosenberg, 1972), firms with more resources to devote to scanning the technological environment are likely to be better positioned than less well-endowed organizations to identify and exploit a new technology (Cohen and Levinthal, 1990). Moreover, firms differ in their experience with related technologies. These technological competencies can be expected to enhance a firm's capability to make use of other related innovations. With respect to process innovations, we would therefore expect to find adoption rates to be higher among firms that have demonstrably greater technological competencies and resources for scanning the external environment.

A third set of factors identified in some studies are special features of economic institutions and inter-firm relationships which explain why – in some regions, nations, or among certain groups of firms – the pace of diffusion was found to be more rapid and the rates of adoption much higher. For example, with respect to the adoption of hybrid corn among American farmers during the 1940s and 1950s, Griliches (1960) observes that the more rapid pace of diffusion in certain regions could be attributable to agricultural extension services in a number of different states which were a source of innovation for additional improvements. As Nelson and Winter (1977) point out, extension service agents have been an especially reliable source of information to farmers in these regions. As such, they may very well have contributed to the faster speed of adoption observed by Griliches. Similarly, Saxonhouse (1974) attributes the rapid rate of diffusion of new techniques among Japanese textile manufacturers both to the importance of business trade associations serving as a conduit for information and to the accepted practice of sharing technical know-how among these firms. The importance of information exchange or *know-how trading* for achieving improvements in utilizing a new technology among steel mini-mill producers has also been demonstrated by von Hippel (1988). In a world of imperfect information and considerable uncertainty about whether and how best to deploy a new technology, these extra-firm economic institutions and networks of relationships among firms can be expected to be particularly important for explaining differential rates of adoption.

In this chapter, we attempt a synthesis of these various theoretical perspectives, taking into account the heterogeneity of firms with respect to the cost incentives or profitability of adopting a particular process innovation, their organizational capacity for learning and technological competencies, and their external linkages to resources for learning about new technological developments. With detailed survey data on the technical, economic, and organizational characteristics of a large sample of US manufacturing establishments – all of which are potential adopters of the new technology – we are able to operationalize a model for predicting the likelihood of adoption of this new technology that simultaneously takes into account all three types of influences.

After accounting for the influence of differences in cost incentives and organizational capabilities, we find that a small firm's propensity to adopt a process innovation is particularly enhanced by the nature of its linkages to external resources for learning about technological developments. These results suggest that the well-known scale and size disadvantages of small firms for engaging in the risky learning-by-doing process necessary to the adoption of new productivity-enhancing technologies may, at least in part, be overcome when there are well-developed social networks for sharing expertise and acquiring new knowledge among economic actors and institutions. In regions or sectors where linkages to such external learning opportunities are particularly well-developed, we would expect to find a more rapid rate of diffusion of productivity-enhancing process innovations to small firms.

14.2 The Implications for Small and Large Firms of Radical Shifts in the Technological Trajectory

Productivity increases arise both from radical shifts to a new, more efficient technology, and from continued, incremental improvement in the way in which an existing technology is utilized (Dewar and Dutton, 1986; Ettlie *et al.*, 1984). Indeed, for some period of time when both emerging and mature process technologies coexist, additional improvements in the mature techniques also occur and frequently accelerate (Harley, 1973). Whether emerging or mature, every technology has its own associated trajectory (Dosi, 1982). Incremental learning about how best to use a particular configuration of equipment is the basis for productivity improvements which proceed under the same technological regime. Moreover, each firm has its own associated learning curve. The knowledge derived from marginal adaptations of the organization and the technology accumulate over time and becomes part of the informal or *tacit* know-how – the craft *art* recognized by many observers as a key ingredient that distinguishes high from low productivity operations employing the same technology (Bohn and Jaikumar, 1986; Kusterer, 1978; Pavitt and Patel, 1988; Skinner, 1986).

New process technologies always involve a change in the ways in which products are made – a change in the allocation of tasks, a change in machinery, a change in work methods which may imply retraining, or a change in organization. For the firm, there is always some uncertainty about how much new knowledge will be necessary and how drastic a change the new configuration of equipment and people will entail (Bohn, 1987; Rogers, 1983). If these changes require substantially new skills and expertise, then a displacement of the learning curve results, i.e., a discontinuity arises between the organizational learning accumulated under the previous production regime and that which is needed for the new technology. This could even result in a short-term decline in productivity until a certain portion of the new learning curve has been traversed as the organization develops the additional expertise needed to more fully exploit the potential advantages inherent in the new technological trajectory.

Certain changes in technology involve such a radical shift *away* from existing techniques that traditional competencies and skills are made obsolete (Abernathy and Clark, 1985; Tushman and Anderson, 1986). In the case of information technology's application to manufacturing in the form of programmable automated (PA) machine tools, the shift to this new technological regime requires the integration of new science-based knowledge of electronics, computers, and software engineering with the accumulated tacit knowledge of metal-cutting practices acquired through years of practical experience; PA also makes some traditional skills obsolete (Kelley, 1989a, 1989b, 1989c, and 1990a). In order to make this shift to the new trajectory successfully, firms have to buy, borrow, or somehow internally develop that expertise and integrate it with the relevant traditional practices to match the requirements of the emerging system. Because of their size, and hence very limited base of resources available to absorb mistakes, small firms are likely to face more severe consequences from underestimating the displacement of their learning curves.

Small firms have little organizational slack and, over the long term, are more vulnerable to business failure than large firms (Hage, 1980; Hage *et al.*, 1989; Scott, 1987). In small manufacturing companies, engineering and management resources are limited to a few individuals per plant. For small firms to engage in an experimental learning-by-doing process requires the diversion of existing resources from production activities. That may have a high opportunity cost. The time that one engineer spends assisting with the break-in of any new piece of equipment is time spent away from solving other design or production problems. The diversion of this scarce resource can cause delays in production which increase costs and may lead to delays in shipment and possibly lost orders from customers, contributing to lower profits and possibly lower sales.

By contrast, large, relatively resource-rich organizations can afford to embark on a number of experiments with process innovations, only some of which may turn out to be successful, without risk to the firm's survival and profitability (March, 1981). Related to size is the tendency of large firms to have developed specialized capabilities in production engineering and management. By devoting some specialized resources to improving production techniques, large firms have an experience advantage in the kind of "learning by doing" that Arrow (1962) identified as a key generator of continued productivity improvements under any technological regime. Moreover, because of their size advantage, large firms are less vulnerable to any severe consequences (such as their own demise) from making a strategic error (such as underestimating start-up time and cost or training time) in deploying any single piece of new equipment that does not achieve its expected savings.

14.3 Economic Limitations on the Technology Choices of Small Manufacturing Firms

As part of a strategy to attain or maintain leadership in one market, the large firm may seek to develop proprietary technology which provides a unique cost or quality advantage over its competitors. Moreover, when a firm operates in a number of markets for which there is a shared technical basis and sufficient scale of operations, there is the possibility of achieving a greater synergy from exploiting advances in process technology. Hence, being relatively quick to use new production techniques can provide such a firm with multiple cost or quality advantages over its competitors in several markets at once.

By contrast, because of the small scale at which they tend to operate, small firms have less opportunity to achieve and exploit such technical synergies. Moreover, even when the incentive to cut costs is great – as is likely to be the case with the small manufacturing firm that has expertise in a mature technology operating in industries where the prospects for sales growth are poor (i.e., where sales trends are flat or only growing slowly), and profit margins are slim – the small business owner/manager is of necessity focused on the short-term. To him/her, the adoption of a new process technology is viewed as being outside the realm of rational choices.[1] Instead, as March and Simon (1958) have suggested, management is likely to focus its attention on familiar problems, attempting to adapt by gaining greater control over variable production costs in order to make more efficient use of existing equipment and labor within the declining technological paradigm.

