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ABSTRACT

U.S. manufacturing firms that make sophisticated weapons systems for the Pentagon are subject to an unusual regulatory regime that obligates them to "volunteer" information on their business practices to the government and to prime contractors as a condition of their special relationship with the government. Within this organizational community, certain types of information sharing with and assistance to other firms have come to be viewed as an ordinary obligation - i.e., a condition of citizenship. This cooperative learning environment is indicative of a collaborative manufacturing network that enables member organizations to learn quickly about relevant process technology innovations and to implement them effectively. We find that defense contractors learn about information technology applications more quickly than enterprises outside the network. Moreover, learning advantages are not confined to transactions specific to the Pentagon, but benefit the non-military operations of the networked enterprises as well.

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The Institutional Context and Manufacturing Performance: The Case of the U.S. Defense Industrial Network

by Maryellen R. Kelley and Cynthia R. Cook

Cooperative relations among enterprises linked to one another in a production network can provide economic benefits in the form of more rapid innovation or greater productivity. Such networks have been identified in a diverse set of industries and locales: in the manufacturing of automobiles (Sako, 1992; Cusamano, 1985) and aircraft (Samuels, 1994) in Japan, the complex of industrial machinery manufacturers in the Baden-Wuerttemberg region of Germany (Herrigel, 1992), and the industrial districts of northern Italy (Brusco, 1982; Piore and Sabel, 1984). The external economies generated in these communities of organizations are not merely the result of a Darwinian selection process whereby organizations with superior capabilities are recruited to the locale or to a business group. Instead, they are embedded in an institutional milieu that sustains long term contracting relations, and norms that place a high value on information-sharing and civic-minded activities which benefit the community as a whole.

Differences among countries in their regulatory environments and the extent to which the state supports or restricts the exchange of resources among enterprises affect the propensity of businesses to form cooperative relations with one another and to maintain cooperative ties (Amsden, 1989; Granovetter, 1994). Within countries, the state may selectively promote cooperation among legally independent firms in certain sectors or regions, or by type of joint activity.[1] However, even when the regulatory environment favors the formation of distinct organizational communities, a network of businesses with transaction ties to one another may not develop institutions that foster innovation (Glasmeier, 1991).

In this paper, we identify key features of the institutional milieu that enable organizations belonging to collaborative production networks to learn quickly about relevant process technology innovations and to implement them effectively. We argue further that, in the United States, the regulatory regime and institutions peculiar to the defense contracting system have fostered the development of such a collaborative network among manufacturing firms that coordinate their operations to make sophisticated weapons systems for the Pentagon.

Excessive rigidities in contracting rules and bureaucratic structures are widely believed to distinguish the defense contracting system from commercial contracting relations. These issues have been investigated by a number of independent studies and commissions.[2] The conventional wisdom posits that there are high barriers to inter-firm collaboration that are exacerbated by intrusive government regulation of contracting relations (Alic et al., 1992; Gansler, 1989). As Fong (1991, p. 69) puts it, the regulatory system promotes "arms-length relationships where contract sponsors establish end product specifications and where contractors fulfill those requirements – often without continuing sponsor guidance." Contrary to the conventional wisdom, our research shows that this unusual regulatory regime actually has promoted a cooperative milieu for learning about new technologies and methods of production. Moreover, we find that the learning advantages of the defense network are not confined to transactions that are specific to the Pentagon, but benefit the non-military operations of the networked enterprises as well.

Hypotheses about the Defense Industrial Network

We hypothesize that the contracting system supported by the U.S. government for the manufacture of complex weapons exhibits key features of a flexible and open collaborative learning network, consisting of groups of firms that cooperate with one another on a project by project basis to develop and manufacture specialized equipment. As a consequence, enterprises directly influenced by the institutions and norms peculiar to the defense industrial network are more willing to share information with and provide assistance to other enterprises in addressing common problems.

In a collaborative network with non-exclusive contracting ties, member organizations are exposed to more opportunities for learning about the capabilities of new technologies and therefore should adopt them at a higher rate than organizations outside the network. To the extent that the defense contracting system functions as a collaborative learning network, member companies are expected to have greater opportunities to evaluate and use new technologies that are of relevance to their operations. Since information technology (IT) applications are of relevance to the manufacture of both defense and non-defense products, we expect IT use to be more common among members of the defense industrial network, compared to their counterparts outside the network.

The network form of organization has been identified as important to the inter-organizational transfer of technical know-how, especially in research and development activities (Powell, Koput, and Smith-Doerr, 1996). Although there may very well be spillovers to commercial technologies from the military-supported research and development activities of defense contractors as Mowery and Langlois (1996) show to be the case in the computer software industry, our analysis focuses on the learning advantages from process technology improvements that enhance manufacturing performance. Even when the advantages are widely acknowledged, as in the case of automobile production (Helper, 1991), cooperative production networks have proven difficult to establish and sustain in the United States. To the extent that the institutionalization of a cooperative production network is rare (although instances of cooperative assistance between enterprises may be common) among U.S. enterprises outside the defense network, we expect defense contractors to enjoy a performance advantage over other enterprises in their non-defense production operations as well.

The advantages of multi-firm networks for inter-organizational learning

Previous research on organizational learning has focused on internal processes of change and strategy (Tyre and Hauptman, 1992), structural features of the learning experience itself – such as the phenomenon of learning curves (Adler and Clark 1991; Argote, Beckman and Epple, 1990) –, or changes in technology and work organization (Goodman and Darr, 1996; Kelley, 1994; MacDuffie, 1995).

With respect to the environment, there are two streams of research that situate performance advantages in relation to an organization's position in some larger context, having to do with network ties or institutional milieu. These theories tend to emphasize the buffering or sheltering effects that insulate an organization from the turbulence and destructive forces in its environment (Baum and Oliver, 1991; Lincoln, Gerlach and Ahmadjian, 1996; Miner, Amburgey, and Stearns, 1990). Network analyses emphasize the importance of ties that connect organizations with different capabilities, bridging gaps in knowledge and therefore stimulating innovation (Burt, 1980; Powell et al., 1996). In our framework, the innovation and performance advantages from ties to the defense network are paradoxically both a product of institutional rigidities and of network bridge-building capabilities, very similar in effect to the system of contracting relations observed in the vertical production networks of Japan, as described by Dore (1986), Nishiguchi (1994), and Sabel (1994).

For-profit enterprises seek to learn about new process technologies and methods in order to achieve a performance advantage in cost or quality over potential competitors. Connections to external sources such as professional societies are important for learning about process innovations that are ordinarily developed outside user-organizations by specialized technology vendors (Burt, 1980; Kelley and Brooks, 1991; Rothwell and Dodgson, 1991). With respect to customer-supplier relations, when the boundaries between two organizations are porous, it is possible for one firm to learn about the other's experiences. The greater the dependency between the two companies, the more incentive there is to share information about methods and techniques (Uzzi, 1996). Such partnering arrangements require both organizations to have complementary skills or knowledge and to be willing to share information. Both also have to agree on how to divide the benefits from any joint activities.

Although a partnership (or joint venture) provides a way for an organization to augment its capabilities, the autonomy of the enterprise can be threatened by its dependency on a single partner. The more captive that an organization becomes to the partnership, the more difficult it is to switch to another customer or supplier (Teece, 1992; Williamson, 1985). When there is an asymmetry in the dependency (and relative power) of the partners, there is also the risk that the more powerful partner will exploit the relationship (Baker, 1990). More problematically, this focus on the presence or absence of direct collaborative ties between individual firms ignores the institutional context within which these arrangements yield economic benefits beyond the partners to the exchange.

