Information Technology, Organizational Capabilities and Context: How do regional economies and institutions matter to the spread of innovation?*

Maryellen R. Kelley
Carnegie Mellon University
Pittsburgh, PA  15213-3890
email: mk0i@andrew.cmu.edu

or

drmrkelley@aol.com

and

Susan Helper
Case Western Reserve University
Cleveland, Ohio  44106
email: sxh23@po.cwru.edu

* This paper was presented at the annual meeting of the American Sociological Association in the Session on Computer Technology and Social Change, Toronto, August 1997. We thank Margaret Lister-Fernando and Patrick Coburn for expert assistance in constructing the final data sets. For their prior work in data preparation and documentation on this project, we acknowledge Jon Gant, Cathleen McGrath, Rob Greenbaum, and P. Davis Jenkins. The data collection effort was supported by a grant (award no. 9122155) from the National Science Foundation. The authors take sole responsibility for any remaining errors.
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Abstract

Resource dependency and institutional theories of organizational structure and economic geography are employed to explain the spread of information technology applications in manufacturing processes. We consider a number of avenues through which institutions affect the spread of three different information technology applications. We find that an ownership change is itself an institutional mechanism that disrupts routines in the acquired enterprise and serves to legitimate the adoption of new technologies. Institutional linkages employed by enterprises for purposive search and active learning promote the diffusion of knowledge about the kinds of adaptations in standard practices necessary to exploit new technologies. Only the influences from the local economy in spreading innovation – especially from regional specialization – indicate an institutionalizing process of change that reflects mimetic isomorphism whereby late adopters conform to the growing dominance of specific information technologies within more specialized regions.
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1. Introduction

In economics, technological change is recognized to be the most important factor in explaining the long term growth of the economy (Solow, 1957; Kuznets, 1971; Jorgenson and Griliches, 1967). Romer’s research (1986, 1990) shows that the mechanisms by which technological change contributes to growth occurs through knowledge spillovers. As Schumpeter (1942) described this process, the advantage gained by an enterprise that is first to innovate is whittled away by the subsequent efforts of competing enterprises to learn about these technologies and by the inability of the initial innovator to prevent such spillovers. Nelson and Winter (1977, 1982) theorize that one source of spillovers is endogenous, arising from the process of learning about a new technology that leads to improvements and understandings which are incorporated in subsequent generations of a technology and new applications. However, knowledge spillovers (and the diffusion of innovations) also imply that enterprises somehow learn from the experience of other organizations.

The mechanisms by which inter-organizational learning occurs are not well understood. Recent empirical studies show that an enterprise’s propensity to innovate is affected by place-specific attributes of the regional economy (Jaffe, Trajtenberg, and Henderson, 1993; Kelley and Helper, in press). Inter-organizational linkages also appear to be important to innovation, especially in new industries such as biotechnology (Barley, Freeman and Hybels, 1992; Powell, Koput, and Smith-Doer, 1996).

Within sociology, relations between organizations and the influences from the environment are of central interest to institutional and resource dependency theories (Aldrich, 1979; Meyer and Scott, 1983). However, much of the theorizing about institutions has tended to emphasize the passivity of organizations to prevailing norms and practices. As Tolbert and Zucker (1983, p. 25) once put it: “organizations conform to what is socially defined as appropriate and efficient, largely disregarding the actual impact on organizational performance.” In such a framework, the diffusion process is simply the result of imitation and selection mechanisms. With respect to the adoption of a process technology improvements at relatively early stages in its use – before the new technology has become dominant – this formulation would imply that institutions are a conservative force, inhibiting innovation. However, when purposive search and active learning activities of enterprises are considered, institutional linkages may serve to spread knowledge about the kinds of adaptations in standard practices necessary to exploit new technologies. Organizational inertia (and the failure to innovate) is thus related to the isolation of an enterprise from such connections and the failure to actively exploit these channels.
In this paper, we draw on resource dependency and institutional theories of organizational structure and economic geography to explain the spread of information technology applications in manufacturing processes. Our chosen technologies are all industrial applications of computers. Computers contribute to the performance of the economy in different ways. New industries specializing in business software, games, graphics, and hardware components have developed and expanded over the past twenty-five years. With respect to existing industries, computers are used in various information technology applications as powerful new tools for automation, monitoring and the control of operations. The use and variety of information technology (IT) applications expanded during the 1980s, yet some enterprises that could benefit from these applications did not adopt them. Within manufacturing, we identify three important IT applications – computer-numerical control machines (CNC), information systems for monitoring and scheduling production operations (ISMP), and computer-assisted design (CAD) systems – that were first introduced at the beginning of the 1980s. Using survey data from two different time periods for the same sample of establishments, we compare how place-specific external economies and institutional linkages affect the propensity of manufacturing enterprises in the same organizational field to adopt these technologies.

2. Organization-specific Capabilities and Experience

When a new technology is in an early stage of its development and diffusion, organizations that adopt the innovation have to be willing to invest resources in learning how to exploit its capabilities. Technological change disrupts the established routines of an organization and often requires a number of adaptations of work rules and practices to yield a performance advantage (Leonard-Barton, 1988; Tyre and Orlikowski, 1994). A process of learning by using is necessary. Some studies indicate that the benefits from a process innovation may not be apparent until several years of use has passed and there may even be short-term declines in productivity during this learning process (Chew, Leonard-Barton, and Bohn, 1991; Kelley, 1996). Hence, the willingness of an enterprise to adopt a new technology depends in part on its capabilities and resources to change existing organizational routines and to engage in a learning by doing process. Below we argue that these capabilities are related to an enterprise’s size and previous experience with related technologies.