In the short run, such small manufacturing firms' aspirations are modest, being concerned simply with survival. Management may forestall wage increases or actually reduce wages. Equipment may be operated more continuously, sacrificing downtime for preventative maintenance and further depleting the useful life of the capital stock. The manager/owner may be willing to accept lower revenues and even profits in order to be more certain of staying in business.[2]

We might further plausibly assume that there are barriers to exit. Small manufacturing firms whose prior success depended on their capacity to exploit their accumulated experience within an increasing obsolete technological paradigm may lack the human or financial resources to absorb the one-time effort and cost of entering a new line of business. At the same time poor growth prospects in their present market niche may not attract entry of technologically more advanced firms. Thus, technologically backward firms may survive in narrow market niches for protracted periods of time by lowering wages and deferring investment, thus retarding the diffusion of new production technology and productivity growth.[3]

14.4 The Importance of External Learning Opportunities to the Diffusion of New Process Technologies

Whether or not a firm will adopt a new technology is generally believed to be determined by some combination of the relative importance of economic incentives for doing so (e.g., to lower costs) and its internal capability to undertake an experimental learning-by-doing process. However, with the exception of Nelson (1990) and von Hippel (1988), little attention has been given to examining how various kinds of linkages with other economic organizations and institutions matter to the adoption and implementation of innovations. The conventional wisdom evident in economic models of diffusion is that late adopters learn about the experience of early adopters through *osmosis*, that is, through informal contact and exchange of know-how among managers and engineers employed in different firms. The importance of the social context, or the set of linkages the firm has (or has somehow developed) to external learning opportunities, has hardly been considered in these models.

The proposition that the economic actions undertaken by management of a particular firm need to be understood as being affected by its network of relations with other firms and economic institutions has long been recognized by sociologists, political scientists, anthropologists, and historians (*cf.* Granovetter, 1984). Membership in trade associations, relationships with equipment vendors and customers are part of a social nexus in which the economic decisions of individual firms are embedded. Moreover, even among competitors, inter-firm relationships may take on a special character that is of particular importance to the success of a region or to the diffusion of innovations. For example, a number of studies on the industrial districts in Northern Italy attribute the success of these regional agglomerations in large measure to long-established relationships of trust and cooperation among technically inter-dependent small and medium sized firms whose economic ties are sometimes rivalrous and at other times collaborative – as suppliers to or customers of one another (Becattini, 1987 and 1989; Bellandi, 1989; Brusco, 1982 and 1986; Lorenz, 1989; Piore and Sabel, 1984; Sabel, 1989).

With respect to the learning opportunities that such external resources present, some firms are better connected than others, belonging to active, service-oriented trade associations, having collaborative relationships with their customers, and being part of an industrial community in which know-how trading with other firms is an accepted practice. We would expect these opportunities to be unevenly distributed among firms of different sizes, industries, and locales. Some firms are poorly linked to external resources as a matter of management policy. More commonly, we believe, the presence or absence of such linkages reflects historical differences in the evolution of economic institutions in particular locales (as seems to be the case of the Italian industrial districts) or particular sectors, and in the relative importance of leading firms in shaping orderly relationships with large networks of supplier-firms.[4]

If learning is the *product of experience* as Arrow (1962) has argued, then for firms to learn about the capabilities of *new* technologies, they must have access to opportunities for gaining trustworthy information about others' experience with them. For this to happen, there must be trustworthy institutions or forums which facilitate the exchange of useful information, help filter out erroneous or irrelevant news, and promote the accumulation of tacit know-how within the firm. External resources on which a firm may depend to learn about new advances and the experience of others with technology include: informal contacts with production managers or engineers in other firms; direct contacts with sales representatives of equipment vendors and distributors; participation in trade and professional associations; sharing information with the firm's customers; and reading trade journals, marketing newsletters, and brochures for general knowledge about the potential of new technologies. Firms may not be persuaded by such published information, however, because they have no way of assessing its trustworthiness, but gatherings at professional associations or industry trade shows may enable users and potential users of a new technology to meet and examine the latest equipment offered by vendors and exchange practical tips with other users about a new technology's limitations as well as its capabilities. Such linkages may be particularly important for explaining why some small firms adopt a process innovation while others with apparently similar characteristics do not.

Through their service activities, capital equipment manufacturers and distributors are also an agency through which best-practice techniques for utilizing a new technology may be *taught* (Ettlie and Rubenstein, 1980; Leonard-Barton, 1988).[5] These equipment manufacturers have been known to sometimes customize the design of new systems for lead users, adapting the innovation to the customer's specific production requirements and providing intensive follow-up support services during the initial implementation phase (Collis, 1988; von Hippel, 1988). They do so in anticipation of winning a large, loyal customer or as part of an experimental developmental effort which will result in improvements in the design of future generations of the technology. When this user dedicates some of its own organizational resources toward that collaborative effort, then it is also likely to engender organizational expertise within the user-firm as a result of close interactions of key personnel involved in such working relationships. These types of contacts are known to occur particularly in the early phases of the development of a new technology, are sometimes reserved for customers that purchase expensive systems, or are made available to large users from which the vendor expects a hefty order.[6]

Another important learning opportunity may arise from a firm's relationships to the businesses that purchase its products. Kelley and Harrison's (1990) research on subcontracting relationships suggest that many firms choose suppliers because of their specialized capabilities. Such business customers with which a small firm has some special relationship could be an important source both for learning about new technological developments and about how to use an innovation.

Previous studies have documented the ebb and flow of relations of trust and collaboration between firms and their business customers (Cusamano, 1985; Dore, 1986; Kenney and Florida, 1989; Minato, 1986; Sato, 1983; Trevor and Christie, 1988). Close relations between a firm and a few customers can be both beneficial and inhibiting to the adoption of new production technology. On the one hand, a close collaborative relationship to one or a few customers may open up the possibility of gaining favored status, and the benefits of technical and financial assistance that flow from that relationship. On the other hand, too close a dependence on a few customers may make small firms more vulnerable to price-cutting pressures and to fluctuations in customers' demands. Under pressure to cut costs, or faced with greater volatility in orders for its products, firms caught in such close relationships could have such small profit margins as to lack the resources and incentive to invest in new technology.

14.5 Programmable Automation: A Comparison of Adopters and Non-adopters of New Process Technology

Programmable automation (PA) in the form of numerically controlled (NC) and computerized numerically controlled (CNC) machine tools and flexible manufacturing systems (FMS), interconnecting such tools by automatic transfer, has been hailed as signalling a fundamental techno-economic paradigm shift which promises to greatly reduce the economies of scale that have driven the design and organization of manufacturing since the beginning of the industrial revolution (Freeman and Perez, 1986; Hirschhorn, 1984; Kaplinsky, 1984; Perez, 1986; Piore and Sabel, 1984). Since instructions controlling the operation of programmable machines can be incorporated into easily altered software rather than unalterable hardware, one piece of manufacturing hardware is adaptable to many different products which can be made in both small and large volume in a wide variety of industries that require the shaping and cutting of metal parts.

To date, PA has been applied mainly to the precision metal-cutting operations of turning, milling, grinding, and boring – operations important in the manufacture of a diverse range of products, from aircraft engines and industrial machinery to coffee grinders and lawn mowers. Machining is a "batch" production process, in which products are made in small to medium-size lots – too small to benefit from the earlier form of fixed-cycle *hard* automation. By 1982, the combined output of NC/CNC machines from six of the major machine-tool producing countries (USA, Japan, Federal Republic of Germany (FRG), France, Italy, and the UK) comprised two-thirds of the total value of production of all metal-cutting machines (Edquist and Jacobsson, 1988, p. 26).

This technology is not unique to particular product lines and appears to be equally technically and economically feasible for large and small firms. Single machines can be installed one at a time and used alongside conventional, non-programmable machines. Since the mid-1970s, improvements in the technology – particularly the incorporation of microprocessors – have made it easier to use, while machine productivity has increased at the same time as purchase costs have come down (Edquist and Jacobsson, 1988).

In what follows, we draw on a national survey of US manufacturing establishments completed in 1987 to examine adoption rates of PA in a range of establishment and firm sizes and to evaluate the significance of three sets of factors for distinguishing how adopters differ from non-adopters of the technology: cost and profitability incentives, organizational resources and technical capabilities, and linkages to external resources and sources for learning about technological developments.

14.5.1 Data description and methods

The data we employ come from a national sample of establishments belonging to twenty-one manufacturing industries, at the 3-digit level of the US Standard Industrial Classification scheme. Following the convention of the US Census of Manufactures, establishments in the sampling frame were grouped into the following size categories: fewer than 20, 20 to 49, 50 to 99, 100 to 249, and 250 or more, employees. In order to ensure a sufficient number of cases within each size stratum, establishments were disproportionately randomly sampled by strata in order to yield a data set with an equal number of establishments from each stratum. Since the distribution of establishments by employment size is highly skewed, with fewer than 10 percent of all plants employing 100 or more workers in the industries studied, this procedure guarantees a sufficient number of large size plants to allow for variation among them in the use of technology, type of product market.

