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TECHNOLOGY DIFFUSION AND ORGANIZATIONAL LEARNING: THE CASE OF BUSINESS COMPUTING*

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The dominant explanation for the spread of technological innovations emphasizes processes of influence and information flow. Firms which are closely connected to pre-existing users of an innovation learn about it and adopt it early on. Firms at the periphery of communication networks are slower to adopt.

This paper develops an alternative model which emphasizes the role of know-how and organizational learning as potential barriers to adoption of innovations. Firms delay in-house adoption of complex technology until they obtain sufficient technical know-how to implement and operate it successfully.

In response to knowledge barriers, new institutions come into existence which progressively lower those barriers, and make it easier for firms to adopt and use the technology without extensive in-house expertise. Service bureaus, consultants, and simplification of the technology are examples. As knowledge barriers are lowered, diffusion speeds up, and one observes a transition from an early pattern in which the new technology is typically obtained as a service to a later pattern of in-house provision of the technology.

Thus the diffusion of technology is reconceptualized in terms of organizational learning, skill development, and knowledge barriers. The utility of this approach is shown through an empirical study of the diffusion of business computing in the United States, reporting survey and ethnographic data on the spread of business computing, on the learning processes and skills required, and on the changing institutional practices that facilitated diffusion.
(ORGANIZATION LEARNING AND DIFFUSION TECHNOLOGY)

Introduction

The recent spread of computer and related technologies throughout the US economy, coinciding with a period of intense competition from overseas, has convinced many policy makers that America's economic future depends on the rapid diffusion and successful utilization of new technologies in the workplace (President's Commission 1985, p. 18). However, several scholars have questioned the usefulness of current theories of technology diffusion for understanding the spread of complex new production technologies. They have called for new perspectives better suited to understanding the dissemination of these technologies (Eveland and Tornatzky 1990, Brown 1981, Kelly and Kranzberg 1978).

In this paper, I review established theories of innovation diffusion, and summarize recent criticisms made of them. I then construct a perspective on technology diffusion that places at its core the issue of organizational learning and know-how. Survey, interview, and archival data on the recent diffusion of business computing are then analyzed, in order to demonstrate the empirical validity of this new theoretical formulation, and its utility in explaining institutional patterns of diffusion.

The Theory of Innovation Diffusion

At the most general level, two metaphors or images inform innovation diffusion research. Perhaps the dominant image is that diffusion is a process of communication

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and influence whereby potential users become informed about the availability of new technology and are persuaded to adopt, through communication with prior users (Rogers 1983). This implies that patterns of adoption across populations of organizations reflect patterns of communication flow. Researchers examine the roles of persons within innovating firms who are especially well linked to outside networks and organizations, and also study patterns of communication and influence within the adopting firm.

The second metaphor is an economic one which views diffusion primarily in terms of cost and benefit: the higher the cost, the slower diffusion will occur. The higher the perceived profit from an innovation, the faster adoption will occur (Mansfield 1968).

1. *Adopter Studies*

Both the communication/influence imagery and the economic imagery inform one style of diffusion research which focuses upon adoption by individuals or by single firms. Typically, early adopters are contrasted with late adopters to generate a list of factors related to early adoption. For example:

(1) Firm size: large firms adopt innovations before smaller ones (Davies 1979, p. 118).

(2) Profitability: those firms for whom an innovation is most profitable become early adopters (Davies 1979, von Hippel 1988).

(3) Innovation champions inside the adopting firm: Rothwell and Zegveld (1985) identify three roles—the product champion, the business innovator, and the technological gatekeeper.

(4) Organization and environmental attributes: intensity of competition, firm size, mass versus batch production, degree of centralization, organizational slack, proportion of specialists, and functional differentiation have been linked to adoption by Abernathy and Utterback (1978), Aiken and Hage (1971), Kimberley and Evanisko (1981), Tornatzky and Fleischer (1990) and others.

2. *Macro-Diffusion*

Macroscopic studies of innovation examine the diffusion of new technologies across entire populations of organizations. One strand of research takes a spatial approach, representing the spread of innovations by a "gravity model" (Rogers 1983). Speed of adoption is a function of the population size of an area, and secondarily of the distance of that area from other centers of population. (Population and proximity to population centers are indirect measures of density of communication, akin to Durkheim's notion of "moral density".) Applied to the US, an innovation is predicted to appear earliest in the two major coastal conurbations (Boston to Washington DC; Southern California), then in the next largest metropolitan areas (inland), and spread after a considerable lag to areas of low population density (Hunt and Chambers 1976, p. 48). The gravity model successfully describes the diffusion of social innovations from TV stations to heroin addiction, but it appears less useful in explaining industrial innovations, perhaps because certain types of manufacturing concentrate in smaller towns (Pred 1977, Mansfield 1968).

A second theme in the macroscopic study of innovation focuses on the S-shaped curve which describes adoption over time: early on few firms adopt, then there is a sudden "take off," followed by a slowing in the rate of adoption (Mahajan and Peterson 1985). Economists explain the S-shape of the curve in terms of the shifting balance of supply and demand, which is a function of the investment required to adopt a technology and the profitability of that technology (Freeman 1982, von Hippel 1988, Jowett 1986, Mansfield 1968, 1977). The steep "take off" of the

S-curve is often due to a substantial drop in the price of the new technology, causing a surge in demand.

Burt (1987), a sociologist, has analyzed the S-curve differently, arguing that distinctive mechanisms of diffusion (structural equivalence versus cohesion) imply different shapes of S-curve. Structural equivalence means that those who adopt at one point in time are similarly situated vis a vis other actors. Cohesion suggests that adoption results from direct communication between a potential user and prior users. Burt has tested the relative importance of these two mechanisms, arguing that structural equivalence plays a larger role in explaining diffusion of tetracycline than does cohesion. He suggests that inter-personal communication is less important for diffusion than traditional diffusion theory suggests, especially in contexts where marketers use multiple channels to get news of the innovation to potential users (Burt 1987, p. 1328).

