Socio-dets and Techno-dets: Determinants of Diffusion and Implementation Patterns of Automated Machine Tools

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Journal of Engineering and Technology Management, 6 (1989) 161-185
Elsevier

Socio-dets and Techno-dets: Determinants of Diffusion and Implementation Patterns of Automated Machine Tools*

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Abstract

Typical of many cases of technology diffusion and implementation, machine tool automation has stimulated debate about the relative influence of social and technological factors. It is argued that reconciliation of these views requires (a) a realistic model of the firm in its environmental and managerial contexts, (b) a conceptual framework that incorporates technological, economic, political and symbolic forces in the processes of diffusion and implementation, and (c) a heuristic strategy that allows these forces to play relatively more and less important roles depending on the time-span and level of aggregation of analysis. Examination of the case of machine tool automation suggests that while social forces may play a central role in the analysis of specific plants, technology and economics assume relatively greater importance in the analysis of aggregate patterns and trends.

1. Introduction

Recent research on the diffusion and implementation of new technologies evidences an unresolved tension between those who privilege technological-economic variables and those who emphasize managerial and social influences. This article attempts to clarify what has become a somewhat confused state of research by constructing a model that allows more rigorous assessment of the relative causal roles of technical and social factors.

The debate between what might be called, without wanting to unduly sim-

*This project was funded in part by the Stanford Institute for Manufacturing and Automation.

plify complex theories, "social determinist" (socio-det) and "technical determinist" (techno-det) approaches is being played out in several arenas:

- The "flexibility" associated with programmable automation (Office of Technology Assessment, 1984) seems for the techno-dets to hold the promise of a world of more varied and complex products, produced by factories that are more responsive to the changing demands of the market (Goldhar and Jelinek, 1985). A socio-det perspective points out that the flexible potential of new technologies is often not tapped by firms (Jaikumar, 1984): technology may not be the constraining factor, since management's preference for stability and other organizational rigidities may take priority over technological capabilities (Abernathy et al., 1983).
- Techno-det analysis of the impact of new technology on working conditions has often concluded that automation generally upgrades skill requirements, and will progressively liberate workers from the factory grind (Blauner, 1964; Woodward, 1965, 1970) and usher in a post-industrial society (Bell, 1960). Socio-dets, by contrast, argue that management policies, not technologies, determine job design, leading some to fear that the new production technologies will be used remove the human dimensions of work, reducing workers themselves to the status of mere cogs in a machine (Braverman, 1974).
- The techno-det explanation of technological diffusion assumes that, conditional on factor prices, productivity pressures will force users in different environments to adopt similar patterns of implementation (see Brown, 1981, Chap. 3). Yet other research highlights the extraordinary staying power — apparently unrelated to economic efficiency — of distinctive national utilization patterns of skill profiles and product characteristics (Sorge et al., 1983; Piore and Sabel, 1984; Maurice, 1986a).

These contrasts between socio-dets and techno-dets reflect a deep-seated split in the broader literature on diffusion and implementation of innovations between, on the one hand, those who assume the superiority of the new innovation and focus their research on the social barriers to its use (e.g., Rogers and Shoemaker, 1971) and, on the other hand, those who tend to assume economically rational users and who therefore focus their research on the limitations of the current state of the innovation and the process of technological improvement (e.g. Harley, 1971).

Our objective in this article is to construct a meta-theoretical space in which important debates between techno-dets and socio-dets can be conducted more fruitfully. After outlying our approach to a synthesis of socio-det and techno-det perspectives (Section 2), we develop a micro model of diffusion and implementation of machine tool automation and a framework for identifying the various technical and social forces at work in that model.

2. Towards a synthesis

We reject *a priori* neither social nor technological determinism for being too one-sided and instead attempt to develop a meta-theoretical framework that allows us to synthesize them through productively confronting their respective strengths and weaknesses. Such a synthesis has proven difficult for three reasons. First, the two approaches tend to operate at different levels of aggregation. Techno-dets typically formulate their arguments as aggregate long-run trends sustained by the pressure of competitive selection. As a result, they usually are content to assume that the local, short-term deviations are just "noise" around the longterm trend (Forbes, 1958). Socio-dets, on the other hand, have often made their case in studies of individual plants over shorter time horizons and either extrapolate their micro analysis to the global level (Shaiken, 1984; Buchanan, 1984) or shy away from what they se as dubious speculations on overall trends (Kelley, 1986). Any synthesis will need to show how the technological and economic forces operate at the micro, firm level and how the political and symbolic forces operate at the macro, aggregate level.

Second, the key factors of diffusion and implementation — automation, product characteristics, workforce profile, managerial strategy, competitive and institutional environment, profitability, national context, plant size, etc. — are strongly interrelated, limiting the usefulness of simplistic, one-sided models. Since individual cases of adoption and implementation of new technology often involve a host of technological and social factors, it is easy for dogmatic researchers to isolate the effects of their favorite causal factor and conclude that it is the only one (Gold, 1981). Thus, a synthesis will require a general model that can incorporate these various factors and accommodate the various perspectives.

The third factor inhibiting the synthesis of technical and social perspectives is that research is often limited to one part of the process — either diffusion or implementation (Gold, 1981). An exclusive focus on the diffusion process (e.g., Rogers and Shoemaker, 1971; Mansfield, 1968) blinds researchers to the role of implementation in generating both technical improvements and know-how that influence subsequent diffusion patterns (Rosenberg, 1976; Rosegger, 1977). An exclusive focus on implementation (e.g., Pressman and Wildavsky, 1984; Elmore, 1978) ignores the fact that early adopters may have different characteristics and implementation approaches from later adopters as the diffusion process itself modifies the innovation (Rogers and Shoemaker, 1971). A synthesis should integrate both diffusion and implementation processes.