All population estimates are weighted averages, which were constructed by weighting each observation by the inverse of the probability of selection from its sampling stratum. The production managers in these plants were surveyed between October of 1986 and March of 1987 (Kelley and Brooks, 1988). All told, 1,015 plant managers were successfully interviewed by mail, yielding a 50 percent response rate. Half of the non-respondents were then contacted by telephone and asked questions which, apart from their substantive value, confirmed the absence of response bias in the mail survey.

The twenty-one industries were chosen because they account for the great majority of machining activity in the US economy.[7] Twenty-five percent of all US manufacturing workers in 1986 were employed in these industries. The data base includes information on the size of the parent company (as measured by corporate-wide employment in the USA) and considerable detail on organizational, technical, and economic characteristics of each plant.[8] All sample establishments use machine tools for some aspect of production operations in their plants. Hence, they are all *potential* adopters of PA technology.

At the time of the survey, fifty-seven percent of the sample plants had not yet installed even one programmable machine. As of 1987, most firms that had failed to adopt programmable automation seem unlikely candidates for doing so at some time in the near future. Despite improvements in the technology that have made it easier to use and less costly to install, two-thirds of non-adopters perceive the payback period associated with the introduction of PA as being too long to justify any investment.

These firms' unwillingness to invest in programmable automation seems to be related to a general reluctance (and possibly lack of financial resources) for making investments to improve their capital stock. The average investment in new equipment of any kind for firms that had not purchased any PA at the time of our survey was less than one-third the amount invested per employee by PA users in the same year.[9] Over the previous five year period (from 1982-1986), during which time more than half of all programmable machine tool installations presently in use in the United States were purchased, less than one-third of the enterprises that made no such purchases ever even considered that alternative. Moreover, in 1987, only 18 percent of those that had not invested in PA said that they had any plans for purchasing this equipment in 1988 or 1989.

In the previous section of the chapter we described how three different sets of factors could be expected to affect the likelihood of a firm adopting a new process technology such as PA: cost and profitability incentives, organizational resources and technical competencies, and external linkages. The majority of PA users (71 percent) have some programmable machines that were first installed more than five years ago, with 10 percent of PA-users having at least some programmable machines still in use that were purchased more than 10 years ago. However, eighty-five percent of PA-using plants have at least one machine from the latest micro-processor generation of the technology – with computerized numerical controls – which was first introduced only in the late 1970s. We cannot know from these data the *changes* in firm and establishment characteristics that may have accompanied or followed the adoption of programmable machines.[10] Our analysis is thus limited to a comparison of the ways in which PA adopters differ from non-adopters at what must be understood to be an intermediate stage in the diffusion of this technology.

We estimated a binomial logistic regression model, with the dependent variable, PA, defined equal to 1 if the production manager at the establishment reported there were any programmable machines in use, and equal to 0 if no programmable tools were present. Technical definitions for all independent variables can be found in Appendix *Table 14.A1*. Complete data on all variables needed to estimate the model were available for 75 percent of the cases in the sample.

14.5.2 Factors distinguishing PA adopters from non-adopters

Cost and profitability

Five variables representing cost and profitability factors were hypothesized to be important inducements to the firm to adopt programmable automation. Relative labor costs, the degree to which production operations at a plant were dependent on machining skills, the presence of a union, the scale of machining operations at a plant, and product markets with a high requirement for "flexibility" are all expected to be important economic factors favoring the adoption of PA.

In previous research on programmable automation, managers have reported that reductions in direct labor costs or increased productivity are the major expected gains from adopting this process innovation (Ayres and Miller, 1982; Hicks, 1983; Parsons *et al.*, 1984; Rosenthal, 1984). As a form of automation that is expected to lead to productivity gains (i.e., increases in output per person hour), we would expect the cost-cutting impetus for adopting PA to be the greatest in establishments where machining labor costs are relatively high. Thus, PA is more likely to have been adopted in plants with relatively high wages for machining occupations.

Another economic factor expected to favor PA adoption is the relative importance of machining skills to the overall production activities of the establishment. The greater the share of all production workers in occupations requiring these skills, the more likely it is that management will seek ways of reducing costs and improving productivity within that operation. Where machining skills are of minor importance to the overall production activities, management is less likely to make an effort to automate that process with computer-controlled machinery.

There is some disagreement in the literature as to how we might expect unionization to affect investment in a labor-saving process innovation such as programmable automation. Freeman and Medoff (1984) argue that when a plant is unionized, management is more likely to pay attention to weeding out inefficient practices and to streamline production, suggesting that PA might be adopted more rapidly in unionized establishments. Similarly, Clark's comparison (1980) of union and non-union firms in the cement industry suggests that management is more likely to introduce labor-saving technology in order to improve productivity when collective-bargaining governs the firm's relationship to its employees. However, research by Kochan (1985) and Schmenner (1982) suggests that when a unionized plant is part of a multi-plant enterprise, *corporate* management's investment decisions are apt to be informed by other industrial relations policy considerations. In his analysis of Conference Board data on corporate patterns of investment in plant and equipment, Kochan finds that unionized establishments received much less investment from the parent company than their non-union sister plants (controlling for age of the plant). Schmenner's research on the Fortune 500 shows a similar pattern of withholding investment from unionized plants. If corporate (multi-plant) strategic considerations are found to dominate the union effect, we would expect to find the adoption of PA technology to be less likely to occur when a plant is unionized, or for there to be no significant impact from unionization at all.

The concept and measurement of *scale* is somewhat ambiguous in studies of innovation.[11] In this analysis, we include a variable that controls for the effect of scale in the sense of *size* of machining operations at a plant. With respect to machine tools, we would argue that the smaller the number of tools in use at a plant (and thus the smaller the scale of machining operations), the more risky it would be for the firm to adopt even one programmable machine. The potentially disruptive consequences from introducing the new technology are greater, the fewer the number of machines in use. Moreover, for firms with a plant that has few tools, the cost of replacing any one of them represents a much larger share of its total capital investment in machine tools than would be the case for firms having plants with larger stocks of machines. Similar to David (1975), we would argue that the cost of adopting a single programmable machine may be too high for firms operating at too small a scale of machining. Thus, for smaller scale machining operations, management may find the adoption of PA to be a much more risky and *lumpy* investment and therefore be unwilling to adopt it, even though it may be profitable to do so. For that reason, we would expect the chances that management will have adopted PA to be less, the smaller the scale of machining operations at a plant.

A number of students of industrial change (Carlsson, 1989; Piore and Sabel, 1984; Kern and Schumann, 1984 and 1987) have argued that manufacturing firms face increasingly volatile and uncertain product markets for their goods. In discussions of the advantages of programmable technologies for small firms, PA has been touted as being especially well-suited to meet the high *technical flexibility* requirements of firms operating in such environments, specializing in manufacturing a diverse array of parts or products in very small batches (Dosi, 1988; Kern and Schumann, 1984; Piore and Sabel, 1984). Because programmable machines can be re-instructed for each change in product, a firm that operates in such product markets will have a greater incentive to adopt the technology since it lowers the costs of switching from one product to another. Hence, establishments with high flexibility requirements should find PA a more attractive investment than plants without such high switching costs.[12]

Internal resources and technical competencies

Firm size is a proxy measure for the extent to which an organization may be said to be resource-rich. Large firms have multiple production sites and a larger base of experience with various technologies that can be brought to bear in adopting any particular process innovation. The larger the firm, the more likely it is to employ professional staff at the corporate level with responsibility for providing technical expertise to production managers at any one of its plants. At any one point in time, larger firms can marshal greater resources more rapidly than smaller firms to deal with unexpected problems in implementing a new technology. Because of this superior adaptive capacity, we would expect that the larger the firm the more capable it is (in terms of resource capacity) to make the necessary adjustments in its operations to accommodate to a process innovation such as PA, and the more likely it will be to have adopted PA in plants for which the technology is suitable, i.e., those using machine tools in production operations.

Information technology has many applications. In manufacturing, computers are used for monitoring and planning functions, such as process planning and production scheduling, quality control and materials flow monitoring, and inventory control. That a plant has adopted any of these information technology applications would indicate greater formalization of management systems of information and control. Such a change may involve only a shift from written record-keeping and inventory procedures to computerization, or it may involve a more radical shift from an informal organic organizational structure to one with a more formal structure and system of control. In either case, the use of information technology in these functions suggests a greater technological sophistication (and by implication, an enhanced organizational capacity) to exploit PA. Although there may be no technical interdependence between the use of IT in these applications and PA (as there would be with computer-aided design), it is a complementary technological competency that should facilitate the adoption of programmable machines. We would therefore expect an establishment with such advanced information technology capabilities in monitoring and planning functions to be more likely to have adopted PA.