A production network is a system for designing and making products by a group of enterprises that coordinate their operations. Firms are connected to *multiple* other organizations, either directly or indirectly through transaction ties mediated by core actors. Membership in a multi-firm production network avoids the vulnerabilities associated with exclusive dyadic relations (Richardson, 1993). Moreover, under certain conditions, the system of cooperative relations among firms in the network accelerates the spread of innovation.

The institutional environment and normative relations that we identify with a *collaborative learning network* allow organizations to acquire new competencies from multiple other firms. We follow Granovetter (1994) and Ring and Van de Ven (1992) in arguing that a cooperative milieu does not arise merely from repeated interactions, as implied by transaction cost economics. Rather, it is sustained by a regulatory regime and by institutions that provoke and reward altruistic behaviors. With respect to learning about innovations, an organization in such an environment has to expend less effort and resources to search for reliable sources of information. In addition, the multiplicity of ties insulates the networked enterprise from the negative consequences of an exclusive dyadic dependency relationship.

A network that provides these learning advantages is comprised of organizations that are bound together by a shared sense of purpose or community identity, and have a commitment to engage in activities designed to enhance the capabilities of other firms in the network. Even though member organizations may compete with one another from time to time for new business, they continue to share information that would not ordinarily be revealed to competitors. Production systems based on these learning-intensive connections derive a competitive advantage from the accumulation of a shared knowledge base and the more rapid circulation of information about new methods and technologies.

Key institutional features of collaborative production networks

A network that advances learning has institutions for accumulating and disseminating knowledge about performance-enhancing improvements in technology that are not available to enterprises outside the system. In the vertical production networks of Japan, for example, annual contract negotiations between a core firm (such as Toyota) and a supplier are the occasion for reviewing progress toward performance goals, identifying problem areas to be addressed during the upcoming contract year, and specifying new performance targets (Nishiguchi, 1994; Sabel, 1994). Industry associations in Japan receive government funding for their intelligence-gathering efforts about technological developments relevant to specific sectors and for their educational and technical assistance programs to small and medium-sized subcontractors (Shapira, forthcoming). Hence, both private and public institutions may be employed by networked enterprises to identify strategically important process technology improvements that enhance the individual organization's performance and, in turn, the overall performance of the multi-firm production system.

The types of interdependencies and power relations linking enterprises shape the kind of information that is exchanged and how benefits from the exchange are distributed among the parties. With respect to innovation sources, a network may rely narrowly on the accumulation of expertise and knowledge in a single product market by an exclusive group of specialized firms – i.e., a closed network – with long-standing contracting relations, as in the case of automobile production. Or, a group of enterprises may be loosely linked through a number of different product markets, forming and disbanding ties to one another on a project by project basis, and have the option to bring in new members – drawing on resources outside the network – from time to time when new expertise is needed. These are the characteristics of an open, flexible network.

There are no economies of scale to exploit in the manufacture of a complex, customized product such as a submarine or a fighter aircraft. For the group of enterprises that coordinate their operations to make these types of products, the economic advantages from cooperation have to do with the generation of external economies of scope. In particular, the practice of shifting from one design problem to another for different customers can lead to *learning spillovers* across product lines through the accumulation of expertise by network members in making frequent adaptations in tooling, logistics, and methods. This adaptive capability is what distinguishes a *flexible* production system from a lean mass production system. The information about technological improvements is not transaction-specific, and is not completely captured in the prices charged for the goods and services exchanged between network members. These non-pecuniary knowledge spillovers (Grilieches and Hjorth-Anderson, 1992) are the major source of the economic benefits derived from the non-exclusive ties of a flexible production network.

According to Cook (1977), organizations in central positions can exert considerable influence on other organizations in the network. With respect to learning, centrally positioned organizations can play several important leadership roles: selecting new members, legitimating the adoption of new practices, and institutionalizing (or enforcing) norms of cooperation. In a flexible production network, the dependency ties to lead firms are relatively weak. Leading customers do not have the power to coerce their suppliers to adopt new practices because their suppliers are not highly dependent on them. But member organizations will adopt innovations that a lead firm (e.g., an important customer) demonstrates to be beneficial to peripheral members of the network. A centrally positioned organization induces other organizations to adopt innovative practices by actions that show how these other organizations may appropriate benefits from these changes. Hence, the impact of a core organization on the network is related to the extent of its efforts to influence other firms' practices and the perception of peripheral network members that these actions are beneficial to the overall community. The willingness of the linked organizations to repeat these actions in relation to other organizations is a key mechanism for diffusing innovation throughout the network.[3]

In sum, a collaborative learning network refers to a distinct community of organizations with norms that obligate member organizations to share information and provide assistance to one another. Non-market institutions and core firms are important actors in the formation and maintenance of these norms of cooperation, and the generation and diffusion of innovations among networked enterprises. The state provides an enabling regulatory regime and supporting institutions for filtering and disseminating knowledge about practices and techniques for improving performance. Core firms provide leadership and instigate campaigns to mobilize the resources of the community to address common problems.

Data and Methods

In 1991, we surveyed a randomly selected, size-stratified sample of manufacturing establishments. Eighty-four percent of the production managers we contacted at that time completed the survey, yielding a final sample of 973 plants. The questionnaire focused on the competitive conditions, technology, and other practices affecting products manufactured at least partially through the machining process at the plant.

The sample was selected from the sector we define as machining-intensive durable goods (MDG), which includes 21 industries at the three-digit level of the standard industrial classification system.[4] Collectively, these industries account for virtually the entire capital goods sector (excluding computers), and include certain consumer products (e.g., hand tools and other hardware for home use). The MDG sector was responsible for one-fourth of all manufacturing output in the United States during the 1980s and early 1990s.

Spending on the procurement of new weapons systems reached an unprecedented level during peacetime in the 1980s. By 1987, at the peak of the Carter-Reagan buildup – and ironically, on the eve of the end of the Cold War – purchases by defense agencies accounted for over 6 percent of the gross domestic product of the U.S. economy as a whole. Most of this spending was for new equipment, rather than personnel. The biggest recipients of defense prime contracts during the 1980s were the makers of aircraft, electronics, and communication equipment (U.S. Congress, Office of Technology Assessment, 1992). By 1990, durable goods industries accounted for 82.5% of defense purchases of manufactured goods and more than half [51.3%] of all defense purchases of durable goods in that year were produced in the MDG sector.[5]

In 1993-95, we interviewed managers responsible for supplier relations in a group of the largest prime contractors engaged in designing and building military aircraft, satellites, radar, and missile systems. We conducted site visits at manufacturing plants and interviewed managers and engineers at various locations in the United States. The authors completed approximately 100 hours of interviews with supplier management personnel on-site at their plants. One hundred additional hours were spent in group sessions with defense aerospace managers who were responsible for supplier development and selection activities. In all, systematic interview data were obtained from 20 major defense contractors and a selection of their suppliers. We also relied on government documents and internal memos and reports provided to us by individual companies for information about the history of practices among defense contractors. The case material and historical documents we collected provide information on how the defense contracting system evolved and changed over the past 25 years.

Our analysis of the defense contracting network is based on both the survey data and case studies. We employ the survey data to quantify the behaviors and capabilities that distinguish organizations with a contracting relationship to the U.S. Department of Defense from those enterprises that have no transaction ties to DoD or its prime contractors. The case materials serve to illustrate the mechanisms that prime contractors and the DoD employed in efforts to improve the performance of their suppliers. Along with descriptive statistics from the survey data, we use the case data as evidence to support our thesis that the beneficial effects from the defense contracting system arise from the institutionalization of practices that distinguish this organizational community as a unique collaborative learning network.