We therefore need a model of technological change that allows us to discuss the interaction of technical and social determinants at both the micro and macro levels of analysis of both diffusion and implementation. Our approach in this article is to take a "worm's eye view" by focusing on the technical and social forces operative in and on the individual firm. By centering the model on the relationship between the organization and its environment, we are also able to address the relationship between local and aggregate dynamics. We use the model to structure a discussion of the technical and social elements of

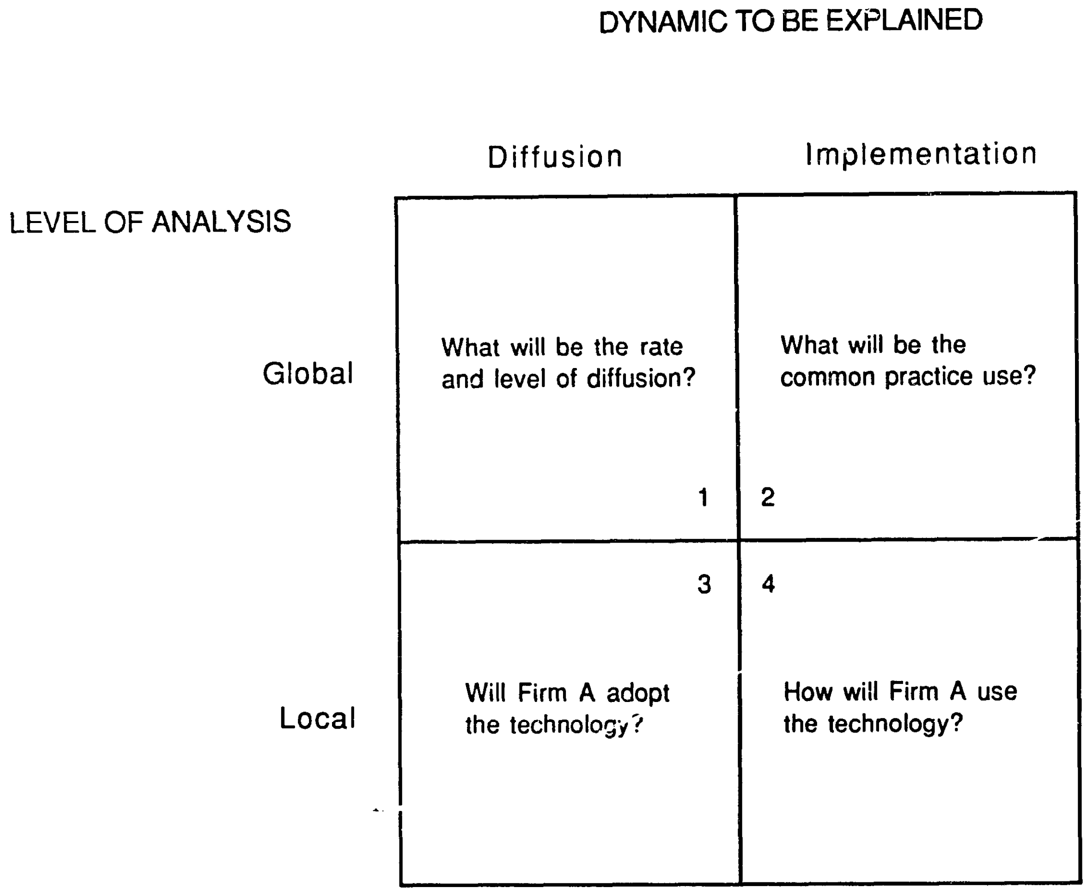

Fig. 1. Four questions.

issues both global and local in the diffusion and implementation of new technology (see Fig. 1):

(1) the rate of diffusion of new technology;
(2) the pattern of typical utilization of new technology;
(3) a given firm's propensity to adopt new technology;
(4) how a given firm will best make use of new technology.

Our model is derived from a study of the literature on the machine-tool automation case. While relying on any single case creates obvious risks, it has the advantage of prompting greater realism and salience, and the case of machine-tool automation provides a rich body of prior research. Debates over the future of machining vividly illustrate the general debates we have discussed above.

Machining, and in particular the computerization of machine tools, is particularly useful for exploring these issues for two reasons. One, the machining process and its output have retained the same general form across several generations of automation. This consistency makes machining automation well-suited for comparative analysis of technological change, and is the reason that so many authors have taken machining as their paradigmatic example of automation.

A second reason for choosing the machine tool case is more practical. This lag between available and installed machine-tool automation is particularly large in the U.S. (*American Machinist*, 1983a). Machine tools are critical to industrial competitiveness and defense readiness (National Research Council, 1983). But there is a large and persistent lag between the available level of machine-tool automation and the automation level of the U.S. installed machine tool base. Understanding the determinants of this technology's diffusion and implementing has a certain urgency. By the same token, this lag makes the issue of machine-tool technology development less crucial than deployment patterns, allowing us in this article to bracket the debates over the forces behind technology development and to focus on technology diffusion and implementation.

3. A model of automation diffusion and implementation factors

Socio-dets and techno-dets can argue their respective cases at two distinct levels of analysis. First, they can privilege some factors over others — socio-dets often focus on labor/management relations or on the institutional environment, while techno-dets often focus on the competitive environment or on technical capabilities. Second, they can reason at a more abstract level, and focus on technical or social forces structuring all these factors simultaneously. We address the second level in the next section. In this section we summarize a model of diffusion and implementation factors designed to address the first level of analysis and to clarify the complexity created by the interdependence of a number of distinct factors at work work in the diffusion and implementation process.

The theory of the firm developed by Edith Penrose in *The Theory of the Growth of the Firm* (1980) provides our starting point. Penrose's theory avoids the barrenness of traditional neo-classical economic formulations; a barrenness resulting from their inappropriate level of abstraction. One, it allows for the fact that firms do not implement new technologies according to a standard recipe book. They learn by doing and by using (Rosenberg, 1976). Two, it allows firms to escape declining returns to scale through product innovation. Three, it emphasizes the scarcity of management expertise, a particularly important factor in implementing new technology (Gold, 1981). The Penrose model thus accommodates the influence of competitive pressures as well as that of internal organizational realities, in particular managerial ability, that lie outside the assumptions of rationality that characterize and limit the neo-classical approach.