Linkages to external resources

As mentioned earlier, there are multiple external resources by which a firm can acquire knowledge about a new technology's capabilities. These can be distinguished by the type of linkage (whether it has a social or interpersonal dimension or not) and by the source of information.

Stories in trade journals and mailings from equipment vendors and their distributors are external sources for learning about technological developments in the form of written media. Thirty-eight percent of all production managers surveyed considered linkage to this channel of information flow to be very important for learning about new technology. Nevertheless, by itself, we do not expect this kind of linkage to external resources to be a sufficiently reliable means for learning about technology. We would therefore not expect to find any difference between PA users and non-adopters with respect to their reliance on such written sources of communication.

Know-how trading in the form of informal exchanges of information through conversations with production managers and engineers outside of the establishment (i.e., in other companies or in other plants of the same company) was the most common external resource cited by respondents as a very important way to learn about new technology. This type of exchange is of course recognizable as the casual individualized form of learning by osmosis which Stoneman (1980) assumes to be the major channel through which new technological expertise diffuses. In our formulation of the set of inter-firm linkages that distinguish PA adopters from non-adopters, we have the opportunity to test how important this kind of informal exchange is relative to other, more structured, collective forms of information exchange. Following Stoneman and von Hippel, we do expect to find a positive effect of know-how trading on the likelihood of adoption of PA, *ceteris paribus.*

Trade associations and professional technical societies provide an avenue for managers and engineers from member organizations to meet and discuss problems of common concern. In contrast to individualized know-how trading, demonstrations of new equipment at meetings of such associations is a highly structured, collective way of learning about technological problems and capabilities. At such events, groups of managers and engineers with common problems and issues have an opportunity to exchange information with each other and to compare the features of equipment offered by different vendors. We would expect that being connected to such organizations and participating in such events affords members a more intensive and comparative learning experience than may occur through individualized know-how trading. Managers and engineers of firms who participate in such activities are likely to be better informed and to have a broader set of knowledgeable contacts to whom they can turn to discuss technological issues. For these reasons, we would expect firms with such linkages to have a higher propensity to adopt advanced manufacturing technologies such as PA.

Direct contact with sales representatives from equipment vendors or their distributors (independent of contact through trade shows) is another structured way of learning about new technology. Unlike the case of consumer products, where sales persons are not expected to know much about the products they sell, sales representatives for industrial equipment products such as PA are expected to have some expertise with the technology, if only to be capable of explaining how it can be used and what the expected benefits are from using it. Hence, they may be an additional source of expertise that managers can draw upon in deciding to adopt and use new technology.

Another way in which expertise is transferred from one firm to another is through a firm's contacts with its customers. Eighty-eight percent of all US metal-working establishments make products using machine tools for sale to other manufacturing firms. More than three-fourths of these say that they have business customers for whom they make machined parts or products on special order and from whom they receive technical information and engineering assistance in making these special parts or products. Such a transfer of technical information suggests a degree of dependency between the two firms that could provide the occasion for other exchanges of technical expertise that may be particularly important in augmenting the capabilities of small firms to adopt a new technology. More generally, we hypothesize that firms with such close connections to their business customers are also more likely to be able to draw on these customers for assistance in implementing a new technology. For these reasons, firms that have such an information sharing relationship with their customers will (we expect) be more likely to adopt PA.

14.6 Findings

The results of our estimating procedure are shown in *Table 14.1.* Ten of the thirteen variables in the model are significant in predicting which establishments are likely to have adopted PA by 1987. As expected, cost and profitability incentives are important. In addition, plants that are part of firms with greater technical and organizational resources are much more likely to be PA users. Finally, establishments with certain kinds of linkages to external learning opportunities have an enhanced chance of adopting PA technology that can permit the small firm to overcome the liabilities of small scale and its lack of adequate internal resources.

Cost incentives

Both the cost of labor and the degree to which the overall production process at a plant is dependent on machining skills are significant predictors of PA adoption. Independent of wages, we do not find that unionization has significantly affected management's deployment of programmable machines.

Figure 14.1 shows a simulation of the predicted probabilities of adopting PA for the typical US machining establishment for different wage rates, with all other variables in the model held constant at their sample means.[13] At more than twice the average wage for machining occupations (about

Table 14.1. Logistic regression of the likelihood of adopting programmable automation.

Variable name	Mean	Standard deviation	Predicted sign	Regression coefficient	Standard error
Programmable Automation	0.46	0.50			
Incentives: Cost & Profitability					
Hourly wage[a]	9.83	3.46	+	1.078[b]	0.310
Dependency on machining skills	76.90	32.15	+	0.027[b]	0.004
Union	0.125	0.33	?	−0.223	0.321
Machining scale[a]	27.00	83.39	+	0.239[c]	0.105
High flexibility requirements	0.34	0.47	+	0.185	0.197
Internal Resources/Competencies					
Firm size[a]	2,590.00	3,516.00	+	0.568[b]	0.088
Complementary IT application	0.46	0.50	+	0.373[d]	0.212
External Resources/Information Sources					
Brochures, ads and newsletters	0.38	0.49	+	−0.337[d]	0.195
Equipment vendors' sales reps.	0.34	0.47	+	0.547[b]	0.186
Informal know-how exchange	0.53	0.50	+	0.176	0.186
Trade & prof. association meetings	0.34	0.47	+	0.490[b]	0.193
Customers	0.88	0.33	?	−0.410	0.356
Customer-provided technical assistance	0.69	0.46	+	0.563[a]	0.248
Intercept				−7.598	0.842
−2 Log likelihood				813.97	
χ^2 (df=13)				236.76	
C				0.808	
N	761.00				

[a]Natural logarithm of variable entered in regression model. Untransformed variable's mean and standard deviation shown in this table.
[b] Probability ≤ 0.01. [c] Probability ≤ 0.05. [d] Probability ≤ 0.10.

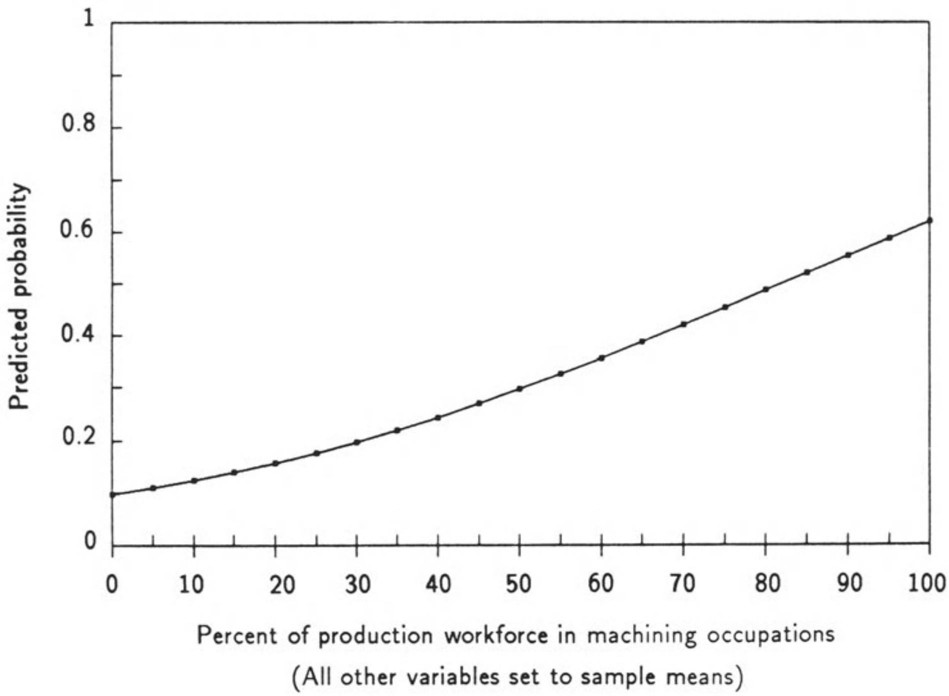

Figure 14.1. Probability of PA adoption by average hourly wage for machining occupations at the plant.

US$20.00 per hour), the probability that there will be at least some PA tools in a plant is quite high ($p > 0.66$). At less than one-half the average hourly wage (about US$5.00 an hour), fewer than 3 out of 10 such low-wage employers will have introduced any PA.