Stability of leadership and expansion of subcontracting in the defense industrial base

From the end of World War II until the present, the Department of Defense (DoD) has contracted with private manufacturing firms to design and develop sophisticated weapon systems (Alic et. al., 1992; Markusen and Yudken, 1992). Modern weapons systems such as tanks, missiles, submarines, or fighter aircraft are complex products that incorporate the latest technical advances from a number of specialized fields, e.g., aeronautics, communications equipment, electronics, and materials. Defense agencies do not have the capabilities to design and build these systems. Instead, the Pentagon contracts with private, for-profit enterprises (and to a much lesser degree, to non-profit research institutes and universities for some basic research) to develop the technologies and manufacture these systems.

For more than thirty years, a substantial share of all high-tech weapons contracts from the defense agencies of the U.S. government has been consistently awarded to a core group of prime contractors. According to Scherer and Burnett (1990), the consistent leaders in defense contract awards have been the "major aircraft, missile, and electronics systems companies," who have received (on average) over 45 percent of all prime contracts since World War II (pp. 292-293).

Although the centrality of a core group of large prime contractors has been remarkably stable (even with the recent consolidations and mergers) for most of the Cold War period, the structure of defense contracting has changed. Large prime contractors have become less important as direct producers and more dependent on subcontractors in both the design and production of weapon systems. Johnson and Hall (1965) estimated that subcontracting costs accounted for less than 50 percent of the costs of selected weapons systems built between 1957 and 1963.

During the 1980s, the subcontracting content of the design and production of weapons systems increased. Our interviews with prime contractors responsible for specific aerospace programs indicate that, by the end of the 1980s, the subcontracting content of major programs ranged between 60 and 80 percent of the prime contractors' production costs. Allied-Signal – one of the top 25 defense prime contractors – reported relying upon 7,500 to 10,000 suppliers during the 1980s. And these subcontractors accounted for 60 percent of total costs of the systems Allied-Signal produced for DoD. At Lockheed Martin Tactical Air Systems (formerly a division of General Dynamics), managers involved in supplier development activities estimate that subcontracts consume more than 70 percent of the cost of the F-16 aircraft and are expected to exceed 80 percent of the aircraft's cost by the turn of the century. By the end of the 1980s, the two U.S. manufacturers of military aircraft engines report similarly high levels of subcontracting content. Over 60 percent of the costs of Pratt & Whitney jet engines goes for materials and components purchased from suppliers. Subcontracts from General Electric Aircraft Engines consume two-thirds of the overall cost of producing a military aircraft engine. By the end of the century, GEAE expects to contract out nearly four-fifths of the costs of making these engines.

For the MDG sector in particular, our 1991 survey results indicate that this industrial base is extensively involved in defense contracting. More than half [51.9 percent] of the production managers in these industries identified their establishment as having a contracting relationship with a defense agency or a defense prime contractor.[6] Sixty-seven percent of these defense contractors have only a subcontracting relationship to a prime. Of the remaining thirty-four percent of defense contractors having a prime contracting relationship with the Pentagon, fully 74 percent also have subcontracts to other prime contractors. Hence, a large majority (87%) of all defense contractors in this sector has a subcontracting relationship to a prime contractor.

Both technical and political considerations appear to be responsible for the rise in subcontracting content of defense production. Weapon systems have become more complex, causing prime contractors to increasingly rely on subcontractors with the specialized technical expertise in certain manufacturing processes, and for making entire subassemblies. Domestic and international political factors also have influenced the expansion of defense subcontracting. Some major prime contractors have expanded the amount of subcontracting within the United States as a strategy to influence key members of the U.S. Congress by showing how spending on specific defense programs will affect the subcontractors located in their districts (Kotz, 1988). When General Dynamics Corporation secured a contract in the mid-1970s with European nations for the F-16 as the preferred fighter plane of the North Atlantic Treaty Organization, it agreed to subcontract a substantial share of the production to enterprises in Europe (Creasey and May, 1988). Other major U.S. defense contractors have followed this practice, assuming subcontracting obligations to enterprises located in the countries purchasing weapon systems originally designed and built for U.S. military forces.

Manufacturers of weapons: a separate "industry" or an open network characterized by non-exclusive ties?

The defense industrial base has frequently been described as "walled off" from the rest of U.S. industry (Alic et al, 1992; Gansler, 1989; Markusen and Yudken, 1992). The peculiar regulatory environment has prompted some analysts to conclude that there is little potential overlap between a production system that satisfies military needs and one designed for commercial transactions, causing companies to "spin away" their defense operations from their commercial activities. The isolation of defense manufacturing from the rest of U.S. industry has long been accepted as a stylized fact in policy discussions.[7] However, there has been remarkably little systematic investigation of the extent of that divide, and the difficulties or ease with which firms traverse the military and commercial industrial spheres.

Recent research on the extent of the capabilities of defense contractors to meet both military and commercial customers' demands suggest that this divide is largely confined to administrative activities, and is much less evident in the manufacturing operations of contractors (Kelley and Watkins, 1995). By the late 1980s, many of the largest prime contractors were divisions of corporations with major commercial interests – e.g., Allied-Signal, Caterpillar General Electric, General Motors, Ford, IBM, Kennemetal, Magnavox, Texas Instruments, TRW, Textron, and United Technologies. For the majority of these large prime contractors, revenues from defense contracts were only a minor share of total corporate earnings in the mid-1980s at the peak of the Carter-Reagan buildup (Alic et al., 1992).

Although large defense contractors may have relied upon separate administrative structures for defense contracts, the defense manufacturing operations of these enterprises were far more closely connected to their commercial operations. For example, General Electric's Aircraft Engines Division, Pratt and Whitney (a division of United Technologies), and Hughes (owned by General Motors) operate facilities that manufacture products for both military and commercial customers. Our 1991 survey of the MDG sector provides further evidence that the defense contracting network is an "open" system with many linkages from prime- and sub-contractors to commercial customers.

Figure 1 shows the percent distribution of all defense contractors ordered by the degree of dependency on sales to the Pentagon in 1990. The figure also shows the contribution to overall defense-related output from the sector's contractors by the degree of the plant's defense dependency. Of the contractors with any defense-related sales in 1990, over 60 percent reported having less than 30 percent of their total revenues coming from defense contracts. On average, these active contractors received only 28 percent of their total revenues in 1990 from defense contracts. Only 7 percent of all contractors were highly dependent – 80 to 100 percent of the total – on defense related sales revenues.

[INSERT FIGURE 1]

Looking at the distribution of defense-related output by contractors' degree of dependency on sales to the Pentagon, we find that more than 50% of all defense related output comes from contractors with substantial "dual-use" capabilities – those that depend on commercial customers for 50 percent or more of their total revenues in 1990. The highly dependent defense contractors – those with over 80 percent of their revenues coming from defense-related sales – contribute 33 percent of the total defense-related output.

Selection biases favor organizations willing to conform to an information-sharing norm

All prime contractors (and subcontractors with contracts in excess of $25,000) are subject to a complex set of regulations, including those specific to the Pentagon as well as the accounting standards and record-keeping requirements that apply to all major purchases of goods and services by any federal agency. Military specifications in a contract for a particular weapon system include detailed performance requirements for all components, the conditions for testing or inspecting, the type of materials and processes to be used, and the methods of manufacture. Prime contractors have responsibility and accountability for meeting the military specifications of the final product, including the portion purchased from subcontractors (Ellenson, 1993). With respect to these purchases, prime contractors are required to buy certain technologies and materials from U.S. owned companies (rather than foreign-owned companies).

Companies that are willing to become defense subcontractors have owners and managers who are willing to accept the scrutiny of the federal government with respect to cost accounting and other management procedures. A certified subcontractor also has to be willing to provide information about its operations to a major prime contractor. Procurement managers in the largest defense aerospace contractors consistently told us that their major consideration in the selection of new subcontractors during the Carter-Reagan buildup was the willingness of the managers to share information and to adapt internal operations to the prime contractors' demands.