M. Lynne Markus (1987) has shown that modifications to the traditional S-curve are required to account for interactive communications media, from telephones to electronic mail, to facsimile machines. For such media, adoption becomes progressively more attractive, the more it has already been adopted by others. Conversely, in their early stages these media face start up problems and discontinuance, because many people with whom one wishes to communicate are not yet using that medium. This is the reverse of traditional diffusion theory, which posits the highest gains to be associated with early adoption, and discontinuance to be associated with late adopters (Rogers 1983, p. 188). Markus' diffusion curve for successful interactive technologies is exponential rather than S-shaped.

For both sociologists and economists, research at the macroscopic level typically proceeds by attempting to fit a mathematical model of the diffusion process to empirical data describing the diffusion of an innovation over time (Mahajan and Peterson 1985). For example, Chow (1967) and Stoneman (1976, 1983, pp. 135–141) have examined the diffusion of mainframe computing in the US from a economic perspective. Both used economy-wide time-series data on the number of mainframes sold (dependent variable), on the price of those computers, controlling for quality, and on overall economic growth (independent variables). Despite the evident sophistication of these econometric studies, their *empirical* ability to model the diffusion of computing proved disappointing. Neither price nor output growth (GNP) proved to be statistically-significant predictors of the numbers of computers diffused. (Other researchers, applying a similar approach to other technologies, have been more successful.)

Critiques of Current Diffusion Theory

In an influential review, Lawrence Brown (1981) has criticized the view of adoption as "primarily the outcome of a learning or communications process." That perspective emphasizes *demand* for an innovation, and assumes that everyone has an equal opportunity to adopt, limited only by their "innovativeness." This places too much emphasis on the demand side and not enough on supply-side institutions of diffusion. Institutions that supply and actively market innovations affect the spread of innovations, and determine to some degree who adopts and when. Since supply-side institutions often focus their marketing and educational activities in certain areas or on certain types of firm, it is unlikely that each firm will have an equal opportunity to adopt. Thus, he argues, research should go beyond the individualistic perspective which stresses the innovativeness of potential adopters, and should examine instead the institutional and market structures that channel new technologies to users (cf., Robertson and Gatignon 1987).

Economic studies of diffusion are not immune from Brown's criticism, despite the fact that they analyze both supply and demand variables. For the economic approach is theoretically indifferent to *institutional factors* on either the supply or demand side. By focusing solely on price and profitability, it ignores nonmonetary barriers and facilitators to diffusion that are the raison d'etre of other schools of diffusion theory.

A different set of criticisms of current diffusion theory is provided by J. D. Eveland and L. Tornatzky (1990, p. 123), who suggest "Problems arise when the diffusion model is applied in situations where its basic assumptions are not met—that is to say, virtually every case involving complex, advanced technology." They point out that diffusion theory has tended to focus on adoption decisions by an individual, and upon a relatively rationalistic adoption decision. Yet for advanced production technologies, "Decisions are often many (and reversed), and technologies are often too big and complex to be grasped by a single person's cognitive power—or usually, to be acquired or deployed within the discretionary authority of any single organizational participant" (*ibid.*, p. 124). When adoption is not a single event, and when complex organizational processes rather than individual decision-making come to the fore, the classical diffusion model (e.g., Coleman et al. 1966), based on an individual's decision being primarily influenced via communication with external agents, seems less applicable.

Eveland and Tornatzky (1990) recommend instead a perspective that views diffusion and adoption as occurring within contexts that constrain and mold choices. They enumerate five elements of context: nature of the technology itself, user characteristics, the characteristics of deployers, boundaries within and between deployers and users, and characteristics of communication and transaction mechanisms. Of particular relevance are their observations that diffusing or deploying a technology is more difficult if (1) its scientific base is abstract or complex, (2) the technology is fragile (in the sense that it does not work consistently), (3) it requires "hand-holding"—aid and advice to adopters after initial sale, (4) is "lumpy" ("affects huge swaths of the user organization"), and (5) it is not easily "productized"—made into a standard commodity or a complete package. They note that many advanced workplace technologies fulfill several of these criteria, suggesting that their diffusion is problematic for both producer and user firms.

Communication versus Knowledge in Technology Diffusion

The limitations of previous diffusion theory become evident if one considers more closely the role of information and knowledge. The classical studies stressed the *flow* of information and ideas, and the importance of contact between originators of the technology and potential users (Coleman et al. 1966). A core idea was that non-adopters lag behind early adopters because the former have not yet learned of the existence of an innovation, or have not yet been influenced about its desirability by better-informed contacts. Diffusion is therefore limited by the timing and pattern of communication.

Unfortunately, the classical studies failed to distinguish between two different types of communication (or information) involved in the diffusion process: signaling versus know-how or technical knowledge. Differentiating between these two leads to very different perspectives on technology diffusion.

Signaling refers to communication about the existence and potential gains of a new innovation. Unless a potential adopter knows about an innovation, and is informed persuasively about the benefits of using it, the innovation is unlikely to be adopted. The classical diffusion studies assumed that signaling information took different lengths of time getting to different potential users (according to their centrality to communications networks and links to prior adopters), resulting in the S-curve of early, middle and late adopters. Signaling was therefore viewed as central to explaining the diffusion process.