The degree of machining skill dependency is a technical attribute of production that is expected to vary with the kinds and mix of products being manufactured at a plant and the extent to which machining operations needed for these products are performed in their entirety within the plant or, in part, contracted out to other firms.[14] The typical manufacturing establishment engaged in machining activity is very dependent on the skills of workers specializing in these operations. On average, about 77 percent of all production workers in the manufacturing plants studied are employed in machining occupations. In *Figure 14.2*, we see that the less the manufacturing process at a plant depends on a work force with specialized machining skills the lower the probability of PA adoption. For example, as the degree

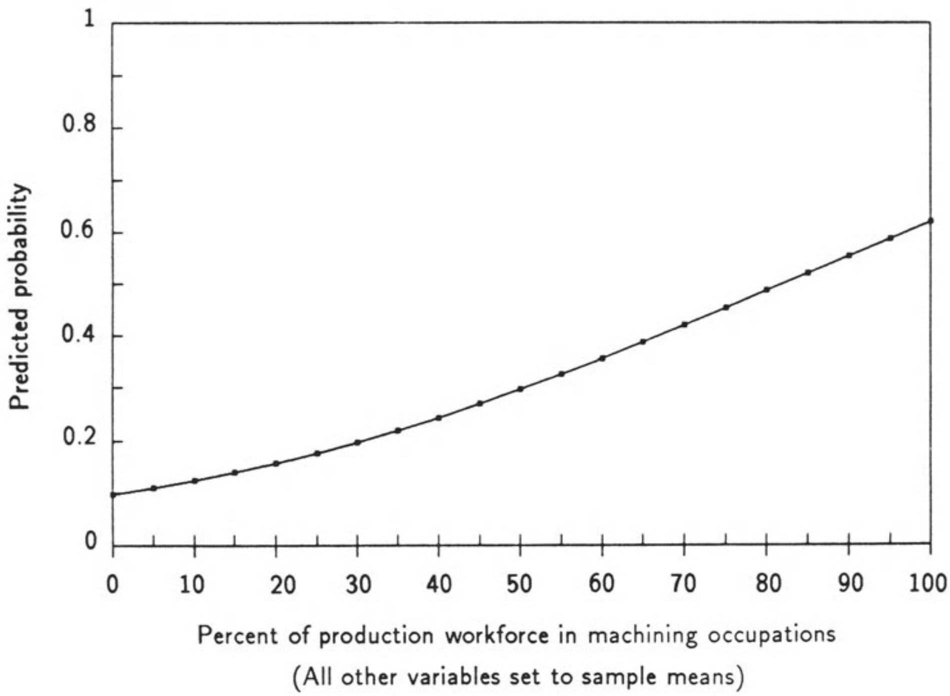

Figure 14.2. Probability of PA adoption by degree of machining skills dependency at the plant.

of skill dependency falls from 75 to 50 percent of all production workers, the predicted probability of PA adoption is reduced at about the same rate, by one-third, from p = 0.45 to p = 0.30 (again with all other variables held constant at their sample means).

These results are consistent with the hypothesis that when management faces higher labor costs and has a greater dependency on particular skills, there will be a greater incentive to adopt such a labor-saving technology as programmable automation. The higher wages we find associated with PA use may in part reflect an increase in the skill demands of machining occupations associated with the introduction of the new technology. Such cause and effect relationships cannot be sorted out with the available data. Hence, we cannot determine the magnitude of the incentive effect that high labor costs may have served to initially induce management to adopt PA.

More than one-third of all machining establishments have high flexibility requirements, making a diverse (50 or more) array of parts/products in very small batch sizes (with 50 percent or more of total machining output in batches of fewer than 10 units). Although the direction of the effect of high flexibility requirements is as predicted (indicating a tendency to adopt PA), these demands are not sufficiently strong, in and of themselves, to significantly affect the firm's propensity to use PA tools.

Scale (or the size) of machining operations across the wide range of industries studied varies from plants that employ only one machine tool to those utilizing up to 1,500 different machines. Our results show that plants with smaller scale machining operations (as measured by the number of tools) have thus far been deterred from adopting PA. This is illustrated in *Figure 14.3*, which also shows that the marginal effect of differences in scale on the probability of PA adoption are relatively small. For example, establishments with 50 tools have 5 times the scale of machining operations as plants in which only 10 tools are deployed, yet the change in predicted probabilities of adopting PA increases from $p = 0.44$ for plants with 10 tools to only $p = 0.54$ for plants with 50 tools, an increase of less than 25 percent. Even for very small scale machining operations, the probability of PA adoption is quite high, *ceteris paribus*. A plant with only 20 tools is nearly as likely to have at least one PA tool as it is to rely exclusively on non-programmable machine tool technology ($p = 0.49$).

Internal resources: the importance of firm size

At plants where information technology is utilized to support a system of control and production planning, there is a significantly greater probability that PA will also be deployed. Independent of the scale of machining operations, cost incentives, and the technological sophistication in related IT applications at a given plant, we find the size of the parent company's organizational resources to be a significant predictor of PA adoption.

As shown in *Figure 14.4*, for the very small single-plant firm with fewer than 20 employees, the chances that there will be even one programmable machine are no better than about 40 percent. For firms with more than 10,000 employees nationwide, we are practically certain ($p \geq 0.96$) of finding at least one programmable machine in its plants (all other things being equal). Even for the plants belonging to moderately large firms with about 500 employees throughout the United States, the chances of there being *no* PA tools at the plant are quite low ($p = 0.17$).

Small firms may be invariably small scale, but the converse is not always true: large firms do not invariably have large scale operations.[15]

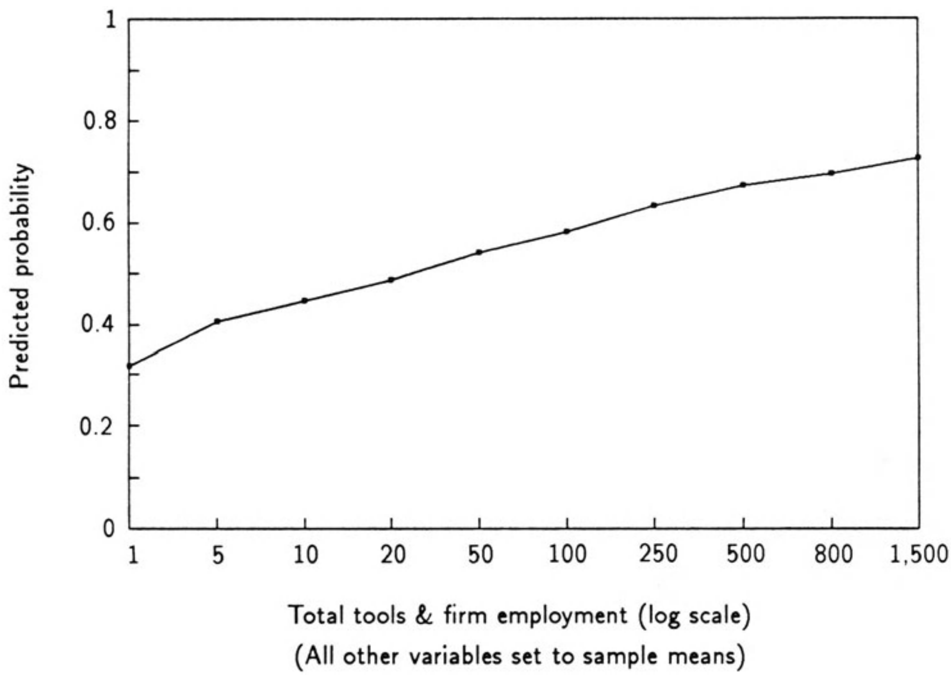

Figure 14.3. Probability of PA adoption by scale of machining operations at the plant.

When we compare the predicted probabilities for the marginal effects of firm size to that of machining scale at a plant (*Figure 14.5*), it is apparent that differences in firm size (taken as indicative of differences in organizational capabilities) are far more important than differences in machining scale *per se* in explaining differential adoption rates among establishments. Small firms with invariably small scale machining operations are, as expected, least likely to have adopted any PA tools.

How much do external learning opportunities affect the chances of PA adoption for small firms?