With respect to competitors, prime contractors may be required to share proprietary information on technologies that the Pentagon deems critical to national security.[8] One informant told us about the "mentor- protégée" program affecting single-source contracts during the 1980s. When there was only a single source for a component or material considered to be critical to the performance of a particular weapon system, the source (or the prime contractor responsible for supplying the system) became the mentor of a competitor (or another supplier) who was designated the protégée. The mentor was required to teach the new source how to produce the critical component. If a proprietary technology was involved, the mentor was also required to license that technology to the protégée. Hence, a subcontractor that develops a new or better method while working on a defense contract may also be required to teach a potential competitor these techniques.

Companies with owners and managers who do not want to be subject to this degree of oversight by the federal government (or its prime contractors) or who feel that their exclusive control over proprietary technologies is a major source of competitive advantage are not likely to participate in the defense contracting network. Because the appropriability conditions for capturing the exclusive benefits of innovation are perceived to be very weak, potential suppliers with the "best" capabilities to exploit innovations in commercial product markets may not be as willing to participate in the defense contracting system. The unwillingness of such commercial enterprises to be involved in a defense contracting relationship has prompted some analysts (Gansler 1989; Rogerson 1992) to contend that those enterprises attracted to defense contracting are less efficient and less inclined to develop and use productivity enhancing technologies.

Certification as a public declaration of network membership

In selecting new subcontractors, major primes maintain lists of companies that have the desired technical competencies. Prime contractors provide firms with the technical potential to be a defense supplier the opportunity to become "certified" as a defense contractor. Certification indicates to other prime contractors and commercial customers that the enterprise has proven to be reliable in delivering orders on time, in maintaining high quality, and to be relatively sophisticated in its use of particular methods, such as statistical process control.

The special selection and certification procedures used by the large prime contractor make it easy for prime and subcontractors to determine whether a particular organization belongs to the defense network. Lists of certified suppliers are published in the journals of industry associations such as the Aerospace Industry Association and the American Defense Preparedness Association.[9] The Pentagon is also required to publicly disclose the names of all subcontractors that received more than $25,000 in a particular contract. At each of the subcontractors we visited, no main lobby of the plant was without its wall of plaques from its defense customers, indicating which supplier certifications and special awards it had received in recognition of its past performance.

As the number of contractors expanded during the 1980s, and the complexity of military weapons systems increased, certain prime contractors (such as GEAE and General Dynamics) began to change their methods of ensuring quality and other performance requirements of their subcontractors. Certifying every established subcontractor on each component or system was proving to be very costly, time consuming, and an increasingly unwieldy method of insuring conformance to quality and performance standards. By the mid 1980s, a number of the largest prime contractors had established new certification/qualification procedures that focused on developing new capabilities in methods and technical processes, rather than adherence to detailed specifications in making each component.

Even though each of the twenty aerospace prime contractors we interviewed reported having developed their own certification program, independent of any other contractor, we found considerable similarity among the programs and the standards that were used. In each program, there were usually two or more tiers of certification. Differences between each rank were based on achieving certain benchmarks in the use of particular methods, such as statistical process control (SPC), or on performance measures, such as the percentage of deliveries made with zero defects or on-time. Moreover, all the certification programs that we reviewed included sanctions for suppliers whose performance did not live up to the required standard – e.g., loss of certification or increased monitoring by the prime contractor. However, it was usually possible for a subcontractor to have the opportunity to be re-certified, when the deficiencies were corrected to the satisfaction of the prime contractor issuing the certification.

As an illustration, Texas Instruments Defense Systems and Electronics Group (DSEG) has three types of certification: Bronze, Silver and Gold. Certification levels are granted depending on past quality levels and the suppliers' SPC expertise. Bronze certified suppliers have provided products meeting the specification requirements without faults for 18 months. Silver certified suppliers inspect their own product on sight, following certain DSEG procedures, which eliminate the need for inspection of the delivered product by DSEG. (That the prime contractor does not need to inspect the incoming product is a big money-saver, and is one of the goals of many of these certification programs.) Gold certified suppliers show consistent and complete conformance to a range of other DSEG requirements.

The role of prime contractors in self-improvement campaigns

At the end of the 1970s, a study of the capabilities of the defense industrial base, conducted by a Congressional committee, identified the following as problems of concern to national security: serious deficiencies in the capabilities of subcontractors, skill shortages in manufacturing, low productivity growth rates (compared to the relevant industries in other countries), and inadequate private investment in new technology (U.S. Congress, House of Representatives, Armed Services Committee, 1980). Since we lack data from this earlier period, we cannot determine whether the industrial network we observe in the 1990s was as technologically "backward" and inefficient at the end of the 1970s as the Armed Services Committee believed. However, the fear of falling behind, or losing technological leadership in the Cold War, was the main justification for new initiatives by the DoD to encourage prime- and sub-contractors to experiment with and conduct demonstration projects on the applicability of new productivity-enhancing technologies to defense manufacturing.

During the 1980s, the mentoring and coordinating roles of large prime contractors were expanded through a combination of government-financed initiatives and company-initiated changes in subcontracting policies. Increasingly, the large prime contractors took on greater responsibility for developing the capabilities of their suppliers in much the same way that the leading firms in Japan's industrial keiretsu were reported to have done during the 1960s (Nishiguchi, 1994). (As we shall see, these initiatives provided unexpected benefits to the commercial operations of defense-linked enterprises.) In most cases, participation by the subcontractor in government or prime-contractor led initiatives was "voluntary" and there were no overt sanctions for non-participation. None of the procurement managers of major prime contractors reported to us a single instance where a subcontractor refused assistance offered by a prime contractor. Hence, we conclude that once inside the network, the regulatory regime habituates defense contractors to provide information to one another, and to participate in self-improvement campaigns for political reasons, i.e., in order to demonstrate a willingness to cooperate and to show a commitment to common goals.

The first large-scale supplier-improvement campaign was begun in 1978 by General Dynamics for the production of the F-16. By 1982, all of the major aerospace prime contractors had established their own technical assistance programs for U.S. subcontractors. Many of these activities continue to the present day.[10] In most instances, the initial funding for activities designed to develop the capabilities of the network as a whole came from the DoD. Government funds were provided to prime contractors under the Industrial Modernization Incentives Program (IMIP) and the Manufacturing Technology Program (ManTech), as well as the discretionary portion of the program budgets controlled by managers employed by branches of the military services (especially the Navy and the Air Force).

The Industrial Modernization Incentive Program (IMIP) provided funding to prime contractors to develop and deploy better methods of manufacture, with an emphasis on large-scale process technology improvements. Each of the major prime contractors for the Air Force and the Navy had an IMIP program. Several thousand projects were undertaken over the ten-year (1982-92) life of the program. However, many of the large-scale projects were never implemented. And others were scaled back to modest efforts in automation or the use of computers to monitor processes.

One example of a successful IMIP project is the Printed Circuit Board/Paraylene Coating project with the Dynamic Controls Corporation, a subcontractor to General Dynamics for the F-16 aircraft. The main purpose of the project was to improve the reliability of the production of printed circuit boards (PCBs). Previously, all aspects of the quality control process were under the operator's direct control. The process was labor intensive, unreliable, and inconsistent. As a consequence of a number of technological changes, this IMIP project "resulted in the production of a more consistent product, ...removed sources of operator error from microprocessor controlled processes, and has improved the working conditions associated with PCB assembly." Importantly, this project also resulted in a savings of over $4 million in the cost of manufacturing a specific military product used in the F16 aircraft.