However, one may question whether signaling information remains a limiting factor in contexts where information about the existence of new production technologies and their benefits is widely broadcast by manufacturers' advertisements, by specialized business journals, and by trade associations (cf., Burt 1987). Mansfield (1985) has documented that signaling about new production technology in the US can be very fast and widespread, implying that it is not a limiting factor, one shaping the pattern or timing of diffusion.[1]

Learning and/or communicating the technical knowledge required to use a complex innovation successfully places far greater demands on potential users and on supply-side organizations than does signaling. The amount and detail of information is far greater in the former case. If obtaining technical knowledge is slower and more problematic, one may hypothesize that it plays a more important role in patterning the diffusion process of complex technologies than does signaling. It should therefore move to center stage in any theory of complex technology diffusion (as detailed below).

A substantial literature examines the technical knowledge base of innovation: research and development centers, the patent system, university-industry links, trade associations and industry consortia (Pavitt 1985, Tornatzky 1983, Tornatzky and Fleischer 1990). One focus is on the *sources* of technological knowledge instantiated in an innovation—whether the knowledge originated in a public institution, a manufacturer, or a user organization (Freeman 1963, 1968; Ray 1969, 1988; Nasbeth and Ray 1974; Pavitt 1985; von Hippel 1988).

The present paper shares with this literature its interest in supply-side institutions and technical knowledge, but departs from this school in one important respect. Most studies of supply-side institutions in innovation conceptualize the diffusion process in terms of knowledge *transfer*. They replicate the traditional diffusion model, insofar as an innovation and its accompanying technical knowledge are viewed as being transferred from the originating institution to user organizations. At the risk of overstatement, one might argue that such studies treat the movement of complex technical knowledge under a model of communication most appropriate for signaling.

There are, however, compelling empirical and theoretical reasons for avoiding the concept of knowledge transfer when applied to complex technologies. Studies have shown that, although one can readily buy the machinery that embodies an innovation, the knowledge needed to use modern production innovations is acquired much more slowly and with considerably more difficulty. Arrow (1962) argues that manufacturers using new process technologies are "learning by doing"—their productivity improves for several years after adopting a new technology, as they learn to use the technology to best effect (cf., Dutton and Thomas 1985). Ray (1969), Pavitt (1985), von Hippel (1988) and others detail the way that production innovations, before they become useful, have to be substantially modified inside user firms. Tushman and Anderson (1986) suggest that innovative technologies can either be competence-destroying or competence-enhancing for firms, according to whether they render obsolete or build upon preexisting skills and knowledge.

Absorbing a new complex technology not only requires modification and mastery of the technology, viewed in a narrow mechanical sense, but it also often requires

[1]Some European economists, however, believe differently. Nasbeth and Ray (1974, pp. 299–301) report that late adopters received information of the existence of numerically-controlled machine tools *ten years* after early adopters. By contrast Mansfield (1985) reported signaling within one year. Coleman et al.'s (1966) study of the diffusion of tetracycline also documented very rapid signaling (cf., Burt 1987).

(frequently unanticipated) modifications in organizational practices and procedures: these too have to be learned the hard way (Stasz, Bikson, and Shapiro 1986; Johnson and Rice 1987).

Thus implementing a complex new technology requires both individual and organizational learning. Individual learning involves the distillation of an individual's experiences regarding a technology into understandings that may be viewed as personal skills and knowledge. Organizational learning is built out of this individual learning of members of an organization, but is distinctive. The organization learns only insofar as individual insights and skills become embodied in organizational routines, practices, and beliefs that outlast the presence of the originating individual. These routines may reflect an amalgam of individual learning or skills, and need not correspond to any one individual's understanding. Furthermore the link between learning and experience is often, but not always, lost to the organization, so that the particular learning experiences that led to any particular routine may be lost, even though the "lesson" remains instantiated in the organizational routine, practice or policy (Levitt and March 1988).

Rosenberg (1982) has extended Arrow's notion of learning by doing, suggesting that it is not only new process technologies (e.g., in manufacturers), that are learned in this fashion. The ultimate or end users of complex products also face what Rosenberg calls "learning by using." He argues that, for complex technologies, the products are so multi-faceted, with interactions occurring between subsystems, that it is impossible for the designer to know in advance quite how they will perform when used. The result is "learning by using": the end user spends several years developing an understanding of the strengths and weaknesses of the technology. The knowledge gained by these users becomes very important to manufacturers for designing new generations of equipment (cf., Eveland and Tornatzky 1990, p. 120).

Neither "learning by doing" nor "learning by using" is the result of knowledge transfer from the originator to the user of the technology. Indeed the point of the concepts is the opposite: to highlight the need for learning and skill formation *in situ*, far from the originator. Rice and Rogers (1980) have labeled this process "reinvention," to dramatize the importance of knowledge creation by the user (see also Clark 1987).

The implication of these studies is that know-how, far from being readily or easily transferred from the originator to the user of a technology, faces barriers and is relatively immobile (Boyle 1986, Eveland and Tornatzky 1990, p. 139). Knowledge often has to be discovered *de novo* within the user organization. Using an imagery of information *transfer* for technical knowledge is therefore unwise: it obscures more than it enlightens.

Theoretical considerations also suggest an alternative conception than transfer. The Schumpeterian thesis argues that the incentive to develop a new technology derives from the inventor's desire to monopolize the use of the innovation. The faster it diffuses, the sooner one's advantage and ability to profit from it go away. A major part of the economics of innovation examines whether licensing arrangements, patents, joint ventures, and other special institutional arrangements intended to make it profitable for innovators to share their innovations, actually do so (Kamien and Schwartz 1982). The existence of these special inducements to share knowledge underlines the fact that the initial inclination of businesses is to hoard and hide know-how, rather than transfer or diffuse it.

These critiques and studies imply that a different theory is needed to analyze the role of learning and technical knowledge in the diffusion of advanced production technologies, one that avoids the traditional notions built around signaling or transfer. The following section sketches such a perspective.