Differences in the size of an organization are strongly related to a number of important structural and economic attributes. Economists view heterogeneity in the size of enterprises as reflecting the scale of operations to which the technology applies and hence the expected profitability of the innovation (Dosi, 1988). Size affects the expected profitability of an innovation in a number of ways. For example, Griliches (1957) found that the earliest adopters of hybrid corn were large farms. He attributed the advantages of large size to economies of scale for seed company salespeople — they had the potential to sell more seeds per visit to large farms. Both Romeo (1975) and Globerman (1975) observed that large firms were more likely to be early users of numerically controlled (NC)
Even when there are no technical constraints on the scale at which a new technology is deployed, we would still expect large organizations to have a resource advantage for engaging in a learning by doing process. A large, relatively resource-rich organization has greater internal capabilities with which to undertake a number of experiments with process innovations, without risk to its survival even if only some of these experiments prove successful (Cohen and Levin, 1989; March, 1981). Moreover, larger organizations are more likely to have slack resources and to employ specialists with expertise in setting up and implementing new technologies. Hence, viewing size advantages strictly from a resource dependency theoretical perspective (Pfeffer and Salancik, 1978), we would expect larger organizations to be more likely to adopt specific IT applications.

A second stream of research on the economics of innovation emphasizes differences in firms’ technological and organizational competencies that have accumulated as a result of experience (Cohen and Levinthal, 1990; Nelson and Winter 1977, 1982; Rosenberg 1972, 1982). In considering the adoption of a new process technology, an organization faces a great deal of uncertainty about its possible uses, how much de-bugging will be required, and how drastic a change will be required in organizational routines. Previous experience with a related technology makes it easier for managers to avoid costly disruptions of production, or at least anticipate their occurrence and hence minimize their effects. To the extent that the development of these organizational capabilities are path dependent, as Nelson and Winter have theorized, then the importance of experience will depend on how close the related technologies are to the new application. Generally, we expect that previous IT experience adds a new competency to an organization in the form of programming expertise and a knowledge of adaptation strategies for introducing these types of technological change.

3. Institutional Context, Organizational Inertia and Learning

New technologies are not adopted by all potential users immediately. When a new technology is first introduced, the advantages over existing methods are not transparent. As discussed in the previous section, a small enterprise is expected to be less likely to adopt a new technology that requires extra resources in the form of skilled technicians and slack capacity to engage in the learning by using process necessary to implement the new technology. However, early adopters’ experience with the innovation often lead to improvements that are incorporated in subsequent generations of the new technology, making it more reliable, more productive, and easier to use. A small organization can compensate for its lack of internal resources through its connections to institutions and its location in regional environments that facilitate inter-organizational learning and the spread of information about these advances in technology. Such external economies
reduce the costs for the individual enterprise of learning through an internal experimentation process.

Potential adopters frequently have trouble estimating the costs of implementing such improvements. These difficulties are magnified if the innovation is a process technology developed outside the user firm, as in the case of the IT applications we investigated. The uncertainty and the magnitude of these implementation costs can be reduced if an organization has the opportunity to learn from the experience of prior adopters. Knowledge of and insights into the experiences of other organizations can be an important way of short-cutting an internal experimentation process.

From the perspective of institutional and resource dependency theories, organizations are influenced by other enterprises belonging to the same inter-organizational field (Zucker, 1983; Aldrich and Pfeffer, 1976). The community of organizations that comprise a field share an underlying technology and common regulatory arrangements and thus are subject to the same institutional constraints (Leblebici, Salancik, Copay, and King, 1991). Institutional linkages have been commonly viewed as a source of stability and rigidity, inhibiting experimentation and innovation by the individual enterprise while supporting adherence to routines (DiMaggio and Powell, 1983; Tolbert and Zucker, 1983). In some formulations (Baum and Oliver, 1991; Lincoln, Gerlach, and Ahmadjian, 1996; Miner, Amburgey, and Stearns, 1990), institutions that link enterprises to one another are conceptualized as a resource for “buffering” an organization from the turbulence of its environment, reducing the volatility in profits related to business cycle fluctuations and enhancing its chances of survival.

Previous studies suggest that institutional linkages may actually accelerate (rather than retard) the diffusion of innovations in early stages. For example, Burt’s research (1980) shows that individuals who are well-connected to professional groups are more likely to learn about an innovation – and to adopt it sooner – than individuals who do not belong to such associations. Similarly, Saxenhouse (1974) identifies local trade associations as a key factor in the rapid diffusion of new techniques among small Japanese textile manufacturers in the late 19th century. These institutional mechanisms do not serve simply to legitimate new practices, but provide a means of bridging the gap in knowledge between leading innovators and those organizations that lack their experience. In institutional milieus where information about hard-earned competencies in using new techniques is shared, the adoption of these techniques will spread more quickly. Hence, rather than being passive receptors of institutional forces, the inter-organization transfer of such knowledge involves purposive search for relevant information and active learning by organizations.
Certain institutional ties support inter-organizational learning. One type of linkage is informal, where information sharing among a community of organizations is the norm. More formal mechanisms for promoting inter-organizational learning include participation in the meetings of industry associations and professional societies and contacts with technology vendors who are willing to demonstrate the use of new equipment. Trade associations also alert their members about pending technological developments and provide forums in which member organizations share information about their adaptation strategies. Hence, organizations with either type of connection are more likely to find out about the benefits of a new technology in the first place, and to have better information about costly problems of implementation and the methods and techniques prior adopters have used to avoid or minimize these costs.

Within economics, a parallel theoretical development known as evolutionary economics emphasizes the importance of organizational routines in limiting the range of choices considered by management in making strategic decisions. Building on Simon’s theory (1957) of bounded rationality, Nelson and Winter suggest that management decisions are constrained by their previous experience which is embodied in current organizational routines and practices. In organizations with established technologies and standardized operating procedures, managers will tend to focus on familiar problems and to prefer solutions that involve only minimal disruption of existing procedures. Organizational inertia — the tendency to persist in relying on previously established routines — deters management from shifting to a new technological paradigm, ceteris paribus.