When the production manager reports that he has linkages – which support learning about new technology – to equipment vendors, to industry or trade associations, and to his customers, we are more likely to find some programmable machines in use at the plant he manages. But the causality is more complex than we had imagined.[16]

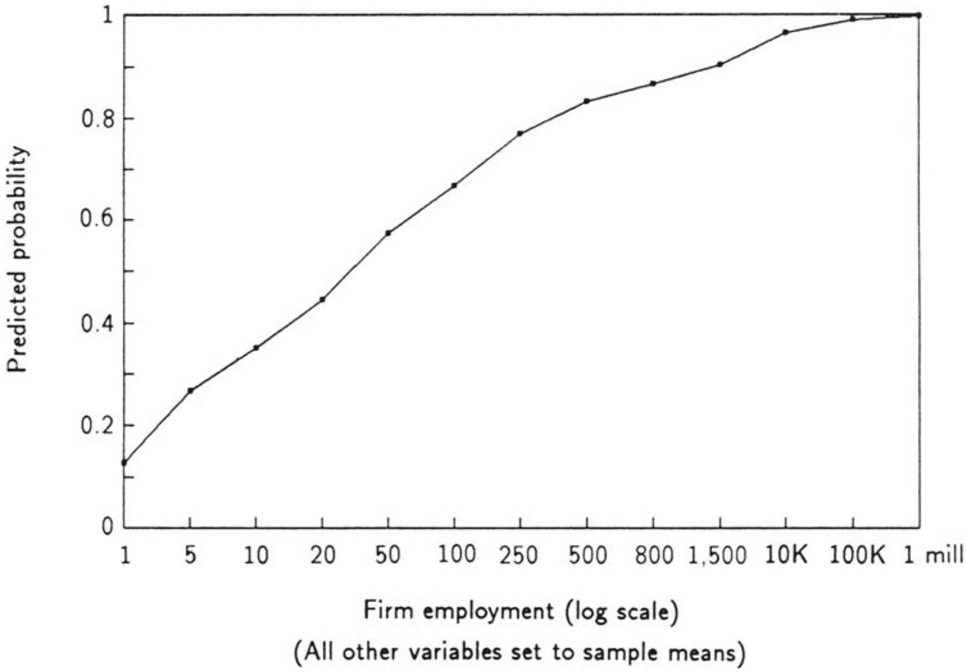

Figure 14.4. Probability of PA adoption by size of parent company.

Informal, individualized know-how trading may be the most common sort of linkage to external resources, but it is not a statistically significant predictor of PA adoption. Moreover, relying solely on written sources of information independent of any personal contact with equipment vendors, distributors, other users, or in isolation from trade shows and demonstrations at professional associations actually *reduces* the likelihood of PA adoption. In addition, when a firm sells its machining output to other firms but has no special order customers willing to share technical information, it's chances of adopting PA are significantly reduced. Linkages that actually reduce the chances of PA adoption have a passive and asocial character to them.

The kind of highly structured and social linkage to other potential adopters and new technology manufacturers that occurs in meetings of industry and professional associations is a significant predictor of PA adoption. Moreover, independent of the contacts that are made at such group settings, further direct contacts with sales representatives from equipment vendors and their distributors are another external linkage that significantly increases the

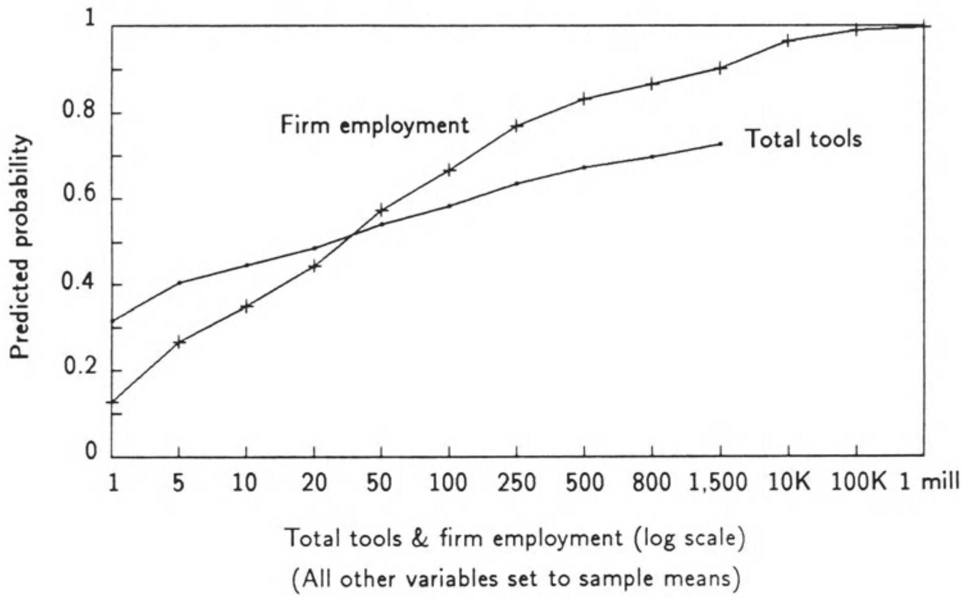

Figure 14.5. Probability of PA adoption by machining scale at plant and by size of parent company.

likelihood of PA adoption. Firms with special-order customers who provide detailed technical information about their orders have significantly greater chance of adopting PA than firms without such close relationships to their customers. Along with informal know-how trading – with it's positive but insignificant impact on the likelihood of adoption – this set of linkages can be best described as having an essentially social and active quality, involving direct interpersonal interchange or contact with outside resources.

In order to evaluate the *combined* effects of those various external linkages that we have identified as *active* and *social* from those we have identified as largely *passive* and *asocial* in nature on the likelihood of PA adoption for firms of different sizes (and hence different internal resources and capabilities for undertaking technological change), we computed the predicted probabilities for the average plant in each of four different firm size categories: firms with fewer than 20; 20 to 99; 100 to 499; and over 500 employees. The scenario identified as indicative of a "passive/asocial" set of external linkages refers to the case in which reliance on external resources is limited to written media, i.e., brochures, ads, and newsletters, and to firms that sell their machining products to some other firm but have no special order

Table 14.2. Estimates of the importance of external learning opportunities to the probability of PA adoption in plants of different size firms.

	Estimated probability of PA adoption		
Size of parent company	Passive/asocial linkages	Active/social linkages	
Firms with <20 employees	0.18	0.65	+256.5%
Firms with 20–99 employees	0.29	0.77	+167.7%
Firms with 100–499 employees	0.42	0.83	+105.4%
Firms with 500 or more employees	0.94	0.99	+5.6%

Notes:
(1) For both scenarios, the plants of these firms are assumed to sell output from the machining process to some other firm.
(2) "Passive/asocial linkages" refers to those situations in which management depends *only* on written media (newsletters, brochures) as an outside source of information about technological developments, is *not* an active participant in industry or professional association meetings, does *not* rely on know-how trading with managers or engineers outside the plant, does *not* depend on contacts with sales representatives from equipment vendors or their distributors to learn about new technology, and does *not* have business customers who share any technical information or expertise.
(3) A plant with "Active/social linkages" is one where management *is* an active participant in industry or professional association meetings, relies on know-how trading with managers or engineers outside the plant, depends on sales representatives from equipment vendors or distributors to learn about new technology, and has special order customers who provide technical information and expertise.
(4) Probabilities are estimated by setting variables measuring one type of linkage (e.g., "active/social") equal to one and those measuring the other type of linkage (e.g., "passive/asocial") equal to zero. For each estimate, all other variables in the model are set equal to the group mean for establishments in that firm size category.

customers who share technical information with them. To have "active" and "social" linkages means that plant management does not rely solely on written media independent of various personal contacts with sales representatives from equipment vendors or their distributors, and with other users. Moreover, management with "active/social" linkages participates in meetings of trade and professional associations where demonstrations of new technology occur, has additional direct contacts with vendors, and has sufficiently close relationships to some of its special order customers, such that some technical information sharing regularly occurs between the two.

The results of these simulation are shown in *Table 14.2.*[17] For all plants but those attached to the largest firms ($\geq$ 500 employees), we find that when management has "active/social" linkages to external resources for learning about new technological developments the chances of PA adoption are substantially higher than those plants with only "passive/asocial" types of linkages. "Active/social" linkages raise the chances of PA adoption the most among plants belonging to the smallest size firms. For the very smallest firms with fewer than 20 employees that have only "passive/asocial" linkages to various external resources, the chances of PA adoption are quite low, less than 1 in 5 ($p = 0.18$). With "active/social" linkages through which the exchange of technical expertise and learning among firms is facilitated, the conditional probability of PA adoption increases by more than 250 percent (to $p = 0.65$). For small firms with 20 to 99 employees, "active/social" linkages to external resources outside the firm increase the chances of PA adoption over firms with "passive/asocial" linkages from less than 3 in 10 ($p = 0.29$) to more than 3 in 4 ($p = 0.77$). Even for medium-sized firms with 100 to 499 employees, we find that such "active/social" linkages to resources external to the firm augment the chances of PA adoption by a substantial margin.