A Knowledge-Barrier Institutional-Network Approach

1. *Organizational Learning Is Partly a Consequence of Immobility of Technical Knowledge*

Far from flowing easily from manufacturers and distributors of complex technology into user organizations, technical know-how is relatively immobile, and often has to be recreated by user organizations. Reinvention and learning by doing are, in part, responses to the difficulty or incompleteness of technical knowledge transfer between firms.

2. *The Burden of Developing Technical Know-How (Organizational Learning) Becomes a Hurdle to Adoption*

As Nathan Rosenberg (1982, p. 140) put it: "...an intuitive familiarity with learning by using, and the time that must often elapse before performance uncertainties are resolved, may constitute an important reason for the decision of private firms to postpone the adoption of an innovation." (See also Gerwin 1988.)

3. *Given Such Hurdles, the Relationships Between Supply-Side and User Organizations in a Network Go Beyond Selling and Buying Equipment*

They become structured around the task of reducing knowledge hurdles for potential adopters of an advanced technology. An appropriate image is of a network of supplier and user organizations with technical knowledge distributed quite unevenly across the network (Tornatzky and Fleischer 1990, p. 121). The institutional network changes as new mechanisms are developed for lowering or circumventing knowledge barriers to adoption.

4. *Mediating Institutions Come into Existence Where Technical Knowledge Is Scarce and/or Organizational Learning Around a Technology Is Burdensome*

These supply-side institutions specialize in creating and accumulating technical know-how regarding complex, uncertain, dynamic technologies. They "stand between" a user and a complex technology (hence "mediating").

5. *Mediating Institutions Capture Economies of Scale in Learning*

By the time a mediating firm has written its tenth compiler or installed its tenth inventory system, it has ironed out errors and learned from earlier attempts. This option of learning through repetition is restricted for demand-side institutions: few customers would have the occasion to develop a computerized inventory system ten times over. Economies of scale are greatest for "rare event learning"—distilling knowledge from events which occur infrequently. Rare event learning occurs when new products/systems are being developed, when unusual combinations of hardware and software are being installed, and in repair.

6. *The S-Curve Reflects Changing Knowledge Barriers over Time*

The changing numbers of adopters over time need not be viewed solely or primarily in terms of shifting equilibria between costs of equipment and profitability (the economic model). Instead, the S-curve may be viewed more broadly, in terms of the changing height of hurdles (both know-how and machinery cost) to in-house adoption. Such hurdles include the difficulties of obtaining knowledge and skilled personnel and the effort of in-house organizational learning about technologies. This construct clearly exceeds the purchase price of machinery that is the typical operationalization of cost in economic diffusion studies.

7. Service Is an Alternative to Adoption or Nonadoption

A third alternative exists beyond "adopt" and "not adopt" a technology in-house—namely to purchase the fruits of that technology on a market, as a *service* from a mediating institution. Service institutions decouple the benefits of new technologies from the customer's need to acquire technical expertise about them. Consumers obtain the benefits of the new technology by getting someone else to provide it as a service, rather than by taking on the formidable task of organizing the technology in-house for themselves. To the extent that expertise and use can be decoupled in this way, knowledge barriers are lowered, and the process of technology diffusion is accelerated.

8. Technology Services Are an Alternative to Knowledge Transfer

Taking the burden of learning off the back of a potential user is *not* the same as transferring knowledge. Running users' data for them, writing software for a customer organization, installing a system for a firm, or advising what equipment to purchase, does not transfer a consultant's know-how or skills to the user organization. These services do not usually enable the customer to carry out the tasks unaided on subsequent occasions. But the provision of these services by mediating institutions does enable user organizations to adopt a complex technology without (initially) having to acquire a full range of technical knowledge in-house, and hence is functional for diffusion.

9. A Transition Occurs from Service to Self-Service

As expertise hurdles are reduced over time—both by manufacturers self-consciously seeking ways to reduce the knowledge burden on end users, and by the training and diffusion of knowledgeable persons (Ettlie 1980)—the balance shifts from "buy" (a technology service) to "make" (deploy the technology in-house), from technological service to self-service. Firms that have already tasted the benefits of the technology, via a service provider, constitute a pool of already-primed potential adopters, likely to adopt in-house once knowledge and other barriers fall.

The same process occurs for diffusion within individual organizations. With high initial knowledge barriers, one finds at first a highly-centralized provision of the technology within a firm, with one department essentially offering the technology as a service to other parts of the firm. As knowledge and expertise barriers are lowered, the technology diffuses, and the norm becomes decentralized "self-service" in end user departments.

Methodology

There is a dearth of government or publicly-available survey data on the diffusion of computing, a situation which has led to complaints that scholars are missing a golden opportunity to study a major technological revolution (Hunt and Hunt 1986, p. 17). However, some market research firms have carried out large-scale surveys of the extent of computer use in representative samples of firms. I obtained market surveys for 1979, 1982 and 1985 from one firm. On-site interviews with managers of a representative sample of New York area firms were carried out by the author and colleagues as part of a study of computer impacts (Rule and Attewell 1989). Qualitative materials from these interviews flesh out the survey data. Third, the policies and roles of manufacturers are accessible because lawsuits forced companies to document their competitive practices (Fisher et al. 1983).

TABLE 1
Computer Utilization Rates 1979–1985:
% with Any In-House Computing

Size Class of Establishment	1979	1982	1985
1–19 employees	2.5	9.1	26.9
20–99 employees	22.7	34.7	47.8
100–249 employees	48.3	59.6	62.8
250–499 employees	50.8	71.9	73.0

Source. Author's analyses of market research surveys by Focus Inc.