These routines are often disrupted when a change in ownership occurs. New owners usually bring new upper-level managers with experience acquired outside the enterprise. The new leadership legitimates a break with past practices. All else being equal, we expect this new management to be a force for change. For establishments that survive a takeover, the new decision-makers are more likely to introduce changes that promise to improve performance, including investment in new paradigm-shifting technologies.1

4. Place-specific External Economies

Two reasons why geographic factors might explain differences in innovative behavior among organizations are localization and urbanization economies (Chinitz, 1961; Hoover, 1971; Isard, Schooler, and Vietorisz, 1959). Localization economies refer to externalities associated with the presence in a place of a mass of other producers in the same sector. Urbanization economies result when firms from different industries concentrate in the same place. The diverse industrial base, the extensive infrastructure and services (e.g., transportation, utilities and various business services) supporting it, and the concentration of institutions that generate new knowledge are sources of urbanization economies that contribute to the wealth and growth of a metropolitan area. Considerable
effort has been devoted to exploring the extent to which these factors contribute to long
term growth and productivity differences among regions. However, few researchers have
analyzed the impact of regional agglomeration on the use of new technologies, even
though many of the arguments about the contribution of agglomeration economies to
growth assume there are important knowledge spillovers among organizations in regions
with such external economies.

Recent research in economic geography and the political economy of regions
suggests that organizations derive a learning advantage from being located in a highly
specialized region. These external economies accumulate over extended periods of time
from the co-location of a large mass of technically inter-dependent (and innovative) firms,
as noted by Saxenian (1994) with respect to the computer software and hardware
producers in Silicon Valley, among automobile manufacturing enterprises in certain
regions of Japan, such as Toyota City (Sako, 1992; Cusamano, 1985), and the complex of
industrial machinery manufacturers in the Baden-Wuerttemberg region of Germany
(Herrigel, 1992). Localization economies are not merely the result of a Darwinian
selection process whereby organizations with superior capabilities are recruited to the
locale. Rather, in such regions, technology vendors are more likely to provide services in
customizing IT use because of the external economies of scale from the concentration of
enterprises with similar problems and needs. Moreover, trade associations are likely to
have large local chapters in regions with relatively high concentration of enterprises in the
same technical field and, as a consequence, will have greater resources to provide
specialized services to their members.

There are two aspects of urbanization economies that are particularly relevant to
technology diffusion: those stemming from the greater diversity of the industry mix
associated with an urbanized locale, and those associated with the concentration of
knowledge-generating institutions in metropolitan areas. A diverse industry mix in a
region makes it more likely that managers will be in contact with counterparts in industries
other than their own, making it easier to learn about an innovative practice originating
outside their own industry (Jacobs, 1967). Moreover, new technologies and the skilled
workers needed to deploy them are often developed outside the industry in which they are
used. A more urban economy offers a labor force with a broader mix of skills, including
new skills that are important to making the shift to a new technological trajectory. For
example, computer programmers and systems analysts are needed to implement
information technology applications, but the industries largely responsible for generating
these skills (that is, computer manufacturers and software companies) are not the same as
the ones using the equipment. In locales with a diverse industrial base, the chances of a
firm finding workers who already have the new skills related to the use of a new
technology are much higher – and therefore the costs of training will be lower – than
would be the case for firms situated in regions that lack such urbanization economies.
Supportive specialized services, research institutions, distribution networks, and supply arrangements associated with diverse locales provide another source of spillovers of technical information (Storper and Scott, 1989). The concentration of universities in urban areas, in particular, provides a number of advantages to local firms: the opportunity to employ new graduates familiar with the latest research and technologies developed in universities, and a greater chance to engage in industry-university research collaborations (Kelley and Arora, 1996; Rahm, 1994). We expect the information spillovers from a high concentration of specialized technical institutions to lead to higher rates of adoption of new technology among nearby firms.

5. Data Description

Our data come from two national surveys conducted in 1987 and 1991 regarding the use of three types of information technology by enterprises making machined products: computer numerically controlled (CNC) machine tools, computer-aided design (CAD), and information systems for monitoring and scheduling the flow of parts through production (ISMP).

All establishments in the sample use precision metal-cutting tools to make machined products. Hence, they are all potential adopters of computer-numerical-controlled (CNC) technology. CNC is a type of programmable automation based on microprocessors that was introduced commercially in the late 1970s. CNC provides a greater degree of flexibility than the earlier numerical-control (NC) version of the technology first studied by Romeo (1975). CNC represents a new generation of programmable automation with its interactive software capabilities, that allow programming to be performed by skilled operators at their machines instead of specialized technicians who write programs off the shop floor (Shaiken, Herzenberg, and Kuhn, 1986; Kelley, 1990). Kelley’s research (1994) shows that adoption of CNC significantly reduced both machine and labor hours per unit of output compared to conventional machine tools regardless of the firm’s scale of machining, the skills of the workforce, and wages. Moreover, Helper (1995) indicates that CNC provides economies of scope, allowing a greater variety of products to be made at lower change-over costs than on conventional machines.

Computer-based information systems for process monitoring and scheduling improve an organization’s performance by better matching jobs to machines, thus allowing both higher capacity utilization and reduced lead time. Reduction in lead times is particularly important for the ability of an enterprise to comply with the demands of a just-in-time production system. Higher capacity utilization increases the productivity of existing capital.
Computer-aided design (CAD) is another type of information technology that has the potential to improve a manufacturing enterprise’s performance significantly. CAD allows an engineer to try out a variety of designs, testing for style and function in a matter of hours or days. In contrast, the traditional practice of drawing a design on paper and having a clay or wooden model made could take weeks. In addition, CAD instructions can be transmitted directly to CNC machines, reducing lead time and eliminating errors due to mistakes in hand transfer of information from blueprints.