This approach grounds our model of technological diffusion and implementation, suggesting that these processes operate within three successively broader spaces: (a) the firm's production process, combining labor, capital and mate-

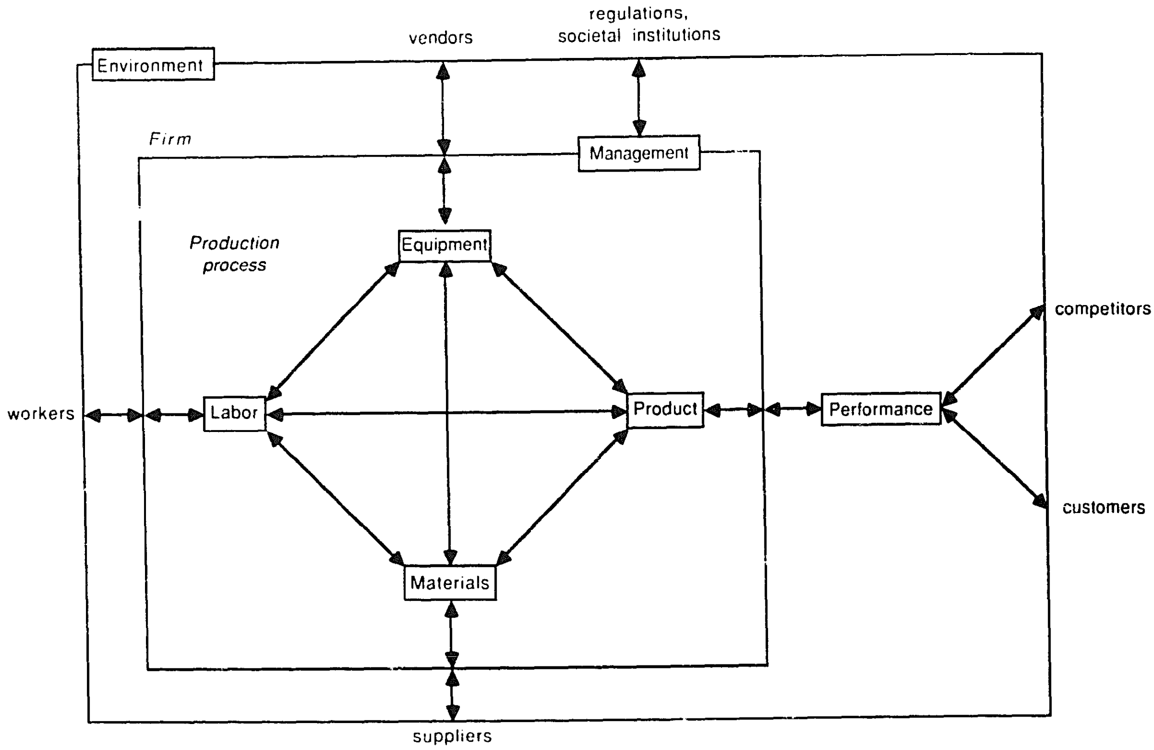

Fig. 2. A model of diffusion and implentation factors.

rials to form products, (b) managerial resources and orientations, and (c) the product market and institutional environment faced by the firm (see Fig. 2).

Review of the literature on the diffusion and implementation of Numerical Control (NC) suggest a focus on seven factors:

(i) The characteristics of the *equipment*, in particular its automation level and its limitations.

(ii) *Labor* characteristics, including the quality and organization of the jobs in the plant in both machining and support (i.e., programming, maintenance, tooling, tooling design).

(iii) The quality and cost of the raw *materials* used in the production process.

(iv) Significant *product* characteristics: cost, quality, average batch size, complexity of parts, lead times, frequency of new products, and the difficulties in machining parts.

(v) *Management* goals (strategy) and resources (competences): management mediates the influences of the environment and production process by acting on both.

(vi) Plant *performance*, or profitability, is determined by market responses to the products' costs and characteristics. Performance provides important information for setting management goals.

(vii) The *environment* appears in this model as almost ubiquitous. It intervenes by shaping the competitive context but also by the pressure of institutionalization on relations with customers, equipment vendors, materials suppliers, workers and other stakeholders. One environment that provides particularly important insights into patterns of diffusion and implementation is the national context.

In the following sections we address each of these factors in turn, identifying social- and technological-determinist views associated with each. But first we identify a second and more fundamental level of analysis on which the socio-det versus techno-det debate is conducted.

4. Four underlying causal forces

Each of the factors in the previous sections' model (i.e., automation, management, etc.) is the result of a combination of social and technological forces. Our review of the literature suggest that there are at least four fundamental causal forces whose articulation lies beneath explanations of relationships among the seven factors (see Adler and Borys, 1988b, for a more detailed discussion):

(i) Technological forces determine the range of available techniques for converting resources into outputs, and their performance potential and limitations.

(ii) Economic forces create pressures on firms and managers to allocate both capital and human resources efficiently. These forces operate not only on market relations among firms, but also within the firm.

(iii) Political forces appear as the exercise of power within firms and between firms and other agents in the environment.

(iv) Symbol systems affect the values and the cognitive resources and strategies available to actors.

Techno-det approaches attribute causal primacy to some combination of technological and economic forces, while socio-det approaches attribute primacy to some combination of political and symbolic forces.

Our approach extends Zald's (1970) political-economy framework. This extension allows us to distinguish technology from economics and thus to accommodate the permanent possibility of divergences of economic interest and the fact that resolution of economic interests occurs through quite different processes than resolution of disagreements concerning technology. We can distinguish economic from political forces in terms of the contrast between the anonymity of the former and the intentionality of the latter. Lastly, we can distinguish political from symbolic forces in order to be able to analyze objective power dynamics as distinct from subjective meanings; thus we can analyze the ideological content of certain symbol systems independently of the power relationships they support.

5. Forces and factors in the diffusion/implementation process

This section uses the case of automation of machine tools to explicate our model of diffusion and implementation. We shall discuss in turn the seven factors of our model, highlighting (a) the roles of the four forces in each factor, and (b) the complex interactions between factors. We shall argue that this complex picture is clarified when we distinguish between short-term/local and long-term/aggregate levels of analysis.