Institutional Features of the Diffusion of Business Computing

Use of in-house computers by businesses began in the late 1950s, but the machines were so complex and expensive that they remained mainly the preserve of large companies until the end of the '60s. Diffusion "took off" toward the end of the '70s (Jowett 1986). The 1980s have seen the spread of computing to even the smallest of businesses, and a parallel diffusion of personal and minicomputers into individual departments within firms. Table 1 documents diffusion by size from 1979 to 1985.

Diffusion and the Question of Expertise

The theory advanced earlier implies that business computing is not just a matter of purchasing objects (the computer and software) but requires considerable skills. Evidence that this can be a barrier can be found in the most extreme case, where firms buy computers but are unable to operate them. About 3% of the firms in the 1985 survey reported having purchased in-house computers but had no applications running on their computer(s). Similarly the site-visits revealed that a handful of firms had abandoned or never used their computers, due to technical problems or a lack of anyone able to operate them. (Similar knowledge-deficit abandonment effects have been documented for other advanced technologies, such as machine vision systems. See Eveland and Tornatzky 1990, p. 123.)

Given the need for expertise, large firms hire professional experts in-house: by 1986 the numbers of computer operators, programmers and systems analysts had grown to 1,739,000 persons (*Statistical Abstract* 1988). However, it is striking that many computerized businesses don't employ computer professionals. In the 1982 survey, 70% of computerized firms with under 20 employees had no in-house computer specialist, and 42% of computerized businesses with 250–499 employees lacked a programming professional. This was not just a feature of very simple computer systems: the 42% of firms without programmers had an average of 9.5 terminals (*not* PCs) per firm—implying quite complex multi-user systems.

What is striking about the computer revolution was the emergence of institutional arrangements that removed a large part of the burden of knowledge acquisition from the backs of potential users, and enabled a relatively complex technology to diffuse rapidly into firms that initially lacked expert knowledge and did not employ in-house specialists.

The Importance of Computer Bureaus for Diffusion

A two-stage process in which firms initially purchased computer data-processing *services* from other organizations, and later purchased in-house computers was especially important in the early decades of diffusion. Computer or data processing service bureaus emerged in the 1960s as one of many strategies to increase the sales of mainframe computers. Manufacturers like IBM and Honeywell opened bureaus, along with nonmanufacturers like ADP and Digicon. Although it is today a multi-billion dollar industry, the theoretical importance of the service bureau as an agent of technological diffusion has not been recognized by scholars.

A bureau typically owns mainframe computers and employs a staff of systems professionals. Client companies either send the bureau written data on business transactions (e.g., accounts receivable) or enter data from terminals in their own establishments linked to the bureau's computer by phonelines. The bureau processes this data and returns reports, payroll checks, or invoices that the client firm then uses in its daily business. Alternatively, the customer firm may have both terminals and printers at its own site and use the bureau's computer and software for remote processing ("time-sharing") (Negus 1972).

There are several reasons for purchasing data processing services rather than obtaining computers for in-house use. Prior to the advent of personal computers, using a bureau required far less capital investment than buying a computer. Also bureaus could capture the economies of scale of processing huge numbers of payroll or receivables; most customer-firms would not have sufficient processing needs to reach such economies of scale. Bureaus could also amortize the costs of developing software across numerous clients, and fully utilize systems professionals where smaller firms could not.

But from a knowledge barrier perspective, using a computer bureau enables a customer firm to enjoy the benefits of computer technology without having to develop in-house technical knowledge about computing. It was and is a way of experiencing the new technology "at arm's length." The economies of scale in learning that bureaus enjoyed enabled them to offer technical services that it would have been hard for a customer to recreate in-house. Bureaus were pioneers in developing transaction processing software for specific kinds of businesses, and were early experts at integrating software written by one manufacturer with hardware from another (Fisher et al. 1983, p. 324).

Survey data reveal what an important role service bureaus have played in diffusion. In 1962, a government agency surveyed 17,414 establishments in New York State that together employed over half of the state's workforce. Only 3.4% of establishments had in-house computing at that time, while about eight times as many (27%) had access to computing either from an outside bureau or from a "pseudo-bureau" (a separate establishment providing processing services to other parts of a firm). (See Table 2.)

Obtaining computer services, as distinct from computing in-house, was important for both small and large establishments in 1962. Only in the very largest establishments (2000 employees) did one find in-house computing predominating over bureau or pseudo-bureau services. In medium and small establishments, "outside" processing was far more common than in-house.

Twenty years later one finds a pattern similar to that in 1962: small firms are more likely to use a bureau than large firms. But by 1979 the employment-size "cut off" for bureau use has moved lower: more large and medium-sized firms have shifted to in-house processing. (See Table 3.)

Notwithstanding the proportional shift to in-house computing over time, the DP bureau industry continues to grow in absolute or dollar terms because the market for business computing is not yet saturated (US Commerce 1989, p. 45-2).

The emergence of a computer bureau industry speeded the diffusion of a new technology by decoupling (user) expertise from the benefits of innovation, by acting as a mediating institution standing between the technology and the user. Other mecha-

TABLE 2
Establishments with Electronic Data Processing in New York State in 1962

Establishment Size	*N*	In-house Computer	Bureau	"Pseudo-bureau"
< 50 workers	3067	3%	11%	87%
50–99	415	3%	29%	69%
100–199	326	20%	13%	67%
200–499	390	36%	18%	46%
500–999	199	47%	22%	31%
1000–1999	139	63%	11%	27%
2000–4999	98	76%	5%	19%
5000 or more	49	92%	6%	2%

Source. New York State (1968).
"Pseudo-bureau" means using data processing services provided by a part of one's firm located elsewhere.

nisms for easing the knowledge demands of this new technology also proved important: the role of manufacturers, the recycling of software, the use of consultants, and the emergence of informal experts.