A size-stratified random sample of establishments was selected from 21 industries (at the 3-digit SIC level) in which machined products constitute an important intermediate or final product.\(^4\) Completed mail surveys were obtained from 1,015 production managers responsible for the machining operations at their plant in 1986-87; another 348 completed a shorter telephone interview in 1987. All plants surveyed in 1986-87 that still made machined products in 1991 were surveyed again.\(^5\) Table 1 shows the adoption rates of three production-focused IT applications in the 1987 and 1991 samples. CNC was the most widely used IT in 1987 and continued to spread during the intervening years. By 1991, more than half of all establishments had adopted this technology. By contrast, CAD was the least used information technology among establishments in the surveyed industries in 1987, but spread at more than 1.7 times the rate of CNC and ISMP technologies between 1987 and 1991.
<table>
<thead>
<tr>
<th>Information Technology Application</th>
<th>Percent of All Plants:</th>
<th>Percent Change:</th>
</tr>
</thead>
<tbody>
<tr>
<td>CNC</td>
<td>35.6%</td>
<td>52.9%</td>
</tr>
<tr>
<td>ISMP</td>
<td>30.5%</td>
<td>45.0%</td>
</tr>
<tr>
<td>CAD</td>
<td>21.1%</td>
<td>39.1%</td>
</tr>
</tbody>
</table>
Our analysis of information technology adoption is confined to those plants that had not adopted the specific IT application by 1987. Of the 337 plants in the sample from the 1986–87 mail survey that had not adopted any CNC machines and that survived to 1991, 322 plants had complete information on the relevant variables for the two periods. For the 292 non-adopters of ISMP technology in the 1986-87 survey that survived and completed the 1991 survey, we had complete information for 282 plants. And for the 444 plants that did not have CAD in the 1986-87 sample and participated in the 1991 survey, we have complete information on 428 establishments.

We matched the survey data for establishments that had not adopted these technologies by 1987 with geographic information from various public sources about the places in which these facilities were located in 1987. Because we have information on two different time periods, we are able to specify organization- and place-specific attributes and institutional linkages that precede the technology adoption decision.

Our geographic unit of analysis is the Bureau of Economic Analysis (BEA) economic area as defined in 1983. Each BEA area consists of groups of counties around a center of economic activity such as a metropolitan area. In establishing the boundaries of BEA areas, commuting patterns were the main consideration. More than 80 percent of BEA areas in the United States had net commuting rates to and from other BEA areas of 1 percent or less. Hence, firms in the same BEA area can be assumed to draw upon the same labor force, local infrastructure, and local institutions.

Data on place-specific external economies come from four sources. The Center for Economic Studies of the U.S. Bureau of the Census provided information on employment in the twenty-one industries in each county in the continental U.S. in 1982 and 1987, based on the Census of Manufactures. Data on engineering degrees awarded between 1982 and 1987 were compiled by the Center for Regional Economic Issues at Case Western Reserve University from the National Science Foundation’s CASPAR Data Base System, version 4.4. Information concerning employment in all industries was compiled from the Census Bureau’s 1987 County Business Patterns. Data on the total labor force in a county come from the 1980 Census of Population.

5. Estimation and Specification Issues

We estimated three logit regression models for the sample of surviving non-adopters of each IT application. Table 2 describes each variable and shows the means and standard deviations for each of the sub-samples of the 1986-87 non-IT adopters that survived and responded to the 1991 survey. Note that only about 1 in 5 non users of CNC in 1987 had adopted that technology by 1991. For both ISMP and CAD, the rates of adoption are much higher, although the overall penetration rates of these technologies in the 1991 sample show that these applications are still not as widely used as CNC. CNC
appears to be at a later stage in its diffusion process, and spreading more slowly among potential adopters. As we shall see, an important reason for the slower pace of change is that the potential population of CNC adopters lack any experience with related technologies and are more dependent on the external environment for learning about the adaptations of organizational routines necessary to exploit this innovation.
Table 2: Means and Standard Deviations of Regression Variables and Definitions

<table>
<thead>
<tr>
<th>Information Technology Application:</th>
<th>CNC</th>
<th>ISMP</th>
<th>CAD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent of non adopting organizations (1987), with IT Application in 1991</td>
<td>20.9% (n=322)</td>
<td>35.9% (n=282)</td>
<td>32.4% (n=428)</td>
</tr>
</tbody>
</table>

**Organizational Attributes**

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Mean</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size (log of number of employees in 1986)</td>
<td>2.488</td>
<td>1.154</td>
<td>2.320</td>
<td>0.959</td>
<td>2.583</td>
<td>1.106</td>
</tr>
<tr>
<td>Experience with related technologies, 1987 or earlier:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NC use (1=yes, 0=no)</td>
<td>0.135</td>
<td>0.342</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>CNC or other IT application (1=yes, 0=no)</td>
<td>---</td>
<td>---</td>
<td>0.430</td>
<td>0.495</td>
<td>0.498</td>
<td>0.500</td>
</tr>
</tbody>
</table>

**Institutional Context**

| Management actively using formal and informal institutions for learning about new technologies in 1987 (1=yes, 0=no) | 0.552 | 0.497 | 0.564 | 0.495 | 0.580 | 0.494 |
| Change in business ownership, 1987-91 (1=yes, 0=no) | 0.132 | 0.339 | 0.131 | 0.338 | 0.160 | 0.367 |

**Regional Economy**

| Specialization in machined products Industries (1987) | 1.154 | 0.521 | 1.130 | 0.516 | 1.154 | 0.522 |
| Diversity of industrial activity across all sectors (1987) | 0.964 | 0.004 | 0.964 | 0.004 | 0.964 | 0.004 |
| Concentration of new graduates from engineering colleges (1982-87) | 0.071 | 0.095 | 0.073 | 0.088 | 0.074 | 0.088 |

**Industry and Region Controls**

| SIC 34 (1=yes, 0=no) | 0.208 | 0.406 | 0.171 | 0.376 | 0.186 | 0.389 |
| SIC 35 (1=yes, 0=no) | 0.663 | 0.473 | 0.756 | 0.429 | 0.733 | 0.442 |

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1. For ISMP, other IT includes any of the following: CNC, CAD, or computerization of quality and inventory control systems. For CAD, other IT includes CNC, ISMP, or computer use in quality and inventory control systems.