5.1 Equipment

This section briefly sketches the evolution of machine-tool technology and then addresses the social and technical factors in three key processes: (a) the appearance in the environment of new machine-tool technology, (b) the adoption by the firm of that technology, and (c) the extent and type of use of the equipment once installed.

While important technological advances have been made in cutting-tool materials and fixturing methods, the automation of machine tools has focused primarily on machine *control*. "Automatic" machine tools using cam controllers have long been in use in the production of simple parts in long production runs. In the 1960s Numerical Control (NC) introduced computerization to machining, creating NC machine tools controlled by a device that reads digital instructions from a magnetic or punched paper tape. In the 1970s microprocessor technology allowed Computer Numerical Control (CNC), in which an on-board controller is programmed at the machine or by downloading programs from computer memory. Since then, diverse activities such as a milling, drilling, and boring have been integrated into Flexible Machining Centers (FMCs), as well as Flexible Manufacturing Systems (FMSs) in which several CNC machines or FMCs are linked by automatic handling equipment and controlled by a central computer. These developments in the control and operation of machine tools are paralleled and amplified by developments in the computerized assistance available for part designers (CAD) and process planners (CAPP).

Although our model focuses on the diffusion and implementation, and not the development, of new technologies, a few comments on the first key process, the appearance in the environment of new machine-tool technology, are in order. Techno-dets view the evolution of machine tool automation as an immanent tendency of technological evolution (Childs, 1969), spurred by a drive for more efficient production (Mansfield et al., 1977). Socio-dets, by contrast, have highlighted the political conflicts that influenced the design of this new technology (Noble, 1984), and have emphasized the social norms and practices that constrain the shape of a broad cross-section of innovations (MacKenzie and Wajcman, 1985). Research in the "social construction" of scientific practice has laid the groundwork for challenging the exogeneity of automation *vis-a-vis* these social factors by demonstrating the influence of collective action on the selection of technology development priorities and alternatives (Latour, 1983; Pinch and Bijker, 1984).

The socio-det position suffers, however, from an important handicap in this debate. While Noble (1984) demonstrates the influence of management's desire for control over workers in the selection of NC over the available alternative (an analog technique called "record–playback"), he fails to demonstrate that this desire was the *dominant* factor. The technical limitations of record–playback were considerable, and while the short-term technical challenges of NC development were perhaps greater than those of record–playback, the digital basis of NC created new long-term automation opportunities that were not achievable through development of the analog technology.

These critiques of the socio-det argument suggest not that it is untenable, but rather that its scope is more limited than its proponents claim. The evidence advanced in its support does not, in general, address the claims of techno-dets, couched as the latter are in terms of large aggregates of firms over the long-run.

The second key process, adoption, is the *locus classicus* of the diffusion literature (see Mansfield, et al., 1977; Brown, 1981, for a review). The key elements of diffusion have been shown to be:

(1) the relative advantages, both real and perceived, of the new technology;
(2) industry pressure, both competitive and institutional;
(3) broader societal and political factors;
(4) the resources and strategy of individual firms (e.g. R&D expenditures, firm size, organizational complexity).

Our model locates elements (2) and (3) in the relevant environmental subsets and addresses (4) in Section 5.5 on management below. As argued by Brown (1981), category (1) is the most troublesome since it encompasses several quite distinct questions. We address these questions at several points in the discussion below:

- Advantages for whom? The major issue here relates to labor/management conflict, and thus leads us to the firm's industrial relations strategy (Section 5.5).
- Necessitating what investment? This leads to a discussion of management's resources (Section 5.5).
- At what cost (or savings) in other factors of productions? This raises questions relative to labor (Section 5.2), materials (Section 5.3) and the internal structure of the equipment base (compatibility, etc.).
- What kind of advantages? This takes us to the linkage between investment in new equipment and expected performance improvements (Section 5.4).

This explains the importance of the third key process, the extent and type of use of the equipment once installed. Shaiken (1984) argues that managerial ideologies often limit the effectiveness of new technologies once installed, since implementation modes are opportunities not only for efficiency gains but also for industrial relations power struggles. Adler (1988) broadens this perspective, highlighting several organizational factors impeding effective implementation of integrated CAD/CAM: skills may be lacking; procedures are often outdated; organizational structures often create fiefdoms; strategic clarity is often lacking; and cultures may undermine collaboration across specialized subunits.

But implementation can also be an opportunity not only for learning how better to use the technology, but also for improving the technology (Rosenberg, 1976). Research has shown that lead users often play an important role in the refinement of new technologies (Von Hippel, 1976).

So the influences on and of equipment as illustrated in Fig. 2 go in several directions:

- adoption is conditional on the presence of competent vendors with appropriate equipment to sell;
- adoption is mediated by the firm's competitive environment, its strategy with respect to technology and other factors of production, and its product marketing strategy;
- both technology adoption and deployment are conditioned by the state of the other factors of production;
- the firm's experience with the new technology can fuel a reverse causality taking new ideas back to the vendors.

The issues reviewed in this section offer fertile ground for debate between socio-dets and techno-dets. Our model is designed to clarify that multi-faceted debate by suggesting a useful way to structure it. The following sections pursue these issues factor by factor.

5.2 Labor

Our discussion of the labor factor is more extensive than those of other factors. This reflects the centrality of the labor-automation relationship in the techno/socio-det debate.

As we saw in Section 5.1, both approaches agree that labor exerts a significant influence on both the diffusion and implementation of technology. They differ, however, on the nature of the influence of labor: Techno-dets often claim that technological innovation and deployment is driven by the compulsion to reduce costs through labor-saving devices (cf. the debate within this perspective reviewed by Rosenberg, 1976), while socio-dets argue that technology is developed and deployed as a means of controlling workers (Braverman, 1974; Noble, 1984).