Manufacturers and Knowledge Barriers

Early manufacturers of hardware understood that a user's knowledge acquisition could be a potential barrier to adoption, and responded to this in several ways. They provided manuals and standard operating procedures, and provided hardware training for users. They also removed from the customer the knowledge-intensive burden for maintenance and repair of hardware. IBM initially made its reputation by promising to fix hardware problems, fast.

But by far the largest knowledge barrier in introducing computing into a firm involves software. Designing and writing programs for the particular applications of a business is a time-consuming task requiring a large set of technical skills. In this area also we see the emergence of a series of mechanisms whose joint effect was to remove a large part of the knowledge acquisition burden from the user.

In the 1950s and into the '60s, organizations seeking to automate voluminous clerical transactional data turned to IBM and other hardware manufacturers for software as well as hardware: the manufacturers were the only ones with sufficient expertise to develop the software. A symbiotic relationship existed, especially between IBM and its largest customers like the Social Security Administration and the IRS. These customers paid for IBM to develop file management utilities, databases,

TABLE 3
1979 *Survey on Primary Mode of Data Processing*

Establishment Size	Manual*	In-house Computer	Bureau	"Pseudo-bureau"
< 25 workers	74%	12%	10%	4%
25–100	48%	32%	15%	5%
100–200	25%	54%	14%	7%
200–500	12%	67%	7%	9%

*Includes accounting machines.
Source. Author's analyses of market research surveys by Focus Inc.

and other then-novel software necessary for their activities.[2] IBM later sold the general-purpose parts of this software along with their hardware to subsequent customers.

Although this resulted in the accumulation of knowledge and experience (by the manufacturer) and the transfer of the product of that knowledge to multiple customers, it only removed a part of the software development burden from users. The applications programs—the software that processed checks, invoices, etc.—still had to be written. For their very largest customers, manufacturers did provide the programming know-how and staff for specific applications. Thus, IBM pioneered methodologies for analyzing the information requirements of large firms (Business Systems Planning) which it provided as a service, and IBM staff coded the software indicated by these requirements analyses.

The provision of maintenance, software, and training along with the hardware was known in the industry as "bundling." These ancillary services were included in the price of the hardware during the '50s and '60s. Indeed IBM mandated maintenance and repair being bundled with its hardware until it was forced to stop that practice, in a consent agreement to an anti-trust suit in 1956. Bundling continued as a central but now voluntary part of IBM's marketing strategy, and was copied by its competitors, until about 1969 (Fisher et al. 1983, pp. 34, 96, 172).

The Role of Consultants

Very large firms set up specialized staff departments (the Data Processing or MIS Department) whose staff wrote applications software for the firm. However many medium and small firms could afford neither to build an in-house programming staff nor to purchase IBM's "total solution" of hardware and customer-written software. Instead, these firms hired outside firms of consultants to advise them over purchases of equipment and to plan whole systems, to program and install software, and to integrate computers into networks. This temporary infusion of expertise has proved to be far from a transitional phenomenon. It has spawned an enormous industry: today, the computer professional services industry does about $32 billion p.a. in business, split with one-third going to consulting and training, one-third to systems integration and one-third to programming (US Commerce 1989).

One important role of consultants today, and an even more dominant one a decade or more ago, was the development and programming of software. Several of the firms in our New York sample commissioned such custom-built software. However writing complex programs from scratch is a difficult task: errors (bugs) abound, deadlines are often exceeded, budgets are used up before the work is completed (Brooks 1974). A substantial minority of interview sample firms told of disaster stories: of software that never worked right, of consultants unable to make software run on requisite hardware, leaving firms in the lurch. Others were more successful, but this era of custom programming seems to have been fraught with difficulty in many settings. Over time however, practices altered to make software acquisition less problematic.

Recycling Software

Private-sector businesses share many activities in common, even if their products or line of business differ dramatically. Accounts receivable, payroll, the general ledger are functions that recur across all manner of firms. It would seem practical to write "generic" software programs for basic business functions, and to customize them for the special needs of a particular customer. This approach became popular during the 1970s. Either taking code written for a previous client, or purchasing a package they

[2] I am grateful to Kenneth Laudon for this point.

then intended to modify, consultants developed applications programs for particular customers.

The logical extreme of this was the appearance of a software industry during the 1960s that offered "off the shelf" or "package" software packages that were supposedly ready to run, without programming by the user. The software industry experienced explosive growth, as IBM and other manufacturers found themselves unable to keep up with the burgeoning demand for applications software and "unbundled" applications software from 1969 on (Fisher et al. 1983, p. 174). Today programming services are a $9.7 billion industry (US Commerce 1989, p. 45-2).

Although the rapid growth of the software industry suggests that "off the shelf" and recycled software are successful products, it is worth pointing out some limitations of this attempt to shortcut one stage in technology transfer. In Greek myth, Procrustes preyed upon unsuspecting travelers, offering them shelter and a bed in his home. The original Procrustean Bed was fatal: a tall guest, whose head or limbs dangled off the end of the bed, had the overlap chopped off (by Procrustes); a short guest was racked and stretched until he fit. An analogous fate was reported by some of those firms in our sample which used off-the-shelf or lightly modified software. The particularities of the firm's business did not match the way the generic software had been written, resulting in great inconvenience. For example a clothing manufacturer bought well-regarded inventory software. But this industry has a lot of merchandise returned by its customers as a part of its normal way of doing business. The generic inventory software could only process these returns of merchandise in the most tortuous time-consuming way, wiping out all the productivity gains of using the program.

Until recently, the only recourse of firms suffering the Procrustean bed was either to scrap the software and buy another package or to employ someone to customize it further to their needs. Either course of action added expense and delay. Lately however, the problem seems less common, because highly industry-specific recycled software is usurping the role of generic software. Thus instead of purchasing a generic inventory package, a firm (say a stationery wholesaler) may choose among several competing packages, each of which is designed specifically for the wholesale stationery trade.