When the very smallest size firms (with fewer than 20 employees) are very well-connected to all four of the "active/social" linkages for which we have identified a positive impact on PA adoption, these external economic advantages compensate for much of the diseconomies of small size and scale. Indeed, the chances of PA adoption for such well-connected small firms actually exceed those estimated for the typical plant of medium-sized firms that are nearly 10 times as large (with between 100 and 499 employees) but have only "passive/asocial" linkages to external sources of expertise.

14.7 Conclusions

In this chapter, we have argued that a combination of three sets of factors explains which establishments are likely to have adopted programmable automation. Cost and profitability incentives (or deterrents), the internal resources and accumulated technical competencies of the firm, and the firm's linkages to external sources of expertise for learning about the new technology's capabilities and limitations are all important in predicting PA use. As of 1987, we find that small-scale, small-size firms are the least likely to have introduced any PA tools. Small firms lack the internal resources and operate at too small a scale of production to generate the kind of internal synergies across a number of product markets, that is, the economies of scope, enjoyed by large diversified companies. Yet as we have shown, the deterring effect of small scale and the lack of internal resources (small size) for engaging in the kind of experimental learning-by-doing process necessary to make the shift to the new technology's learning curve can be overcome when certain external resources are available to supplement the small firm's limited capabilities. Without the kinds of connections to trade associations, to equipment manufacturers, and to special order customers – which help to transfer technical know-how and therefore underwrite the risks of adopting a new process technology – our results would suggest that the isolated small firm (i.e., characterized by passive/asocial linkages to external resources) that relies wholly on traditional techniques is not likely to even attempt the necessary retooling of machines and people. Instead, we would expect such firms to pursue a strategy of lower wages and more intensive use of aging capital for the short to intermediate term. That strategy may permit these firms to continue to exist for a while longer as long as they do not face much of a threat from new entrants to their markets who are more technologically advanced.

There are two ways to consider the implications of these findings for policy. One could argue that the greatest obstacle to diffusion is simply the tradition-bound firms' tenacity, i.e., their stubborn commitment to continuing to do business as usual as long as they can. Hence, a policy designed to more aggressively drive them out of business would presumably hasten the process of diffusion. If there is no alternative use for the capital of such firms and if the work force would need to be substantially retrained in order to be productively employed elsewhere in the economy, a policy designed to force the closure of these plants could result in a net social welfare loss. Even though the firms that remained in business would be more efficient than those that were encouraged to close, such a policy may be more costly to society than allowing these firms to continue to produce, albeit less efficiently. Alternatively, one could argue that the absence of strong "active/social" linkages to external resources for learning about new technology developments among small firms in different sectors and locales is what is limiting the more widespread and rapid diffusion of new manufacturing technologies such as programmable automation.

In certain other national economies, the most well-known example being that of Japan, these linkages are reported to be far more common, helping to diminish the disparities in technological sophistication between large and small firms that might otherwise prevail.[18] National economies with institutional arrangements that are generally supportive of such ties among many manufacturing firms may thus be more successful in sustaining their technological leadership in various markets in this period of transition to a new techno-economic paradigm.

In the United States, technology assistance programs to manufacturing firms now operate in more than thirty states (Shapira, 1990). Such programs can provide a trustworthy source for connecting potential PA users to equipment vendors or their distributors. But technology assistance programs that emphasize one-on-one assistance to small companies are in danger of ignoring the problem of weak linkages. These activities cannot substitute for the collective learning experience that is more likely to occur through interactions among members of the same trade or professional association. Nor can these agencies substitute for the absence of special customers with whom a small business can develop a collaborative relationship that not only is a resource for learning about technology but may also provide some degree of stability of demand for its products. The creation of these kinds of strong, supportive linkages of an "active/social" character should be an objective of public policies designed to foster modernization among small manufacturers.

Acknowledgments

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Notes

[1] For the small firm, the economic environment so conditions these choices, that as Simon (1957) put it, the firm's "planning horizon" becomes "sharply limit[ed]."

[2] Howland's research (1988) on plant closings provides some support for our view of small manufacturing firms as facing a severely constrained set of investment alternatives and strategic choices. For example, she finds that when faced with the same poor economic prospects, small, single-plant firms are much less likely

than branch plants of large firms to close, preferring instead to stay in business at a reduced level of operations and profits.

[3] Insofar as large firms that may themselves be quite sophisticated in their use of advanced manufacturing technologies continue to rely on suppliers with these characteristics, their ability to compete against firms with a technologically advanced supplier chain is also diminished.

[4] For example, nearly all researchers see the collaborative production networks in Japan as being led by great industrial conglomerates (Cusamano, 1985; Dore, 1986; Florida and Kenney, 1989; Freeman, 1988; Johnson, 1982).

[5] See Guile (1986), for a discussion of the possibility that distributors, rather than manufacturers of the new technology themselves, will play an increasing role in disseminating such knowledge and the possibility of market failure when the conditions for appropriating returns from such marketing activity are very weak.

[6] Such close connections to equipment vendors may not be equally available to all potential adopters of a process innovation. There is little incentive for vendors or distributors to provide individualized tutoring to the myriad of small firms that have not adopted any new technology and are individually likely to make only a small investment. Services available from makers of new equipment or their distributors may thus be a very imperfect mechanism for accommodating many small, weakly linked firms to a new technological trajectory.

[7] The industries surveyed include: nonferrous foundries (SIC 336), cutlery, hand tools, and hardware (SIC 342), heating equipment and plumbing fixtures (SIC 343), screw machine products (SIC 345), metal forgings and stampings (SIC 346), ordnance and accessories, not elsewhere classified (SIC 348), miscellaneous fabricated metal products (SIC 349), engines and turbines (SIC 351), farm and garden machinery and equipment (SIC 352), construction and related machinery (SIC 353), metalworking machinery and equipment (SIC 354), special industrial machinery, excluding metalworking (SIC 355), general industrial machinery and equipment (SIC 356), miscellaneous machinery, excluding electrical (SIC 359), electrical industrial apparatus (SIC 362), motor vehicles and equipment (SIC 371), aircraft and parts (SIC 372), guided missiles and space vehicles (SIC 376), engineering and scientific instruments (SIC 381), measuring and controlling instruments (SIC 382), jewelry, silverware, and plateware (SIC 391). Fifty percent of the sample establishments were in SIC 354 and SIC 359.

[8] These data have been analyzed to examine the morphology of subcontracting relations (Kelley and Harrison, 1990; Harrison and Kelley, 1990), productivity in the use of PA (Kelley, 1990b; Kelley and Xue, 1990), and the determinants of skill-upgrading approaches to job design and training opportunities (Kelley, 1989a, 1989b, 1989c, and 1990a).

[9] In 1986, an average of US$6,265.51 per employee was invested in new equipment among establishments with programmable machines, compared to the US$1,972.40 per employee in establishments that had no PA technology.

[10] However, from responses to questions asked of those who were planning to install PA in 1988-89, it seems clear that the introduction of this new technology is associated with an expectation of greater requirements for flexibility, that is, an expansion in the line of products the firm plans to manufacture. In seventy five percent of the plants where managers say they plan to introduce PA in the next two years, they expect to increase the variety of products being manufactured, which suggests that plans to *diversify* away from product lines, or new customers, may be an important stimulus to technology adoption.

[11] To David (1975), for example, scale implies both size and volume of production. Scale economies in the use of the reaper permitted larger size farms (in terms of acreage and hence volume of output) to amortize the cost of purchasing a reaper over its greater expected use in harvesting more acreage. With respect to scale as size, he finds that for farmers operating at a very small scale, only when the relative costs of labor rose above some threshold, were new harvesting machines likely to be purchased. For a detailed review of the different measures and concepts, see Gold (1981).

[12] Appendix *Table 14.A2* shows averages of selected characteristics of establishments, grouped by size of firm and by whether or not any programmable machine tools have been installed as of 1987. Larger firms (and larger scale facilities) are often assumed to specialize in fewer products and longer production runs, and hence to be less *flexible*. We do not find support for this assumption. As shown in the table, establishments with high technical flexibility requirements are as prevalent in plants of large as in plants of small-size firms.