In this section we focus on the reciprocal relationship — the influence of automation on labor. We identify three such influences: changes in the number of workers in the shop, changes in the content of jobs, and changes in work organization. This review suggests that while political and ideological influences are central to understanding individual firms in the short run, aggregate trends appear to be more the result of technical-economic factors.

5.2.1 Employment levels

NC has two effects on employment levels. The first is the effect of NC on the total quantity of labor in the plant. A purely technological perspective argues that, all else equal, increases in efficiency will reduce employment levels for a given level of output (Steffy et al., 1973). Some socio-dets view this argument primarily as a threat used by management to maintain a docile workforce (Braverman, 1974); they argue that actual employment levels are influenced by the intensity of work effort; that this intensity is the central object of labor-management conflict; and that automation at most mediates this relationship. These technological and social hypotheses both ignore the influence of properly economic factors. In favorable economic environments, new products and/or lower costs of production will lower prices and expand sales so that new jobs are created within the firm. Even in unfavorable environments, the pace of implementation is in reality such that attrition is often a more cost-effective way of dealing with labor surpluses than layoffs (New York State Department of Labor, 1969).

A second employment effect is the effect of automation on the *composition* of labor within the plant. Techno-dets focus on how NC lowers the relative number of operators and increases the relative number of programmers and, perhaps, maintenance workers. But if the operators are able to create and edit programs themselves, the use of a more highly skilled operator workforce might allow a firm to reduce the number of programmers and/or their skill requirements. Socio-det accounts of NC implementation point out that managers often deny operators such control, even when it is technically efficient (Wilkinson, 1983).

5.2.2 Job content

The effects of automation on job content has been the subject of study of researchers from several disciplines; machining has been a popular case to study (see Adler and Borys (1988a) for a review). The clash between technological and social determinist views has been very sharp — especially because no compelling data have yet been assembled on whether NC operators are more or less skilled than conventional machinists.

The first generation of research on NC skill requirements was dominated by techno-dets who sought simply to map the changing job demands associated with the shift to NC, using methods akin to job evaluation (Crossman et al., 1960, 1966; Hazlehurst et al., 1969). A second generation, "labor process" analysis, in contrast, argued that the struggle between managers and workers over the intensity of work determines job content and that the effects of NC implementation were by-products of a management strategy intended to increase managerial control over a "deskilled" workforce (Braverman, 1974; Noble, 1977, 1979, 1983, 1984; Shaiken, 1984).

The labor process research has, however, drawn criticism both from other socio-dets and from techno-dets. While Braverman (1974) assumed that managers were always dominant in deciding job content, others point to the importance of countervailing worker power (Montgomery, 1976; Brighton Labor Process Group, 1977). Braverman (1974) also assumed that productivity is gained only through control over workers, rather than giving workers the autonomy to work more effectively (Friedman, 1977).

Techno-det critics of the labor process research points out that Braverman assumed that automation does not shift cost curves over time in favor of higher skills and/or greater worker control. Social conflict may not dictate trends so much as create occasional and temporary impediments to using NC in the most efficient way–with upgraded workers (Adler, 1986).

Buchanan (1984) invokes economic forces as a mediating variable. His research suggests that NC might have a deskilling effect if the plant produces only simple parts in long runs; but that it will have a strong upgrading effect in plants with complex products and short runs. Thus the economics of the plant's product market and the economic returns to product characteristics such as smaller batches and part complexity — to be addressed below — intervene in the relationship between NC and job content.

Rather than addressing these techno-economic issues, a third, more recent generation of research focuses on the social factors that mask them. It analyzes the labelling of jobs as "skilled" and "unskilled" and the factors in the firm's institutional environment that influence plant management policies. This "social constructionist" school has favored explanations based on idosyncratic mixes of economic, social and political factors local to particular organizations, industries, regions, markets, and/or unions (Elbaum and Wilkinson, 1979; Jones, 1982; Wilkinson, 1983; Elbaum, 1984; Kelley, 1986).

Nonetheless, these social constructionist studies also show, sometimes unwittingly, that although local institutional factors influence the relationship between technological change and skill requirements, automation is distinctively influential in that its effects are cumulative (Rosenberg, 1976). In a given plant at a given point in time skill is only loosely coupled to technology (Kelley, 1986); but over larger aggregates and longer time horizons, technology's "objective" requirements might become more salient since competition does not equally support all skill configurations (Kelley, 1984a, see also the survey of NC managers by Williams and Williams, 1964; and Noble, 1979, p. 42; 1984, p. 269).

In part, much of this debate is conducted via divergent underlying conceptualizations of work content. Job evaluation uses a technical definition, identifying mental, motor, perceptual and discretionary dimensions. Economic determinists use a human capital definition, conceiving skill as productive ability whose value is determined by competitive markets to be equal to the resources consumed in acquiring the ability (e.g., training). Labor process research uses a more social definition, focusing on worker autonomy. Social constructionists deny the applicability of any such generalized schemes, instead arguing that job content should be conceptualized in whatever terms the relevant actors themselves use.

5.2.3 Work organization

The effects of NC on work organization have been another favorite topic of both techno- and socio-dets. It has perhaps suffered the most from the reductionism into which the debate often falls, and benefits the most from an expanded conceptualization of the debate. The central issue has been the effect of automation on the degree of the division of labor — particularly the separation of operating and programming responsibilities.

Technological and economic determinists often posit a tendency for automation to fragment tasks. From this perspective NC creates two new jobs (programmer and operator) to replace the older one (machinist); the technical demands of the tasks are such that they should be separate jobs.

Economic determinists hypothesize that the "Babbage principle" (Babbage, 1835) makes it more efficient to use automation to divide jobs, since the wage bill for programmers and operators is lower than it would be for a comparable group of machinists each of whom perform both tasks (Steffy et al., 1973).

The political determinism of the labor process school assumes that automation is used if and only if it consolidates management control over workers. It thus hypothesizes that NC is used to separate execution (operation) and control (programming) (Braverman, 1974).

Symbolic determinists hypothesize that the efficiency or control properties of NC work organization are not as influential as norms and institutionalized implementation practices. They hypothesize that whether or not operators also program their machines is determined by national or local custom (Maurice, 1986b).