Cost savings in the manufacture of specific military products were rarely traceable to a specific IMIP project, however, in part because the types of improvements in manufacturing techniques supported by IMIP were systemic in nature, affecting both military and commercial production. As a result, prime- and sub-contractors had difficulty in showing that the subsidy from the Pentagon provided a significant return on the DoD's investment by the usual cost-benefit method of analysis. Because there were so few instances where an IMIP project led to substantial cost savings in military-specific production, the Navy and the Air Force considered the program to be a failure, and the program was terminated in 1992. The benefits accrued to the commercial operations of contractors were not even considered in the Pentagon's evaluation of IMIP.

IMIP provided funds to a prime contractor for the technical assistance in assessing the applicability of new manufacturing technologies to its own and its subcontractors' operations. There were no government funds available for the purchase of these technologies. The main legacy of the IMIP program appears to be the development and refinement of new management tools by prime contractors for assessing the capabilities and weaknesses of their suppliers. At the time of our interviews in 1993-95, we found that the assessment methods developed with IMIP funds were still being used by major contractors.

Not only did prime contractors initiate programs to improve their own performance and those of their subcontractors during the 1980s, but subcontractors also began their own improvement programs with their suppliers. For example, Menasco, a division of Coltec Industries, specializing in making landing gear for commercial and military aircraft, instituted its own supplier development and certification programs with two levels of certification. Suppliers with SPC systems are qualified to work on existing programs. In order to participate in any new project, Menasco requires its suppliers to demonstrate their competency in a number of new methods. Setting new thresholds of performance and capability forces those subcontractors who want to continue doing business with Menasco to continue to make process technology improvements. This imitation of prime contractors' activities extends the influence of the large prime contractors (the most centrally positioned organizations in the defense contracting network) to peripheral members of the subcontracting network.

A higher norm of cooperation: the statistical evidence

Our statistical analysis of the 1991 survey of establishments in the MDG sector confirms our case study research that defense contracting institutions foster a greater exchange of information and technical assistance among firms in the network than occurs in the absence of these institutions. Table 1 compares establishments that belong to the defense contracting network to those plants in the MDG sector without defense contracts on several measures of cooperative exchange of information and assistance in the enterprise's relations to its largest customer and its competitors in the same product markets. The table also includes two indicators for the importance to the enterprise's production manager of meetings of industry associations and professional societies for learning about innovations. On every indicator, defense contractors have a higher incidence of cooperative learning arrangements with their customers and their competitors, and greater cohesiveness as a community, as evidenced by the tendency to depend on industry and professional group activities for learning about new technological developments.[11] The difference is marked in many cases; in particular, defense firms are significantly more likely to receive technical assistance from their customers, to subcontract machining work with competitors, to share technical training and information on using machine tools with competitors, and to share equipment with competitors. Defense contractors are also more likely to get information about new machining technologies from trade shows or technical society meetings, and to receive technical assistance or training from an industry or trade association.

[INSERT TABLE 1]

Summary

The defense network has many of the key features of a collaborative learning network. A regulatory regime of defense contracting habituates member organizations to having relationships with other contractors and to the government that span conventional organizational boundaries and favor the development of information-sharing and a cooperative approach to problem-solving as a norm governing inter-firm contracting relations. A stable leadership of prime contractors is responsible for bringing innovations into the network, and ensuring that new knowledge is shared. There are various, systematized methods of coordinating the diffusion of knowledge about new technologies. Finally, we have statistical evidence showing a higher incidence of information-sharing with and technical assistance to/from defense contractors, compared to their counterparts outside the network.[12] We conclude that by the end of the Cold War, the system and structure of relations among defense contractors exhibit the distinctive features of a flexible and collaborative learning network.

Learning advantages and spillovers from the defense industrial network

Our indicators for new capabilities are the use of information technology applications in production. Our performance indicator is the hours it takes to complete the steps necessary to make a precision-machined product. With the 1991 survey data, we test for statistically significant differences in these indicators between defense contractors and their non-defense counterparts operating in the same sector. For the purposes of this analysis, we consider all establishments making machined products in the selected industries to be potential competitors.

Use of new technologies

The 1991 survey data include information on the adoption of six information technology applications in manufacturing-related processes: computer-controlled (CNC) and numerically controlled (NC) machine tools, and flexible manufacturing systems (FMS) – which we combine under a single category – the applications of a programmable form of automation (PA) to the machining process; computer-aided design systems (CAD); computers for process monitoring and planning; IT for quality control; the use of computers in materials and parts planning; and programmable automation applied to processes other than machining. The productivity benefits of these technologies are potentially quite large. Computer-controlled machine tools can remove metal at faster speeds while maintaining much tighter tolerances than is possible with traditional machines controlled manually by production workers. CAD systems have eliminated the necessity to construct prototypes, and help to shorten the product development cycle. Using information technologies in materials planning can reduce inventory costs and make it easier for an enterprise to coordinate the deliveries of its suppliers and to meet just-in-time delivery schedules of its customers.

The benefits from these IT applications can be appropriated by producers of defense and commercial products alike. To the extent that these IT applications are most advantageous for reducing costs, we might expect defense contractors to have less incentive to adopt them, since cost minimization is a less important goal in these transactions than the achievement of quality and other performance goals. However, when we compare the use of these IT applications in 1991among defense contractors with that of their exclusively commercial counterparts in the MDG sector (as shown in figure 2), we find that establishments linked directly or indirectly to the defense contracting system have higher rates of use for each of the six IT applications. Table 2 contains logit regression results where the dependent variable in each column is defined =1, if the production manager reported having the specific IT application, and =0, if computers were not used for that function in the plant. For each regression, we employed the same set of independent variables, including a control for the size (or scale) of the manufacturing operations at an establishment, and indicators for the presence or absence of a cooperative information-sharing relationship with other organizations (customer-firms and competitors) and the provision of technical assistance by industry groups.

[INSERT FIGURE 2 AND TABLE 2]

Participation in the defense production network is consistently (and significantly) a strong predictor of the use of all six IT application for which we had data.[13] However, our results do not show a consistent, independent relationship between IT use and any of the three measures of cooperative links to specific types of organizations. Only with respect to the use of IT for quality control, do we find positive (but not always statistically significant) effects from all three types of linkages. With the exception of PA in the machining process, a cooperative information-sharing relationship with a plant's largest customer shows a positive effect on the use of other IT applications. However, this effect is not always statistically significant. For three types of IT use – process monitoring, quality control, and PA applications in non-machining processes – a cooperative information-sharing relationship with a plant's largest customer is a significant factor. Having a cooperative relationship with competitors has no significant effects on the use of *any* of the IT applications we studied. We infer from this result that cooperation with competitors does not augment an enterprise's technical capabilities, independent of the institutional context within which these cooperative relationships are situated. The availability of technical assistance from industry associations increases the likelihood of CAD systems and IT for quality control, but has no significant effects on the likelihood that an establishment will employ any of the four other IT applications we studied.

[INSERT FIGURE 2 AND TABLE 2]

Efficiency in making machined products

All of the establishments we surveyed in 1991 make a precision-machined product. The respondents provided detailed specifications on the complexity of tooling, precision requirements, the cost of specialty materials, the amount produced, and the hours involved in making up to two specific products – one made on non-automated machines and another using PA machining technology. A composite measure, *machining production hours per unit of output*,[14] is the dependent variable in all regression models shown in tables 3 and 4. The lower the number of hours it take to make the selected product, the more efficient we assume the machining production operations to be.

Important quality-related differences in the properties of machined products – related to their shape, type of material, and function – affect the length of time that would normally be required to complete the machining process, independent of the skill of the operator, the type of technology, and organization-specific attributes. We adapt the hedonic regression method to the problem at hand by specifying a vector of quality-related attributes of machined products that are well-known and normally taken into account in production planning and scheduling.[15] We treat these quality and complexity attributes of the product as controls for industry differences in the type of products manufactured among plants.