Today, specific inventory packages are available for meat wholesalers, liquor stores, and dozens of other industry segments. This kind of highly-specialized off-the-shelf software—"niche software"—has eased the prior problem of finding expert programmers to modify generic software and has lessened the knowledge-acquisition burden on adopters.

Analogous forms of "niche" customization have been reported for other technologies. Ray (1969, 1988) noted that the oxygen process in steel production was held back until different versions were developed to meet the distinctive needs of producers of various specialized types of steel: the generic process placed too much of a development and modification burden for most potential users.

Standards, Shells, and Interfaces

The factors mentioned thus far reduced the need for knowledge transfer by reducing the necessity for programming knowledge on the part of potential adopters. In addition, a series of developments have made software easier to operate for nonprogrammer end users. On mainframes, operating systems automated more and more activities; job control languages became simpler from the user's perspective. The development of shells—programs that link multiple applications and enable end users to move from one to another via simple menu choices rather than complex command sequences—also helped. And most recently, user-friendly graphics-based interfaces, modeled on the MacIntosh's desktop, enable end users to direct computers without knowing procedural languages or complex commands.

Troubleshooting Expertise: Help Lines and Users Groups

Industrial sociologists have noted that highly-automated technologies may require relatively less skill to operate when they are working normally, but require correspondingly large amounts of skill when things go wrong. Operating skills recede in importance compared to troubleshooting and diagnostic skills. Developing in-house operating know-how is relatively straightforward: it accumulates almost continuously as the technology is used. But troubleshooting know-how depends on learning from (relatively) rare events.

From manufacturer-provided on-site repair, to writing software with "help screens" available at the touch of a button, to toll-free telephone numbers for technical assistance, to sponsoring user groups and electronically-accessible bulletin boards—one can trace a series of innovations intended to remove, or at least lighten, the burden of "rare event learning" for end users. When an unfamiliar problem occurs, there is someone to turn to. One of the most recent of these innovations is the development of "remote operating software." These programs allow an expert troubleshooter located far away from a customer to dial up the customer's microcomputer, and watch remotely as the user attempts some task on the computer which is proving problematic. While watching, the remote expert may identify a mistake that the user is making. Or the remote expert may "take control" over the user's machine and run diagnostic software to identify the problem, even though s/he is located far away.

Dynamics within the User Firm: Centralized to Self-Service

The dynamics of diffusion within individual firms shared many of the characteristics of macro-diffusion. During the '60s and '70s, large firms provided computer services to their numerous operating departments in a centralized way. Data processing or MIS departments operated mainframes, wrote code, and essentially acted as computer bureaus for the rest of the firm (Table 2). Operating departments might have terminals connected to the corporate mainframe, but were very dependent for expertise and hardware upon centralized computer departments, which offered access and expertise as a service.

The monopoly of centralized processing unraveled in the '70s and '80s in many, but not all firms, encouraged by several developments (Leigh and Burgess 1987). Programming bottlenecks were widespread, as central data processing staff were inundated with requests from operating departments for debugging and modification of existing software, as well as requests for new applications. Often central DP focused on one or two critical areas, leaving other potential users disenfranchised (Iacono and Kling 1988). At the same time, the availability of first minicomputers and then microcomputers, meant that obtaining in-house processing power became financially feasible for operating units. The spread of off-the-shelf and niche software meant that operating departments could aspire to using new applications, without having to program them from scratch. Taken together, this led to a rapid diffusion of computing activity beyond central DP. What ensued was a period of strife, as some central DP departments tried to hold onto their monopoly, sometimes citing the need for standards, sometimes invoking the idea that distributed computing was wasteful, while centralized computing realized economies of scale (Kling and Iacono 1984). In most firms, diffusion seems irreversible (Rockart and Flannery 1983). Central DP have adapted by redefining their role to include provision of end-user advice centers, planning, and providing the communications/interconnectivity infrastructure of the firm (Sprague and McNurlin 1986). Key high-volume financial and transactional software typically remain within the jurisdiction of central DP, and run on mainframe systems.

Mavens and Gurus: Informal Expertise

Given the discussion so far, one might infer that the knowledge-acquisition or skill burden on the end user of business computing is minimal, given the range of service provision and the simplification of software interfaces, etc. That would be quite incorrect. Even when the knowledge-burden of maintenance, programming, and activating programs has been removed from the end user, there remains the not-inconsequential task of learning how best to apply the technology in the business context. Fieldwork among computer users reveals that using applications programs and applying computer applications to business tasks requires a surprising depth of skill and knowledge. Part of this involves discovering "work arounds" or "kludges"—methods of circumventing awkwardnesses or bugs in programs. Another part consists of methods of making programs do things they weren't designed to do: clerks append memos in blank database fields to alert fellow workers to problems with a particular transaction, thus creating a crude electronic mail where none was designed for. Managers twist spreadsheet programs to perform tasks never envisioned by their vendors. (The tip of this knowledge iceberg appears in the letter columns of computer magazines where word processor and spreadsheet users share their latest tricks.)

A final area of skill-acquisition occurs when users find ways in which the technology can change how their firm does business. From managers who use spreadsheets to pore over figures to find new ways of reducing costs to the low-level employee at American Hospital Supply who first suggested placing a terminal in a customer's office—end users have experimented with the technology to enhance their business activity.

My fieldwork experiences suggest that informal computer experts are a very important feature of staff and operations departments where computers are used extensively. There is a folk terminology for describing people who are especially skilled or knowledgeable: computer gurus, computer mavens, power users. Office workers and managers alike depend upon such people for advice, for training, for figuring solutions to new problems, for troubleshooting malfunctioning programs. These skills are developed by people whose main responsibilities are doing work, not building systems. Their abilities and role may even go unnoticed by higher management or by a firm's formal computer specialists. This is very different from acquiring computer expertise in the traditional sense, which required hiring a formally-trained staff of computer professionals.