Evidence indicates that some separation of programming tasks from machining tasks is a likely outcome of NC adoption since it offers important technical and economic benefits that are often visible to managers (Steffy et al., 1973). In the short-run and for the case of an individual firm this influence may be countered by local custom or managerial choice in response to other institutional forces. Recognizing this influence does not stop us from hypothesizing that in the long-run aggregate, the degree of specialization of programming and setup is most strongly influenced by market forces such as the demands of product characteristics. The smaller the average batch size, for instance, the more costly is the coordination of specialized functions relative to potential operating economies, and the lower is the optimal degree of specialization, and thus the more likely the programmer-operator combination will be in the long-run aggregate.

5.3 Materials

Although they are given little attention by either techno-dets or socio-dets, raw materials are nonetheless a major cost factor and they both condition and are influenced by NC (Steffy et al., 1973). Techno-det promoters of NC claim that the reliability of NC lowers scrap rates, making it less risky for firms to machine high-cost materials (Childs, 1969). At the same time, they caution that NC users become more dependent upon suppliers of raw materials, since programmed machine tools cannot respond to imperfections in castings as effectively as can human machinists. Computerized monitoring of tool "chatter", designed to automatically adjust to unforeseen cutting requirements, has been slow to develop (American Machinist, 1983b).

Socio-dets might point out that the use of more expensive materials is a strategic decision made by managers. Some managers may choose not to experiment with new and unfamiliar materials, or may not be able to create supplier relations that ensure adequate casting quality.

From an economic perspective the central issue is the market demand for products made from expensive and difficult-to-machine materials. If NC does bring the ability to machine new materials, the question remains whether there is unsatisfied demand for such products. If so, then those firms whose managers are unwilling or unable to utilize these materials will be out-performed by those whose managers are willing and able.

This suggests that, in competitive contexts, the socio-det view captures important factors whose influence is felt primarily in the short-run local case; while the influences highlighted by the techno-dets will be found primarily in the aggregate long-run, and in more competitive markets.

5.4 Product

A major focus of NC researchers, product characteristics include the cost dimension — drawing our attention to the efficiency of NC and the role of labor in achieving the gains promised by techno-dets — and the other characteristics of the product portfolio — highlighting the broader capabilities brought by NC and the role of labor and the firm's product market in realizing these capabilities.

5.4.1 Cost

Many of the technical-economic efficiency claims made for NC — that NC generates savings in direct labor, quality, tooling and downtime costs compared to conventional machine tools — are far from established (Adler and Borys, 1986). In this paragraph we suggest that recognizing the influence of social factors on the efficiency of real NC installations affords a richer analysis that more closely reflects the experiences of individual NC-using firms; attention to aggregate trends, on the other hand, prompts the need for refinement of the technological determinist approach itself.

A first set of factors generating higher efficiency stem from NC's technical capabilities: higher reliability, reductions in tooling and fixturing costs, improvements in product quality, and less downtime all lead to lower operating costs for NC relative to conventional machine tools (Steffy et al., 1973; Putnam, 1978; Dept. of Defense, 1978).

In relation to the diffusion process, techno-dets often highlight these projected cost advantages. A socio-det, however, might highlight the role that expectations of technical performance play in the NC diffusion process. This approach suggests that actual performance characteristics are difficult and costly to measure and will fluctuate according to local conditions. The high cost of experimenting with NC by purchase of an NC machine tool makes vendor information and trade publications the primary sources of information about NC. Thus vendor promises may create myths about NC's capabilities.

Social forces on costs may be even more important in the implementation process. Human ingenuity remains a crucial influence in eliminating defects in automated systems (Shaiken, 1984). Machine shop efficiency demands that operators collaborate with part programmers to prove out new parts and identify programming errors. And if the high cost of NC relative to conventional machine tools demands lower downtime to extract an adequate return, this makes NC shops particularly susceptible to operator sabotage and neglect.

A second, and more economic source of increased efficiency is the Babbage principle (Babbage, 1835). We have discussed the implications for job content of this argument above; here we would argue that when specialization occurs in the context of changing automation levels, the expected hourly cost reductions may not materialize, since automation not only eliminates tasks but also creates new tasks.

A socio-det perspective on the Babbage principle highlights the effect of increased labor force control provided by the automation of the machine control function. In this perspective, NC may lead to higher apparent productivity. It is not through increasing output per hour of work that this is achieved, however, but through increasing the hours effectively worked in the day (Braverman, 1974).

In summary, while a techno-det model might view the efficiency gains due in tooling, fixturing, quality, downtime and labor costs as inevitable and immanent in the technology, a socio-det model would argue that these improvements are neither inevitable — since realizing the technical potential depends on labor force skills and attitudes — nor immanent — since some of these attributes of NC are in fact attributes of labor control strategies.

Ongoing debate in these areas could be clarified by recognizing the differences between the short-term local and long-term aggregate effects posited by each argument. Technological determinist claims seem naively optimistic to the manager responsible for implementing NC; from this short-run, local perspective, social forces loom large. On the other hand, the researcher concerned with aggregate trends might view the social factors as noise in the overall pattern of implementation. If competitive pressures are sufficient to eliminate the organizational forms that have failed to overcome the social barriers to technical efficiency the remaining firms will display these efficiency effects.

5.4.2 Product portfolio

Techno-det claims about the flexibility of automated systems can be evaluated by considering the effects of NC on the firm's product portfolio. The characteristics of the product, the batch sizes in which it can be efficiently produced, and the range of product types that the plant can offer to its customers are all potentially affected by NC. Despite the attractiveness of these claims, it is neither clear that they are feasible, nor that they are profitable.

As far as feasibility is concerned, techno-dets highlight several advantages of NC relative to conventional machine tools: multi-axis capabilities, accuracy, reliability, and the ease of changing tooling and fixturing on NC machines. These technical characteristics, they suggest, will lead NC users to produce more complex parts, use harder-to-machine and more expensive materials, shorten their production runs, expand their part portfolios, and reduce their new product lead times (Childs, 1969; Belitsky, 1978; NC Society, 1981).