2. Where the plant's production manager reported on the 1987 survey that he/she participated in the meetings of professional societies and trade associations or had informal contacts with managers/engineers at other, similar enterprises and considered these activities to be important sources for learning about relevant new technologies. this variable =1. If plant management did not have such contacts (i.e., was isolated from such institutional ties) or did not consider them to be important for learning about new technologies, variable =0.

3. For the ith BEA area, Specialization in Machined Products Industries = Machined Products Sector Location Quotient, where

\[
\text{Location Quotient}_i = \left( \frac{\text{employment in machined products industries in BEA}_i}{\text{employment in all manufacturing industries in BEA}_i} \right) / \left( \frac{\text{employment in machined products industries in U.S.}}{\text{employment in all manufacturing industries in U.S.}} \right)
\]

4. For the ith BEA area, Diversity of Industrial Activity = 1-Hirschman/Herfindahl Index, where

\[
\text{HHI}_i = \frac{\sum_{j} (\text{employment in industry}_j / \text{employment in all industries})^2}{\sum_{j} \text{employment in industry}_j / \text{employment in all industries}}
\]


6. For the ith BEA area, Growth in the Machined Products Sector (1987) = \(\frac{(1987 \text{ employment in machined products industries in BEA}_i - 1982 \text{ employment in machined products industries in BEA}_i) * 100}{1982 \text{ employment in machined products industries in BEA}_i}\).

7. Region’s size = the loge (total 1980 labor force) in the BEA area.
The first set of models estimate the likelihood of IT use as a function of organizational attributes and the institutional context. The results of that estimation are shown in Table 3. For all three types of IT application, the larger the organization in 1986, the more likely it is to adopt the new technology by 1991. In addition to size, we find consistent effects of experience on adoption. An establishment that had some experience with a related technology in 1987 was significantly more likely to adopt another specific IT application (or the next generation of technology, as in the case of experience with NC) by 1991. Although institutional linkages have the predicted sign (+) in all equations, the results are not always statistically significant. With respect to the effect of a change in business ownership, our results are consistent with our hypotheses and are statistically significant for predicting CNC and CAD adoption, but not the use of ISMP.
Table 3: Logistic Regression Results for the Effects of Organizational Characteristics and Institutional Factors on the Adoption of CNC, ISMP, and CAD in 1991

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Organizational Size (1986)</td>
<td>0.5321*** (0.1481)</td>
<td>1.2862*** (0.2186)</td>
<td>0.3489*** (0.1194)</td>
</tr>
<tr>
<td>Experience with Related Technologies, 1987 or earlier:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Any NC Use</td>
<td>2.9037*** (0.4326)</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>CNC or Other IT Use</td>
<td>---</td>
<td>0.6467* (0.3185)</td>
<td>0.9200*** (0.2924)</td>
</tr>
<tr>
<td>Institutional Context</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Management Actively Using Formal and Informal Institutions for Learning about New Technologies in 1987</td>
<td>0.4552 (0.3657)</td>
<td>0.6087* (0.3121)</td>
<td>0.1835 (0.2304)</td>
</tr>
<tr>
<td>Change in Business Ownership, 1987-91</td>
<td>1.2833** (0.4482)</td>
<td>0.7075 (0.4568)</td>
<td>0.5268† (0.2924)</td>
</tr>
<tr>
<td>Industry Controls</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SIC 34</td>
<td>1.2759† (0.6944)</td>
<td>0.5215 (0.6709)</td>
<td>-0.1166 (0.4711)</td>
</tr>
<tr>
<td>SIC 35</td>
<td>1.2786* (0.6375)</td>
<td>-0.0969 (0.6083)</td>
<td>0.1530 (0.4163)</td>
</tr>
<tr>
<td>Intercept</td>
<td>-4.9826*** (0.8900)</td>
<td>-4.4460*** (0.8209)</td>
<td>-2.4817*** (0.5399)</td>
</tr>
<tr>
<td>-2Log Likelihood</td>
<td>231.977</td>
<td>276.384</td>
<td>483.057</td>
</tr>
<tr>
<td>$\chi^2$</td>
<td>97.989***</td>
<td>91.917***</td>
<td>55.780***</td>
</tr>
<tr>
<td>Number of Parameters</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Number of Observations</td>
<td>322</td>
<td>282</td>
<td>428</td>
</tr>
</tbody>
</table>

*** Statistically significant at p ≤ .001
** Statistically significant at p ≤ .01
† Statistically significant at p ≤ .10
* Statistically significant at p ≤ .05
The regression results shown in table 4 include three indicators for different sources of agglomeration economies: specialization in machined products industries (1987), diversity of industrial activity across all sectors (1987), and the concentration of new graduates from engineering colleges located in the region (from 1982 to 1987). These measures of the local economy are computed for the entire group of counties comprising each BEA area.

*Specialization in machined products industries (1987)* is our indicator for localization economies and it is measured by the location quotient for the 21 machining-intensive industries listed in note 4. Values greater than 1 indicate BEA areas that have an above-average degree of specialization in machined products compared to the nation as a whole.

*Diversity of economic activity (1987)* measures one aspect of urbanization economies. We follow Henderson (1994) in using the Hirschman-Herfindahl Index (HHI) as our indicator of diversity. This index is computed as the sum of squared employment shares for each industry at the two-digit SIC level. The HHI ranges between 0 and 1, with high scores on the HHI indicating a low level of diversity. For ease of interpretation, diversity of economic activity is defined as 1-HHI, so that a high score indicates a highly diverse regional economy.

*Concentration of new graduates from engineering colleges (1982-87)* is our second indicator of urbanization economies. We take this number to be an indicator of the prominence of knowledge-generating institutions in the BEA area that specialize in fields of particular relevance to the IT applications relevant to this industrial sector. More degrees granted in electrical or mechanical engineering fields imply a greater potential local labor supply for new engineering skills, and lower costs of recruiting engineers for the firms that need these skills. This measure also serves as an indicator of the density of applied university-based R&D and the availability of local faculty consultants in fields relevant to this sector. For these reasons, we expect there to be both technical information and human capital spillovers that increase the likelihood that nearby firms will adopt CNC technology, ceteris paribus. To adjust for differences in population among BEA areas, we divide the number of degrees by the size of the population (in 10,000’s) in the BEA area as reported in the 1980 census.