Having controlled for differences in product quality and complexity, we expect three types of variables to affect the efficiency with which machining operations are performed: cooperative inter-organizational relations and a supportive institutional environment, the technology and operations strategy of the enterprise for the machining process at the plant, and establishment-specific policies concerning wages, educational requirements, and labor relations as these pertain to the machining workforce. The effects of this set of factors are assumed to be independent of the type of product, i.e., as if we were comparing plants making a "standardized" product.

In table 3, we present results of regression analyses that examine the efficiency of manufacturing products whether or not the product is designated to go to a commercial or a military customer.[16] In addition to the defense network tie, we include two variables that measure different aspects of the cooperative industrial milieu. If a plant has two or more of the cooperative attributes with its largest customer (as shown in table 1), we consider it to have a cooperative relationship with its most important customer. Similarly, if a plant has two or more cooperative ties to competitors, we treated it as having a cooperative competitive milieu.

[INSERT TABLE 3]

In the first column of table 3, we consider the effects of vertical and horizontal cooperative relationships on performance. In the second column, we include a variable measuring whether or not the plant is a member of the defense contracting network. And, in the third column, we include measures for technology use, operations strategy, and labor characteristics.

With respect to a vertical cooperative relationship (with the establishment's largest customer), we find a consistent performance advantage. Establishments with such a relationship are estimated to be between 14 and 18 percent more efficient, on average, compared to plants that lack these ties.[17] After accounting for the specific (and recent) experiences of an organization with its largest customer and competitors, we find that an organization belonging to the defense contracting network is 19% more efficient, on average, compared to its counterpart outside the network. The results in column 3 indicate that much of the effect from participation in the defense network is captured within an organization through its use of new technology, and other improvements in the management of its operations. When the effects of these factors are considered, we find that there is no longer a statistically significant difference in machining hours related to defense contracting status, and the size of the coefficient measuring the influence of the defense contracting tie becomes smaller. These results suggest that the typical defense contractor is able to appropriate the benefits from the network through improvements in its own use of technology and operations strategy. From our case study research, we attribute the willingness of contractors to make these improvements largely to the supportive learning environment provided by the extensive supplier development activities undertaken by prime contractors and the DoD during the 1980s.

Evidence of learning spillovers between defense and commercial industrial spheres

Many of the techniques that contractors have learned how to use through DoD-supported supplier development activities peculiar to this network are applicable to non-defense production as well. Interviews with several subcontractors that joined the network in the early 1980s indicate that a major attraction for these companies to become defense contractors was the opportunity to learn about new techniques, such as statistical process control. Large prime contractors, such as GEAE and GD, were reported to routinely provide technical assistance in learning these methods at no cost to their subcontractors. In turn, the "dual-use" capabilities of suppliers resulting from these non-exclusive ties allowed the DoD and prime contractors to learn from their suppliers about the latest developments in commercial practices and technologies.

General Electric's use of IMIP and ManTech funds provides an example of the way in which the technologies introduced under the auspices of these two programs benefited both military and commercial operations of defense contractors. According to Eberstadt (1991), GEAE received $100 million from IMIP and ManTech over several years and invested another $133 million of its own funds, while persuading its suppliers to invest an additional $60 million in a specific manufacturing technology. The combined effort focused on developing a new, less-costly method for cutting cooling holes in turbine blades. As Eberstadt describes it:

> "ManTech helped GE develop an entirely automated method for using lasers to drill cooling holes through turbine blades. IMIP further helped GE combine laser drilling with other steps (wax insertion, deburring, wax removal, air-flow inspection) in a fully automated process so that all the operator had to do is insert the blade blank. This system is equally applicable to military or commercial products...The combination of advances GE has made under these programs enables the company to increase direct labor productivity at a given site by 20-50 percent, while at the same time cutting defects....GE claims IMIP and ManTech funding has allowed the *company to trim over $20,000 per unit from the cost of some of their commercial engines, and over $10,000 per unit from other* [military] *models"* (pp.61-62, emphasis added).

In table 4 we present regression results for products that are slated specifically for commercial customers. Here we are testing to see whether participation in the defense contracting network provides a productivity advantage that spills over to the commercial operations of contractors with dual-use capabilities, i.e., those that make products for commercial and military customers in the same facility. As we showed in figure 1, dual-use capabilities characterize the vast majority of all defense contractors in the MDG sector.

[INSERT TABLE 4]

Assuming that we have adequately controlled for product attributes and the plant's recent experience with vertical and horizontal cooperative relationships, our analysis of machining performance indicates that a defense contractor makes a commercial product in 38% fewer hours, on average, than its strictly commercial-oriented counterpart operating outside the network. Moreover, after including the technological and operational characteristics of the plants in our regression model (column 3 of Table 4), there remains a significant performance effect related to an establishment's link to the defense contracting network. Defense contractors are estimated to make a standardized product of the machining process for commercial customers in 23% fewer hours, on average, than enterprises solely oriented to meeting the needs of commercial customers.

If we consider the combined advantages from the use of programmable automation and participation in the defense network, our analyses show that the average high-tech defense contractor can produce a standardized commercial product in 70% fewer hours than the average low-tech manufacturer with no connection to the defense contracting network.

Conclusions

In general, the findings presented in tables 3 and 4 confirm our hypothesis that the supportive learning environment peculiar to the defense contracting network provides a performance advantage to member organizations. In all regression models, a cooperative relationship with a plant's largest customer is consistently related to better machining performance, although these effects are not statistically significant in the regression models where the data are confined to products manufactured specifically for commercial customers (i.e., excluding products specified for a military customer).

Our results also show that cooperative ties to competitors do not provide an efficiency advantage. Instead, we find consistent evidence that a cooperative relationship with competitors is associated with *poorer* performance, on average. Since we measure only recent efforts at cooperation among competitors (1989-90), these results may reflect the efforts of less technologically sophisticated enterprises to catch up with performance leaders who have already made investments in new productivity-enhancing technologies and methods of organization. Or, alternatively, our results may be interpreted as providing some confirmation of the dangers of cooperation among competitors: that such relations are collusive, i.e., used by weaker competitors to protect themselves from the threat of losing market shares to more efficient competitors.

In other regression models that we ran separately for all plants belonging to the defense network and all plants with no defense contracting ties, we found that this perverse effect is only statistically significant among plants with no connection to the defense contracting network. If we consider this result to reflect the influence of collusive cooperative arrangements, then the absence of significant collusive effects among defense contractors may be attributable to the influence of government oversight of contracting relations within the defense network. Because of the limitations of our cross-sectional survey data, we cannot distinguish between the more benign and pernicious interpretations of the perverse effect of cooperation with competitors on the efficiency of machining operations outside the defense contracting environment.

Our case studies and survey data indicate that the structure of relations, systems for supporting information sharing, and the regulatory regime of the defense contracting network fit our model of a cooperative, non-exclusive learning network. By the end of the Cold War, the defense industrial base had developed capabilities that surpassed the strictly commercial operations of enterprises in the same sector. We attribute the performance advantages distinguishing defense contractors from their strictly commercial counterparts to the habit of information-sharing that the defense contracting system demands, the efforts of the DoD and the largest prime contractors to enhance their suppliers' capabilities by training in the use of new methods, and campaigns designed to motivate subcontractors to undertake their own self-improvement activities.

The regulatory regime of defense contracting has a self-selection bias. Organizations with managers who are not very "trusting" in their contracting relations or who are unwilling to share proprietary information are not likely to participate in the defense contracting network. Hence, suppliers that joined the defense network for the first time during the Carter-Reagan build-up were more likely to be "open" to suggestions for improvements from customers and suppliers and, in turn, to share the knowledge acquired from their contacts with enterprises outside the network. Since the expansionary period for adding new contractors coincided with the Carter-Reagan buildup, which ended in 1987, the performance advantage we identify with defense contracting status in 1991 is likely to be the result of at least several years of experience and acculturation to the information-sharing norms of the network. Thus, we are quite confident that the differences in practices and performance we observe in 1991 are the outcome of the structuring of the cooperative learning network system itself, and not simply a reflection of a selection bias that brought the best performers or best learning organizations into the defense contracting system.