A socio-det approach would suggest that actually achieving these improvements depends on the quality of operator, programmer, and maintenance labor. For instance, it has yet to be shown that fixturing costs, rather than shop organization, is the key constraint in achieving smaller batch sizes. Adler (1986) has pointed out that many other factors apart from technology stand in the way of firms that try to pursue such flexibility: the social and technical feasibility constraints are still very real. These factors may explain why firms don't appear to be taking advantage of the potential product advantages of NC (Putnam, 1978; Noble, 1984).

As concerns the profitability of new product characteristics, the techno-dets assume that characteristics such as smaller batches are economically beneficial — that there is a latent market demand that NC will allow firms to exploit. Goldhar and Jelinek (1985) thus argue that the capabilities of new technologies will lead to focus on economies of scope, rather than of scale. However, these product market economies have not been demonstrated. Approximately

50–70% of all machine parts produced in the U.S. for example, are already handled in lots of less than 200 pieces (Kurlat, 1977), and even smaller lots are typical in the U.K. (Childs, 1969). We have found no research to demonstrate the existence of latent market demand for these characteristics, nor of NC's ability to stimulate and/or tap it.

In this discussion of product portfolio changes, we see again an opportunity for synthesis based on the local/global distinction. The social factors seem to act as "impediments" to greater flexibility, rather than shaping longer-term global trends. Conversely, the reduced cost of flexibility may not immediately find a market, but might, through competitive pressure over the longer-term, be expected to encourage the emergence of greater demand for greater variety.

5.5 Management

We argue throughout this paper that aggregate diffusion of new technologies is influenced by firm implementation and vice-versa. But the goals and capabilities of a management mediate the diffusion–implementation relationship at all points.

First, as we have already seen, management actively mediates relations between the firm's equipment base and vendors, between its materials and suppliers and between its labor force and the broader labor market. Second, the factors of production and the product characteristics are a function of the resources management brings into the production process, management's ability to orchestrate this process, and management's expectations regarding the profitability of its operations. Third, we can identify a direct linkage between management and some specific environments, such as the regulatory environment and the broader context of societal values.

Across these three locii of management influence, we propose to distinguish two transversal characteristics: management objectives and resources. We have already identified the numerous points at which management objectives (strategy) intervene in the diffusion and implementation process. There are also several points at which resources become critical.

First, the adoption of and adaptation to NC may be mediated by the characteristics of plant management (Mansfield at al., 1977). Many machine shops are small jobbing shops, owned and operated by former machinists. A techno-det would point out that job-shop managements tend to be less experienced with advanced technologies, and that one might thus expect these job shops to be rather conservative. An economic determinist would highlight the relative difficulty of access to financial resources experienced by smaller firms. A socio-det counter-argument might be that the entrepreneurial environment of the small shop is more favorable to innovative effort, compared to the large machine shop which may be run as an in-house supplier to other plants in a large corporate network and which may be concerned primarily with meeting budgets rather than with improving productivity. Mansfield et al. (1977) also found that organizational complexity, measured by the number of decision-makers involved in adoption decisions, slows the adoption process.

Second, management decisions to adopt new technologies are influenced by the availability of information on the technologies' capabilities and requirements (Mansfield, 1968): the availability of vendor information, as well as management's confidence in its veracity; management's previous experience in implementing new production technology; and management's awareness of similar firms using NC should influence adoption decisions.

Socio-dets and techno-dets argue about relative roles of social and efficiency factors in shaping management objectives and resources. We have elsewhere suggested that both socio-dets and techno-dets can rather easily agree that the influence of technical and economic forces is probably greater in governing the evolution of the firm's equipment than their influence on the evolution of other, more subjective, facets of the firm, such as its culture (Adler and Borys, 1988b). But beyond this agreement, socio-dets and techno-dets will inevitably disagree profoundly on the relative importance of social and technical factors in shaping management's role in the short or the long term process of diffusion and implementation.

5.6 Performance

Our model positions performance as the result of the intersection of the firm's output cost and product characteristics on the one hand and the market and competitors' actions on the other.

Socio-det perspectives often argue not only that firm performance is the resultant of a range of technical-economic performance factors, but also that several different combinations may be feasible, and thus that the precise combinations observed are determined by social forces. Moreover, socio-det approaches often allow management a considerable degree of latitude in defining criteria of effectiveness of implementation (Zaltman et al., 1973).

Techno-det approaches, on the other hand, tend to minimize the range of viable alternative technical options and generally see technical-economic imperatives as imposing relatively unambiguous criteria of effectiveness (e.g., Aldrich and Pfeffer, 1976). Techno-det models emphasize the power of competitive selection, arguing that, while various patterns of diffusion/implementation may exist at any point in time, not all of them are equally competitive. They argue that less effective combinations will not survive long the force of competition in the market and the pressure of managerial adaptation to these competitive constraints.

A middle course, similar to the 'enactment' model (Weick, 1969; Smircich and Stubbart, 1985), suggests that managerial intent and material conditions reciprocally interact, leading to "evolutionary implementation", rather than either realization of management choice or blind adaptation to environmental conditions (Majone and Wildavsky, 1978).

Some view these alternative perspectives as a sign that organizational research on "effectiveness" has fallen into a morass (Goodman et al., 1977). In part, this morass is due to the difficulty of separating normative and descriptive aspects of the problem. If, however, we take a purely descriptive approach, the scope conditions we have proposed at several points bring some clarity to this debate. We can grant with the socio-dets that different stakeholders have potentially divergent interests. But over the longer term, it is the technical-economic conditions which give greater or lesser latitude for actors to define effectiveness and performance in alternative ways. In very munificent environments, enactment and equifinality may predominate. In more competitive environments, profitability will assert itself independently of any individual actor's will. The firm can certainly reach out and attempt to reshape the environment, by building long-term relations with customers and alliances with competitors. But the environmental context will also govern how much latitude the firm has in this process.