*Percent change in machined products sector employment (1982-87)* is a measure of how favorable a region is as a place for expansion of the machined products sector. Other place-specific factors that are favorable to the growth of this sector but which are independent of the influences from our measures of localization and urbanization economies are presumed to be correlated with the growth of that sector in the region. The higher the growth rate over a period of time, the greater the incentive to invest in new
technology. Since data on sales revenue were not available, we used employment growth in the BEA area for the selected 21 industries over the previous five year period as our indicator for local demand for machined products. We expect the effect of the sector’s growth in the region in the previous period (1982-87) to affect subsequent decisions (in 1991) to invest in new technology.

There are 183 BEA areas in the United States. They differ greatly in the size of the population and in area. In all equations with geography variables, we included the log of the number of people in the 1980 labor force of the BEA area as a control for the size of the BEA area.
Table 4: Logistic Regression Results for Adoption of CNC, CAD, and ISMP in 1991, including Influences from the Regional Economy

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Organizational Size (1986)</td>
<td>0.5766***</td>
<td>1.3026***</td>
<td>0.3397**</td>
</tr>
<tr>
<td>(0.1633)</td>
<td>(0.2300)</td>
<td>(0.1229)</td>
<td></td>
</tr>
<tr>
<td>Experience with Related Technologies, 1987 or earlier:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Any NC Use</td>
<td>3.6428***</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>(0.5233)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CNC or Other IT Use</td>
<td>---</td>
<td>0.7087*</td>
<td>0.9539***</td>
</tr>
<tr>
<td></td>
<td>(0.3307)</td>
<td>(0.2710)</td>
<td></td>
</tr>
<tr>
<td>Institutional Context</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Management Actively Using Formal and Informal Institutions for Learning about New Technologies in 1987</td>
<td>0.9044*</td>
<td>0.5494†</td>
<td>0.2273</td>
</tr>
<tr>
<td>(0.4094)</td>
<td>(0.3349)</td>
<td>(0.2375)</td>
<td></td>
</tr>
<tr>
<td>Change in Business Ownership, 1987-91</td>
<td>1.3736**</td>
<td>0.6242</td>
<td>0.5524†</td>
</tr>
<tr>
<td>(0.5014)</td>
<td>(0.4719)</td>
<td>(0.3026)</td>
<td></td>
</tr>
<tr>
<td>Regional Economy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specialization in Machined Products Industries (1987)</td>
<td>0.8418*</td>
<td>0.6768*</td>
<td>-0.3603</td>
</tr>
<tr>
<td>(0.4041)</td>
<td>(0.3277)</td>
<td>(0.2371)</td>
<td></td>
</tr>
<tr>
<td>Diversity of Industrial Activity across all sectors (1987)</td>
<td>192.6***</td>
<td>-2.8612</td>
<td>3.7842</td>
</tr>
<tr>
<td>(55.1800)</td>
<td>(48.2981)</td>
<td>(33.7476)</td>
<td></td>
</tr>
<tr>
<td>Concentration of new graduates from engineering colleges (1982-87)</td>
<td>4.4908**</td>
<td>-0.3595</td>
<td>1.4596</td>
</tr>
<tr>
<td>(1.7722)</td>
<td>(2.0376)</td>
<td>(1.2815)</td>
<td></td>
</tr>
<tr>
<td>Growth in the Machined Products Sector (1982-87)</td>
<td>0.0317***</td>
<td>-0.0016</td>
<td>0.0061</td>
</tr>
<tr>
<td>(0.0099)</td>
<td>(0.0081)</td>
<td>(0.0058)</td>
<td></td>
</tr>
<tr>
<td>Industry and Region Controls</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Size of the Region (1980)</td>
<td>-0.2676</td>
<td>0.0244</td>
<td>-0.0177</td>
</tr>
<tr>
<td>(0.2322)</td>
<td>(0.1730)</td>
<td>(0.1245)</td>
<td></td>
</tr>
<tr>
<td>SIC 34</td>
<td>1.4336†</td>
<td>0.4197</td>
<td>-0.0879</td>
</tr>
<tr>
<td>(0.7750)</td>
<td>(0.6805)</td>
<td>(0.4744)</td>
<td></td>
</tr>
<tr>
<td>SIC 35</td>
<td>1.1773</td>
<td>-0.0771</td>
<td>0.0853</td>
</tr>
<tr>
<td>(0.7303)</td>
<td>(0.6132)</td>
<td>(0.4228)</td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>-188.8***</td>
<td>-2.8235</td>
<td>-5.5407</td>
</tr>
<tr>
<td>(52.8009)</td>
<td>(46.2844)</td>
<td>(32.0983)</td>
<td></td>
</tr>
<tr>
<td>-2Log Likelihood</td>
<td>200.307</td>
<td>270.990</td>
<td>478.020</td>
</tr>
<tr>
<td>χ²</td>
<td>129.659***</td>
<td>97.311***</td>
<td>60.818***</td>
</tr>
<tr>
<td>Number of Parameters</td>
<td>11</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>Number of Observations</td>
<td>322</td>
<td>282</td>
<td>428</td>
</tr>
</tbody>
</table>

*** Statistically significant at p ≤ .001
** Statistically significant at p ≤ .01
* Statistically significant at p ≤ .05
† Statistically significant at p ≤ .10
When regional attributes are added to the regression models, the organizational attributes of size and experience remain statistically significant. Institutional linkages that promote inter-firm learning become significant and have a greater effect on the adoption of CNC, once differences in the regional economies in which a plant is located have been taken into account. By contrast, when attributes of the regional economy are included in the model, the effect of such learning opportunities is diminished (but remains statistically significant) in explaining ISMP use.