[13] The estimates of the predicted probabilities of PA adoption displayed in *Figures 14.1* to *14.5* and *Table 14.2* were derived using the following method: For each variable X_j of value V,

$$(1)\quad Z_j = \sum_{i=1}^{13} \hat{b}_i \bar{X}_i + \hat{b}_j(X_j); \qquad i \neq j$$

$$(2)\quad \text{Prob (Adopt PA} = 1 | X_j = V) = (e^{Zj})/(1 + e^{Zj}).$$

[14] For an analysis of subcontracting behavior, see Harrison and Kelley (1990) and Kelley and Harrison (1990).

[15] Appendix *Table 14.A2* shows the mean values of selected characteristics of establishments belonging to firms of different sizes. An inspection of the group means shows that among large firms (with greater than 500 employees) there are great differences in the scale of machining operations related to PA use, but for the smallest size firms (with fewer than 20 employees) there are no differences in scale and skill dependency related to PA use.

[16] We cannot know from these data whether some of these linkages – especially to equipment vendors – existed before or were developed after purchasing the technology. However, when we compare the differences among non-adopters between those firms that are planning to purchase PA in the next two years and those that have no such investment plans, we find that well-linked firms

are more likely to have plans to introduce PA. Reliance on other users, active involvement in trade associations, and ties to business customers willing to share technical expertise are all significant factors, positively related to plans to purchase PA. However, firms with a tendency to rely more on equipment vendors or distributors as a source of information, independent of their contacts through trade shows and professional association meetings, are no more likely to be planning to introduce the new technology. These findings provide additional evidence for our contention that in political-economic environments where networks of relationships among economic actors for transferring technical know-how flourish, there will be a more rapid diffusion of new technologies to small firms.

[17] The details on average characteristics by PA use for plants grouped by these firm size categories can be found in Appendix *Table 14.A2.*

[18] In a recent report of the US Congressional Office of Technology Assessment (Gorte, 1990), entitled *Making Things Better: Competing in Manufacturing,* firms in Japan were described as having business customers that are nearly 1.5 times as likely to provide engineering support as we find among US firms. The higher incidence of such close relationships among Japanese firms may explain the higher rate of adoption of PA technology by very small Japanese subcontractors (to that of US firms of similar size) reported in a recent unpublished survey of such firms undertaken by the Shoko Chukin Bank in 1988.

Appendix Table 14.A1. Variable definitions.

Variable table	*Definition*
Hourly wage	$=\log_e$ average hourly wage of workers employed in machining occupations at the plant.
Dependency on machining skills	=% of all production workers in the plant employed in machining occupations.
Union	=1, if production workforce is unionized; =0, if non-union
Machining scale	$=\log_e$ (total number of machine tools).
High flexibility requirements	=1, if 50 or more different parts or products manufactured with machine tools *and* if 50 percent or more of that machining output is produced in batch sizes smaller than 10 units; =0, otherwise.
Firm size	$=\log_e$ (total company employment in the USA).
Complementary IT application	=1, if computers are used for any of the following purposes: process planning / scheduling, quality assurance, process monitoring, materials flow/inventory control, materials/parts planning; =0, otherwise.
Brochures, ads, newsletters	=1, if plant manager considered any of the following sources of information to be very important for learning about new developments in machining technology: advertisements, direct mail (catalogues/brochures), articles in publications; =0, otherwise.
Equipment vendors' sales rep.	=1, if plant manager considered either of the following sources of information to be very important for learning about new developments in marketing technology: sales representatives from manufacturers or sales representatives from distributors; =0, otherwise.
Informal know-how exchange	=1, if plant manager considered conversations with individuals at other companies or conversations with individuals at other plants of this company to be a very important source of information about new developments in machining technology; =0, otherwise.
Trade & prof. association mtgs.	=1, if plant manager considered presentations at technical society meetings or exhibits at trade shows to be very important sources of information for learning about machining technologies; =0, otherwise.
Customers	=1, if plant manager reported that the output of machining operations was sold to customers outside this company; =0, if output of the machining process used solely internally by the firm.
Customer-provided tech. assistance	=1, if plant managers reported that products or parts were made to special order for customers who provided any of the following technical information: blueprints or drawings, written specification sheets detailing how each operation is to be performed, direct assistance from the customer's own manufacturing engineering or programming staff or other types of technical assistance; =0, if no technical assistance provided by special order customers.

Appendix Table 14.A2. Selected establishment characteristics[a] by firm size and by PA use.

	Firm size: <20		
Variable names	No PA	Any PA	Total
Total machine tools (scale)	13.00	16.00	14.00
Plant employment	8.00	9.00	8.00
Company employment (firm size)	8.00	10.00	9.00
Company/plant employment	1.09	1.11	1.10
Hourly wage (US$)	8.92	11.14	9.69
Dependency on machining skills (%)	82.67	97.07	87.66
Union	0.048	0.057	0.051
Complementary IT application	0.205	0.336	0.250
Customers	0.885	0.992	0.922
Customer-provided technical assistance	0.679	0.914	0.760
High flexibility requirements	0.295	0.430	0.342
Brochures, ads, newsletters	0.348	0.373	0.357
Equipment vendors' sales reps.	0.219	0.406	0.284
Informal know-how exchange	0.527	0.619	0.559
Trade & prof. association mtgs.	0.256	0.357	0.291
% of total	65.40	34.60	100.00
Unweighted N	96.00	56.00	152.00

Appendix Table 14.A2. (continued)

	Firm size: 20–99		
Variable names	No PA	Any PA	Total
Total machine tools (scale)	30.00	30.00	30.00
Plant employment	35.00	37.00	36.00
Company employment (firm size)	41.00	42.00	41.00
Company/plant employment	1.28	1.22	1.25
Hourly wage (US$)	9.94	9.46	9.66
Dependency on machining skills (%)	51.95	78.57	67.74
Union	0.131	0.113	0.120
Complementary IT application	0.801	0.671	0.724
Customers	0.841	0.818	0.827
Customer-provided technical assistance	0.625	0.689	0.663
High flexibility requirements	0.381	0.350	0.363
Brochures, ads, newsletters	0.345	0.433	0.397
Equipment vendors' sales reps.	0.305	0.493	0.416
Informal know-how exchange	0.396	0.550	0.487
Trade & prof. association mtgs.	0.227	0.491	0.383
% of total	40.70	59.30	100.00
Unweighted N	90.00	145.00	235.00

[a]Means weighted by the reciprocal of the probability of selection in the sample stratum.

Appendix Table 14.A2. (continued)

Variable names	Firm size: 100–499 No PA	Any PA	Total
Total machine tools (scale)	22.00	46.00	38.00
Plant employment	126.00	115.00	119.00
Company employment (firm size)	211.00	190.00	197.00
Company/plant employment	4.33	3.13	3.55
Hourly wage (US$)	10.22	10.45	10.37
Dependency on machining skills (%)	24.24	61.38	48.54
Union	0.340	0.317	0.325
Complementary IT application	0.862	0.853	0.856
Customers	0.736	0.851	0.811
Customer-provided technical assistance	0.512	0.607	0.574
High flexibility requirements	0.245	0.327	0.289
Brochures, ads, newsletters	0.270	0.434	0.377
Equipment vendors' sales reps.	0.219	0.511	0.410
Informal know-how exchange	0.283	0.446	0.390
Trade & prof. association mtgs.	0.318	0.447	0.402
% of total	34.60	65.40	100.00
Unweighted N	60.00	114.00	174.00

Appendix Table 14.A2. (continued)

Variable names	Firm size: ≥500 No PA	Any PA	Total
Total machine tools (scale)	19.00	121.00	102.00
Plant employment	230.00	595.00	530.00
Company employment (firm size)	57,862.00	23,627.00	29,807.00
Company/plant employment	673.19	85.60	191.67
Hourly wage (US$)	10.91	10.74	10.77
Dependency of machining skills (%)	16.17	53.67	46.90
Union	0.492	0.493	0.493
Complementary IT application	0.881	0.946	0.934
Customers	0.533	0.778	0.734
Customer-provided technical assistance	0.260	0.445	0.412
High flexibility requirements	0.414	0.298	0.319
Brochures, ads, newsletters	0.304	0.560	0.513
Equipment vendors' sales reps.	0.371	0.483	0.462
Informal know-how exchange	0.444	0.528	0.513
Trade & prof. association mtgs.	0.356	0.615	0.568
% of total	18.10	81.90	100.00
Unweighted N	38.00	162.00	200.00

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