5.7 Environment

As indicated by Fig. 2, the environment affects each of the six other factors in our model. The scope of the environment involved in each of these factors will differ from firm to firm: Some firms compete in local product markets, while others compete more globally. Similarly, the labor market for some jobs is more geographically limited than that for others. Rather than attempt to account for the numerous organization–environment linkages across all these factors, we suggest that two concepts — resource scarcity and information complexity (Lawrence and Dyer, 1983) — can capture the overall contours of these relationships. After we describe these concepts, we discuss the implications of broadening the scope of the environment.

5.7.1 Two dimensions of the environment

Resource scarcity affects the ability of the plant to purchase automated equipment. While corporate finance theory assumes that there is no such thing as capital shortage, capital rationing is nonetheless a common experience for managers. If a plant "cannot afford" NC, it won't implement NC; nor will it have the slack resources to experiment with new production methods or product characteristics. "Lack of capital" is a reason commonly cited by firms who have not adopted NC (Putnam, 1978, p. 100). In contrast, plants in particularly munificent environments may forego investment in expensive NC technology, since there is little need to modernize an already profitable plant. A curvilinear relationship between resource scarcity and propensity to invest in NC is thus hypothesized (Lawrence and Dyer, 1983).

Tangible resources are not the sole environmental factor in NC diffusion and implementation. In a rapidly changing and overly uncertain environment, the planning capacities of managers may be exceeded. Thus they will not be inclined to invest in new technologies (particularly those that are expensive and may entail significant start-up costs). In a very stable and predictable environment, on the other hand, managers would also tend to forego adoption of NC because they would see no reason to change. We thus hypothesize a curvilinear relationship between information complexity and propensity to adopt NC.

As we argued in the previous subsection, management has considerable latitude in how it interprets the resource scarcity and information complexity characteristic of its environment, and in the short-term, there is a considerable degree of equifinality. But over longer time horizons, individual firms ignore the technological and economic constraints at their peril; over larger aggregates, in anything but exceptionally munificent environments, the objective states of resource scarcity and information complexity will shape the process of adaptation.

5.7.2 Local, national and international environments

Socio-dets have argued that their case is strongly bolstered by the persistence of significant differences in NC use patterns across countries. British machining operations, for instance, tend to use less-skilled workers than their West German counterparts (Hartman et al., 1983). Such patterns might conceivably result from widespread managerial habits, rather than economic rationality or technological imperatives. What if, for example, the "myth of deskilling" (Adler, 1984) were so wide-spread in a given country that *all* machine shop managers assumed that NC required less-skilled operators, despite objective evidence that higher-skilled workers would increase their performance (such is the basic argument presented by Shaiken, 1984)? Given the complexity of the interdependence of the variables we have examined, it is not inconceivable that such an ideology might outweigh technology and economics — especially if the illusion were so widespread and market conditions such that more efficient competitors were not sufficiently numerous to drive the idealogues out of the market. Indeed, recent socio-det studies of machine tools utilization patterns in France, Germany and Japan show that these patterns reflect deep constraints imposed on management by the national educational and social systems (Maurice, 1984, 1986a).

However, the cross-national comparisons used by these socio-dets are typically snapshots. Whether they represent enduring national features depends on the robustness of these social factors *vis-à-vis* the pressures of efficiency and competitiveness. These pressures can arise from intra-country, inter-company competition or from international competition. Unfortunately, the socio-det orientation of many cross-national studies has led them to pay insufficient

	INTERNAL	EXTERNAL
TECHNOLOGICAL	available competences equipment base fit between available technologies and tasks	best practice technological innovation vendor characteristics
ECONOMIC	efficiency economic interests allocation rules incentives 1	extent of rivalry product and factor markets international competiton 2
POLITICAL	3 dominant coalition intensity of conflict degree of interest organization mode of governance	4 associations within industry government regulation organized labor other stakeholders (consumers, etc.)
SYMBOLIC	cognitive limitations corporate culture organizational sub-cultures status differences	performance expectations social construction of skill categories societal values

Fig. 3. Forces in and on the firm that shape diffusion and implementation (adapted from Zald, 1970).

attention to these pressures, leading to some truncation of an important debate. The available qualitative indices of plant performance do in fact indicate a relative superiority of the German and Japanese approaches over the British and French (Daly et al., 1985). Such indices would lead a techno-det to hypothesize that increased international competition will lead to the international diffusion of the superior patterns — albeit over a very long time horizon.

Unfortunately, international studies on NC do not allow us to assess the degree of within-nation uniformity in utilization patterns, nor do we have any data on the efficiency of the national firms on the international markets in which the machine-tool users compete. Absent these data, it is impossible to tell how long these distinct utilization patterns will last.

6. Conclusion

Our discussion has focused on the relative influence of technological, economic, political and symbolic forces on each of seven factors. We can summarize these discussions with a chart that expands and refocuses Zald (1970), by clustering the technological, economic, political, and symbolic forces operative *in* and *on* the organization (see Fig. 3).

In reviewing these alternative explanations, we conclude that it is no coincidence that most socio-det research on NC has focused on individual firms, while most techno-det research has examined larger aggregates. If we partition Fig. 3 into four quadrants, we can see that the case for the influence of political and symbolic forces is particularly strong in Quadrant 3, *within* the individual firm. The extrapolation of this finding to Quadrant 4, the broader environment of larger aggregates of firms, is less compelling: in anything but exceptionally munificent environments, technological and economic forces would predominate at this global level. If we have argued that time-horizon is a second key scope condition, it is because management does have a real margin of manoeuvre, and much adaptation to technical forces only happens through trial-and-error and through competitive selection.

In sum, we have argued that, rather than adopting either the techno-det or socio-det alternatives, researchers should (a) acknowledge the difference in level of abstraction between fundamental forces and the various factors that embody them: (b) broaden their focus to include a multiplicity of fundamental forces rather than dogmatically insisting on the role of only one; and (c) assess whether the articulation they propose of these forces and factors — and in particular the relative causal weights of the various forces — is influenced by the time span and level of aggregation.

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