For the different attributes of a regional economy, we find evidence that localization economies are important to the spread of both CNC and ISMP use. However, our two indicators of urbanization economies and the effect of growth of machined products industries within the region are only significant factors in explaining the adoption of CNC in 1991. We find no evidence that regional attributes or institutional linkages for learning from the experience of other enterprises affect the spread of CAD.

6. Discussion of Findings

Compared to the other types of IT application, CNC use in 1991 is more likely to be influenced by a combination of regional and institutional factors. By the late 1980s, this IT application was widely adopted in machined products industries. Between 1987 and 1991, the factors influencing its spread are largely external to the organization, arising from institutional connections and agglomeration economies, suggesting that the institutionalization of this innovation is the result of a combination of purposive search and “mimetic isomorphism” (DiMaggio and Powell, 1983). By 1991, CNC had become the preferred (and dominant) technology for precision metal cutting operations. An enterprise that lacks inter-organization ties for learning about this innovation or happens to be located in a less munificent region, i.e., in a place that lacks urbanization and localization economies, are more likely to persist in using conventional, non-programmable machining technology.

Although our results show that organizational size and experience with a related technology to be significant predictors of IT use in 1991, there are substantial differences in the magnitude of the effects of these variables by type of technology. Comparing the effects of organizational size (shown in figure 1)\(^9\), we see that there are very small increases in the predicted probabilities of CNC and CAD adoption related to comparable increases in size of an organization. By contrast, for the same difference in organizational resources, we find a larger effects on the probability of ISMP adoption.

With respect to experience with a related technology, figure 2 shows that the previous experience with NC machines has a far greater effect on subsequent CNC use than experience with related IT use has on subsequent ISMP or CAD adoption.\(^{10}\) One interpretation of this result is that IT use is path dependent, as Nelson and Winter’s
evolutionary theory of technological change would predict. The closer the related technology is to the new IT application, the more relevant is the knowledge learned from using it and the easier it is to modify organizational routines to accommodate the new technology. However, the effect of any previous experience with production related IT applications is still quite important: nearly doubling the chances of ISMP and CAD adoption in 1991. Clearly, there are some general capabilities in programming and in changing organizational practices which carry over from one IT use to another.

Moreover, in other specifications (not shown), we tested for the influence of previous CNC use in 1987 – independent of other types of IT experience – on CAD and on ISMP adoption in 1991. The results of that analysis shows that CAD adoption – but not subsequent ISMP use – is strongly related to experience with CNC. We interpret this finding to suggest that the experience of proofing out of programs through the use of visual graphics technologies is more closely related to CAD than other IT applications, since the transition to CAD involves the exploitation of that same graphics technology for design purposes.
Figure 1: The Effects of Organizational Size in 1986 on the Probability of Adoption of CNC, ISMP and CAD Technologies in 1991

![Graph showing the probability of IT adoption for CNC, ISMP, and CAD technologies based on the size of the establishment in 1986.](image-url)
Figure 2: Predicted Probability of IT Adoption in 1991 with and without Previous IT Experience
In figures 3 and 4, we compare the magnitude of the effects of the institutional environment on the adoption of IT, for those applications where these factors were statistically significant in the regression models shown in table 4. The increased chances of adoption from institutional factors are the greatest for CNC use, compared to the effects on ISMP or CAD adoption. For enterprises with inter-organizational learning connections, the chances of CNC adoption are twice that of enterprises without such ties. For those organizations that underwent a change in ownership, the chances that new management will introduce CNC are more than triple those of plants that have had the same owners during the 1987-91 period. In contrast, the effects of institutional linkages on ISMP use and a change in ownership on the adoption of CAD are much smaller.

The only regional factor that significantly influences the adoption of IT applications other than CNC is the effect of localization economies. In figure 5, we compare the predicted effects from the degree of a region’s specialization in machined products industries on the adoption of CNC and ISMP use. In this case, the learning spillovers from location in regions with similar degrees of specialization in machined products industries are much higher for the ISMP technology than for CNC use. Moreover, the gap in the effects of localization economies on the predicted use of these new technologies widens, the more specialized the region.
Figure 3: The Predicted Effects of Management's Participation in Informal and Formal Technology Transfer Institutions on the Probability of Adopting CNC and ISMP Technologies in 1991

- Isolated or not actively involved in professional or trade associations in 1987
- Actively engaged in seeking out information from trade or professional associations in 1987
Figure 4: The Predicted Effect of a Change in Business Ownership on the Adoption of CNC and CAD Technologies in 1991

- **Same Business Owners, 1987 & 1991**
- **Business Ownership Change between 1987 & 1991**

Probability of IT Adoption in 1991

- **CNC**:
  - 0.100
  - 0.304
- **CAD**:
  - 0.281
  - 0.405

Type of Information Technology
Figure 5: The Effects of the Degree of a Region’s Specialization in Machined Products in 1987 on the Adoption of CNC and ISMP Technologies in 1991
7. Conclusions

We find strong and consistent evidence that large organizations are more willing to engage in the learning by doing process necessary to adopt IT applications. There also seems to be inter-relatedness among IT production applications. Organizations with previous experience in using one or another type of IT are more likely to adopt ISMP and CAD.

Our results indicate that institutions do not always serve a conservative function to reinforce norms and legitimate established practices and technologies. Instead, certain types of institutional linkages provide a window through which experience from other organizations can be observed. The benefits from such institutional ties are realized by organizations that actively exploit these opportunities for inter-organizational learning. When the management of an organization uses its linkages to others (in the same inter-organizational field) to actively search for information and learn from others’ experiences, there is a greater chance of adopting a new technology. Moreover, such connections broaden the scope of an organization’s knowledge of innovations which were developed outside the community of organizations that comprise its own specialized field.

From 1987 to 1991, we estimate that 14 percent of all establishments in the machined products industries were acquired by another firm or spun off as an independent enterprise.\textsuperscript{11} Previous research on mergers and acquisitions (Pfeffer, 1972; Pfeffer and Nowak, 1976) from a resource dependency perspective has explained this re-structuring in terms of inter-organizational dependencies. When viewed from an institutional theoretical frame, ownership changes can be considered an instrument for disrupting the organizational routines of the acquired entity and for legitimating changes in methods and techniques that promise to improve organizational performance. For two types of IT – CAD and CNC – a change in ownership increases the likelihood of investment in the new technology.