Nor do we believe that the performance advantages of the defense contracting system to be simply the result of a disguised industrial policy carried out under the veil of national security, as suggested by Hooks (1990) and Markusen and Yudken (1992). Instead, we perceive the role of the state as providing the legitimization for an enterprise to share information that was of benefit to other organizations (but not necessarily to itself) – including customers, suppliers, and competitors – and a regulatory environment that reinforced an ethic of cooperative problem-solving among firms. With its emphasis on the virtues of altruism and sacrifice for the collective welfare of the nation, militarism is an ideology that serves to legitimate activities that benefit others in the community of organizations that share these values that are not always reciprocated in subsequent transactions.

Collaborative learning networks such as we find in the case of the defense production system form as a result of a confluence of institutional and technical conditions. These are not easily constructed, nor sustained solely by the interactions of the members of a specific organizational community. In the United States, where organizational autonomy is highly prized, and innovation is commonly viewed as an asset of a firm to be protected, the extent to which major prime contractors have attended to their suppliers' competencies and the performance of the greater industrial community is notable for its rarity. By contrast, in his provocative book on the political economy of modern Japan, Samuels (1994) argues that the development of Japan's industrial might in the post World War II period reflects an ideological transformation of its pre-war institutional legacy of militarism to that of economic nationalism.

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Notes

1. With the passage of the National Cooperative Research Act in 1984, the U.S. government allowed collaboration among firms in their research and development activities, but required the participants to show that they had plans to independently produce or license the results of their joint R&D activity.
2. For a recent review of the history of acquisition reform, see: Sapolsky, Gholz, and McKinney (1996).
3. In a formal analysis of the effects of network position on the behavior of other actors belonging to the same network, Gould (1993) demonstrates that altruistic actions are more likely to be imitated by peripherally connected members when the actions are initiated by prominent or centrally positioned organizations.
4. The industries are: nonferrous foundries (SIC 336), cutlery, hand tools and hardware The industries are: nonferrous foundries (SIC 336), cutlery, hand tools and hardware (SIC 342), heating equipment and plumbing fixtures (SIC 343), screw machine products (SIC 345), metal forgings and stampings (SIC 346), ordnance and accessories, not elsewhere classified (SIC 348), miscellaneous fabricated metal products (SIC 349), engines and turbines (SIC 351), farm and garden machinery and equipment (SIC 352), construction and related machinery (SIC 353), metalworking machinery and equipment (SIC 354), special industrial machinery (SIC 355), general industrial machinery and equipment (SIC 356), miscellaneous machinery, excluding electrical (SIC 359), electrical industrial apparatus (SIC 362), motor vehicles and equipment (SIC 371), aircraft and parts (SIC 372), guided missiles and space

vehicles (SIC 376), engineering and scientific instruments (SIC 381), measuring and controlling instruments (SIC 382), jewelry, silverware, and plateware (SIC 391).

5. These figures are based on the estimates of direct and indirect effects of defense spending in as reported in *Industrial Output Effects of Planned Defense Spending, 1990-1994.*

6. Our estimate of the extent of the defense industrial base in the MDG sector in 1991 corresponds closely to results obtained from the Census Bureau's 1988 survey of 10,000 manufacturing plants (U.S. Department of Commerce, 1989). Using this government data source, we computed the percent of plants with defense contracts in 1988 for the same set of industries. Nearly half (49.7 %) of establishments with 20 or more employees in the MDG sector reported to the Census that they had defense prime contracts (selling directly to one of the federal defense agencies) or subcontracts to defense prime contractors.

7. In a recent critique, Burns (1992) points out that the term "defense industrial base" is itself ambiguous and has been used to characterize government support for a wide variety of technologies and industry projects deemed of economic and national security importance. Indeed, Burns quotes Undersecretary of Defense Costello (1976-80) as having employed the term "defense economic base" to include all actual and potential suppliers (and potential technologies) of relevance to national defense needs; not just the current set of prime- and sub-contractors.

8. For a more detailed discussion of the types of regulations and technology sharing requirements imposed on defense contractors, see: Alic, et al., 1992, pp. 146-152.

9. ADPA identifies 702 corporate members of its 1992 "Honor roll of industrial preparedness." These companies are described variously as "concerned about and dedicated to the security of

our nation" and representing the "movers and shakers that contribute to the strength of the industrial base." *National Defense,* October 1992, pp. 86-92.

10. During the 1980s, the Department of Defense spent nearly $200 million per year on programs providing technical assistance, demonstration projects on how to implement technological changes, and for research to develop process technology improvements. This level of spending exceeded the amounts that state governments budgeted for similar activities aimed at all small and medium-sized manufacturing enterprises (Shapira, 1990).
11. We find no statistical differences between defense contractors and their non-defense counterparts in the MDG sector with respect to average age of the plant, size (as measured by employment or sales revenue), and the value of shipments per employee.
12. In other analyses (not shown), we find no correlation between the degree of dependency on defense contracts and the incidence of cooperative interchanges with other organizations.
13. Means and standard deviations of all regression variables are included in appendix table 1.
14. This measure includes the hours it takes to set up machines, the hours of metal cutting and finishing operations, and the hours involved in programming the CNC/NC machines.
15. There is an extensive economics literature on hedonic regression methods in analyses of prices and productivity. See Griliches (1990) for a review of these applications.
16. Definitions, means and standard deviations of the variables used in these regressions are included in appendix table 2.
17. Technically, the coefficient for each dummy variable in these models is an estimate of the difference in the $\log_e$(production hours per unit of output), our dependent variable. The

percent change in the difference in production hours is given by the transformation [antilog (z)]-1, where z = the coefficient estimating the effect of the dummy variable.

Figure 1: Percent distributions of defense contractors and defense-related output from the MDG sector, grouped by the plant's dependence on revenues from defense customers