In sum, the mechanisms described earlier that lowered the knowledge threshold for adopting computers have not, thereby, eliminated learning and knowledge on the part of computer users. They have simply shifted the locus of that learning.

Discussion

This paper developed a theoretical framework for examining the diffusion of complex production technologies which are (in Eveland and Tornatzky's terms) scientifically demanding, fragile, and lumpy—the antithesis of a reliable commodity. In such situations, knowledge and technical know-how become important barriers to diffusion, and supply-side institutions have to innovate, not only in their design of products, but especially in the development of novel institutional mechanisms for reducing this knowledge or learning burden upon end users.

The institutional history of business computing suggests a sequence of ways that an organizational network lowered knowledge barriers. Early on, supply-side organizations provided services rather than simply selling machinery. Initially these were comprehensive: operating services, installation services, programming, repair. These services reduced the burden of in-house learning for users, and speeded diffusion, but were costly. This phase was fraught with difficulties for many users.

The long-term solution to this demand for expertise was to automate and to standardize. From the development of assemblers and compilers, to the use of high level languages, to the development of shells and user-friendly interfaces—work that once required substantial skills has been given to the machine. This increased the complexity of software and the demands placed on hardware, but that complexity is inside the machine, largely hidden from the user. This has stimulated a shift away from service to a self-service mass market for computer technology.

Know-how based services remain an important component of the network, but their scope contracts and centers on the most complex knowledge areas, for example, new product development, installation, and repair. Most users are able to manage the day to day exigencies of operating the technology, with help from home-grown gurus, and occasional appeals to service firms.

Gershuny and Miles (1982) argue that the movement from service to self-service is a widespread socio-economic dynamic, applying to shifts from movie houses to VCRs and from laundries to washing machines as much as to production technologies. I would be more cautious. The trajectory can reverse for particular technologies. Technological advances can increase complexity and uncertainty, making end users dependent again on specialized experts, building new knowledge hurdles for potential adopters. One example is LANs, which have made many end-user departments dependent on central MIS again. Even more recently, Kodak Corporation has given up jurisdiction over operating its centralized mainframe computing centers, preferring to have IBM provide this as a service.

It is also clear that, in the case of complex production technologies like business computing, there is not a zero-sum choice between computing as a purchased service versus self-service or in-house computing. For while the historical trend has certainly been from service to in-house for *operating* computers, the role of computer services has not diminished. This suggests that service and in-house should be viewed as complements, rather than opposites. Even as the knowledge burdens are reduced in one area (e.g., computer operations) and that activity moves in-house, the complexity and knowledge burden in other facets of computing increase, leading to expansion of service in that area (e.g., consulting over connectivity and computer networks). One could argue that, *in order to* reduce the complexity and uncertainty in one area, complexity and uncertainty increase in another. Thus the price of making computer operations user-friendly (icon interfaces and menus, help screens, query-by-example, communications) has been extra complexity in hardware and software, that has raised the knowledge burdens of hardware and software design and manufacture. Within an organizational learning framework, this means that even as some activities are routinized, making in-house learning-by-doing an attractive option, others become more complex, so much a matter of rare event learning that user organizations prefer to let other organizations specialize in providing them.

Insofar as this model of technology diffusion highlights the interplay and choice between service versus in-house, it parallels Williamson's (1975, 1981) notions of markets (buy a good or service) versus hierarchy (make, bring in-house). One may therefore question whether this paper's "knowledge barrier institutional network" approach to diffusion is simply a special case of transaction-cost economics. However, in the most immediate reading, transaction-cost analysis would predict the *opposite* institutional trajectory from that found for the diffusion of business computing.

The transaction-cost approach assumes that purchasing on a market would normally be more efficient than producing within a hierarchy. This general advantage of markets is only reversed when certain costs of doing transactions on a market exceed the inefficiencies of producing within one's own firm. The most significant aspect of these transaction costs involve the *specificity* of assets. Asset specificity refers to the idea that in order to make a transaction with a particular seller, the buyer may have to commit certain investments, much of which would be lost if the buyer were to have to shift to a different supplier. In-house production becomes more attractive if asset specificity increases; it becomes less attractive if assets become less specific, more interchangeable.

For Malone et al. (1987) information technology has tended to reduce transaction costs, and make various information processes and products *less specific*, and is therefore leading to a broad shift away from hierarchy, towards markets. This leaves a riddle as to why computing technology itself has diffused with the opposite trajectory: from services purchased on a market to more in-house (hierarchy) deployment.

It would be hard to argue that assets involved with computing have become more specific with time (as Williamson's theory usually explains shifts towards hierarchy). Software that a decade ago could only be run on one machine is now usable on several platforms. Where once code was typically custom-written, today it is much more often obtainable off-the-shelf. Software development expertise that was a decade ago highly-specific to IBM is today more highly diffused across a highly-competitive market of suppliers. At the hardware level, more manufacturers have entered the fray, and the adoption of industry-wide standards makes more machines interchangeable. In terms of skilled personnel, the various technical computer occupations have expanded rapidly, and rapid circulation of personnel allows for circulation of expertises (Ettlie 1980).

In sum, the trajectory of business computing from service to in-house is the reverse of what would be expected from a simple transaction-cost approach. The direction is understandable if changes from market services to in-house deployment result mainly from a progressive lowering of know-how barriers and cheapening of equipment, rather than from changes in transaction costs. It therefore seems sensible to treat a knowledge barrier approach to technology diffusion as a distinct theory in its own right.

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