With respect to the regional economy, regions with a high concentration of enterprises in the same industries facilitate the adoption of CNC and ISMP technologies. In such regions, potential adopters of these technologies have a greater chance of contact with early adopters of a new technology and greater access to more information about how these technologies are being used within their own specialized industrial community. Moreover, within such concentrations, there is likely to be greater pressure to imitate the practices of leading enterprises. Hence, there may be bandwagon effects from the greater mass of enterprises in the region that belong to the same inter-organizational field. That suggests that there may be regional differences in the extent to which mimetic isomorphism is a strong institutional force in the diffusion of new technologies. The
external economies from regional agglomeration do not provide knowledge spillovers equally for different types of IT applications. The benefits from localization economies are specific to CNC and ISMP technology adoption decisions of firms in the 1987-91 period, but not the decision to use CAD. The adoption of CAD is unaffected by region-specific factors of any kind.

CAD use appears to be influenced the least by contextual factors. We cannot tell from our results whether this has to do with the relatively early stage of the technology’s diffusion or its path dependence. At an early stage in the diffusion of a new technology, we expect the pioneering organizations – those that adopt an innovation early – are more willing to engage in an internal, experimental learning by doing process. We posited that the willingness to experiment with various IT uses to be a function of organizational size and experience. Differences in experience and organizational size are important predictors of CAD and other IT uses. Hence, our findings confirm the importance of these factors in the spread of process technology innovations. The absence of regional influences on CAD use may mean that this technology is at too early in its stage in the diffusion to have built up the associated regional infrastructure in business services important to its use. Alternatively, the absence of regional influences may indicate that CAD use is more path dependent than the other IT applications we studied, implying that experience with IT applications – especially CNC use – will continue to be the most important factor (independent of size) affecting the spread of this innovation.

Compared to ISMP and CAD, experimentation with programmable forms of automation the machining process has a much longer history. According to Noble (1986), NC technology – the predecessor technology for CNC – was commercially available more than twenty years before the 1986-87 survey. Hence, the regional and institutional infrastructure supporting the development of programmable automation has had a much longer time to develop. That existing infrastructure provided support for the rapid spread of CNC use in the 1980s. By 1991, CNC had become the dominant technology for programming and controlling precision metal cutting machines. Our findings for CNC provide the strongest support for the thesis that the institutional and regional contexts condition the speed at which innovations spread – especially among smaller enterprises and those lacking experience with related technologies, as appears to be the case for most of the pool of potential CNC adopters we studied. More generally, these results suggest that the importance of the regional context is conditional on the stage of a technology’s diffusion and the pace at which technological change occurs. When change is slow, as in the case of CNC development and use, the related infrastructure of technical services that we identify with agglomeration economies has sufficient time to develop. When technological change is rapid, as in the case of CAD, organizational capabilities and technically related experiences matter the most.
We have theorized that purposive activity undertaken by an organization in relation to its institutional environment is important to the spread of innovation. The strategic choices management makes in attending to influences from the environment affect the spread of innovations. Our results show that when institutional linkages are exploited as opportunities to learn about the experience of other enterprises and for their connections to the developers of a new technology that are outside a particular inter-organizational field, innovation diffuses more rapidly. The conservative aspects of institutions on organizational practices are embedded in bureaucratic routines. An ownership change is itself an institutional mechanism that disrupts such routines in the acquired enterprise. New owners bring new managers who mandate changes in past practices. Such leadership changes shake up organizational routines and serve to legitimize the adoption of new technologies. Finally, we interpret the influences from the local economy in spreading innovation—especially from regional specialization—as indicative of institutionalizing processes affecting the use of information technologies in manufacturing. The spread of CNC and ISMP use between 1987 and 1991 is at least in part the result of imitation and conformance to the growing dominance of specific information technologies within more specialized regions.
References


31


Notes

1 Organizations that do not survive a takeover are not included in our samples.


3 For example, nine of the local chapters of the National Tooling and Machining Association are located in locales specializing in tool and die making. In these locales, the local association provides its own apprenticeship program to train workers in the use of CAD, CNC and other technologies.

4 The industries are: 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 (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).

5 For the 1987 sample, the response rate for the mail survey was 52.8%, and for the combined telephone and mail surveys in 1986-87, the effective response rate was 89.4%. A random sample of one-half of the non-respondents to the 1987 mail survey were telephoned. Respondents to the shorter telephone survey were more likely to be rapidly growing firms and to have adopted CNC. Hence, the response bias associated with the 1986-87 mail survey, such that it is, somewhat over-represents non-adopters of CNC technology. Of the original sample of 1,363 plants, 1,164 of them survived and were still manufacturing machined products in 1991. For these surviving plants, the effective response rate to the 1991 telephone survey was 83.6%.

6 For a complete list of BEA areas and a discussion of their construction, see Johnson and Spatz (1993).
Since the sample is size stratified, each observation is weighted by the reciprocal of the probability of selection into the sample stratum.

The location quotient is the most commonly employed indicator for comparing the degree of specialization of a region in a selected set of industries (Bendavid-Val, 1991, pp. 73-75).

The estimates of the predicted probabilities of IT adoption for each of the technologies shown in the figures were derived using the following method.

For each variable $X_j$ of value $V$,

\[
(1) \quad Z_j = \sum_{i=1}^{11} b_i X_i + b_j(X_j), \quad i \neq j 
\]

\[
\text{and} 
\]

\[
(2) \quad \text{Prob} (\text{Adopt IT} = 1 \mid X_j = V) = \frac{(e^{Z_j})}{(1 + e^{Z_j})}. 
\]

In other specifications (not shown), we found that the experience with other IT (not NC) had no effect on CNC adoption.

Among branch plants of large enterprises, changes of ownership are more common. Twenty-five percent experienced such a change between 1987 and 1991.