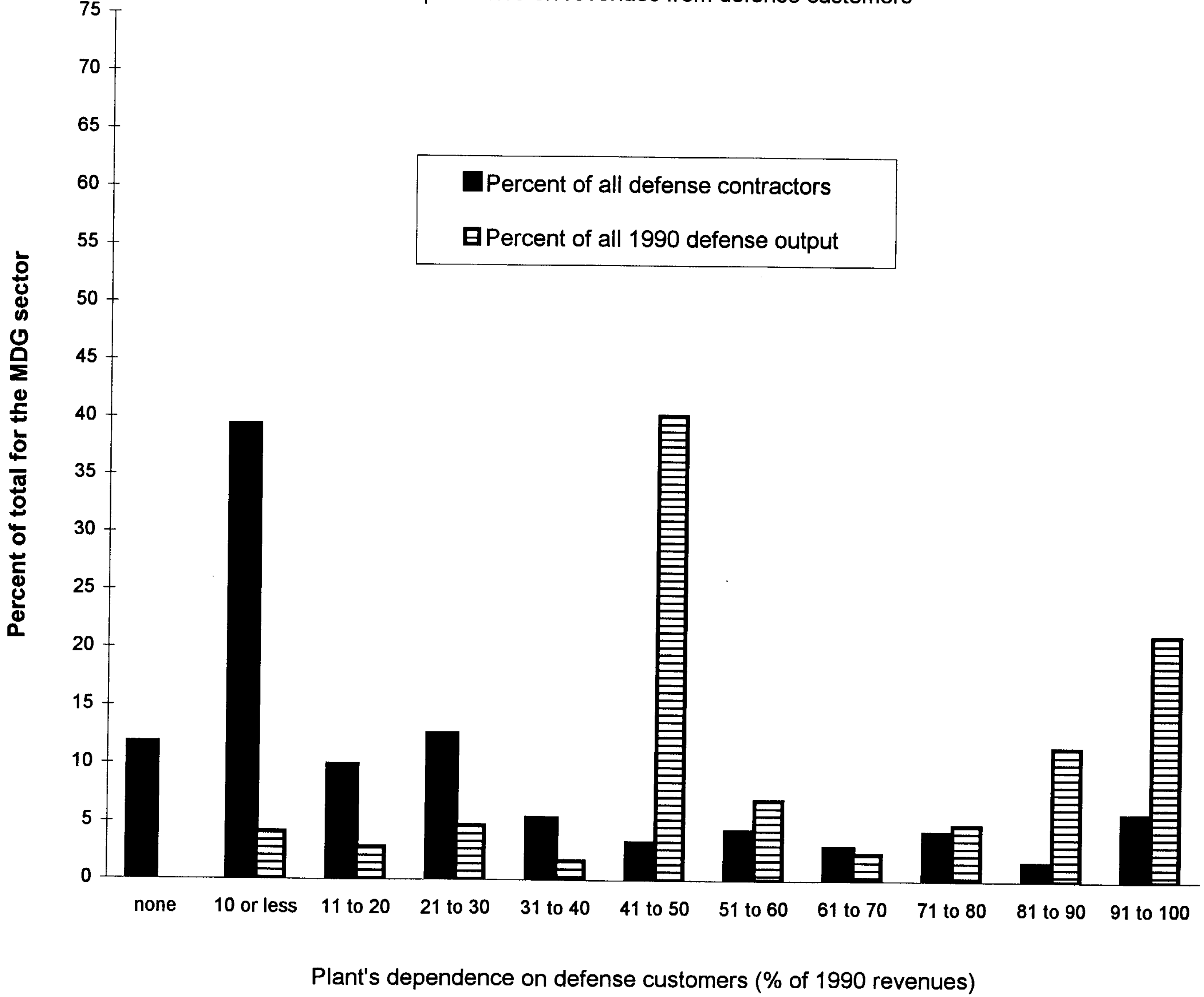
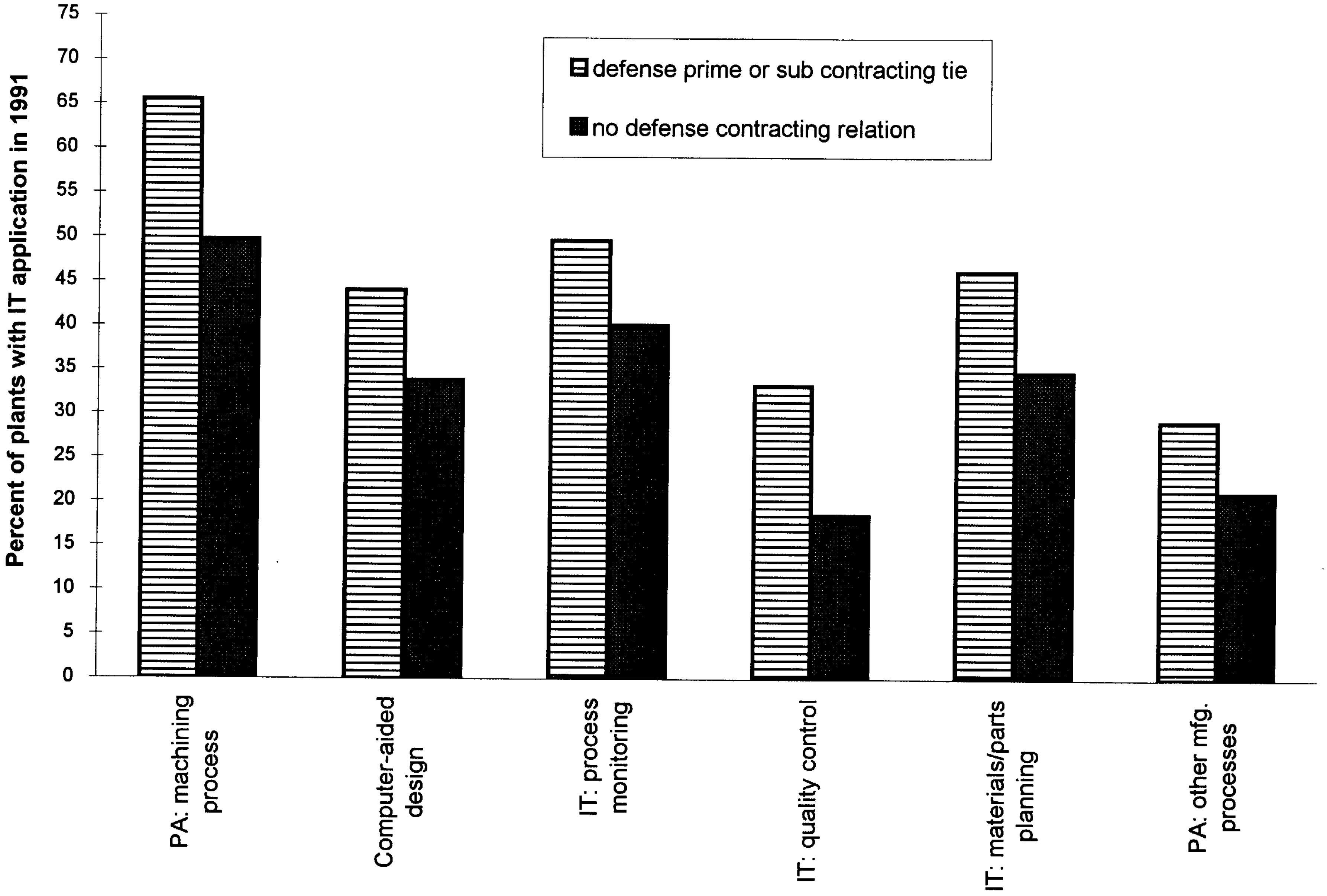


Table 1: The incidence of collaborative activities among plants with defense contracting relation compared to plants with no defense contracting tie

	Plants with defense contracting relation (%)	Plants with no defense contracting ties (%)
Measures of Cooperative Relationship with Largest Customer		
In 1989 or 1990, did your largest customer:		
provide technical assistance to your plant?	**29.4**	**23.9**
collaborate with your plant in developing new products?	43.5	41.0
loan equipment or machinery to your plant?	12.9	9.9
provide financing for materials, equipment, or supplies for your plant?	16.1	13.2
Number of observations	421	314
Measures of Cooperative Relationship with Competitors		
During 1989 or 1990, did you or a competitor:		
subcontract machining work to one another?	**44.4**	**37.8**
Share technical training?	**21.1**	**13.6**
share information on methods of using machine tools?	**31.1**	**22.3**
collaborate on standards?	**17.0**	**13.7**
use each other's equipment or machinery?	**21.2**	**9.0**
Number of observations	387	288
Linkages to Industry Associations		
Are trade shows or technical society meetings a very important source of information for you about new developments in machining technology?	**57.3**	**45.5**
Number of observations	530	437
In 1989 or 1990, did your plant receive any technical assistance or training from an industry or trade association?	**17.6**	**11.7**
Number of observations	526	435

Note: items in bold are significantly different ($p \leq .10$) between plants with defense contracting ties and those outside that contracting network.

Figure 2: Adoption rates of information technoloy applications in the MDG sector, by defense contracting relation



Note: Differences in adoption rates related to defense contracting status are statistically significant at $p < .05$

Table 2: Logit Regressions, Factors Distinguishing Users from Non-users of Production Applications of Information Technology

Type of IT Application:	PA in Machining		Computer-Aided Design		IT: Process Monitoring		IT: Quality Control		IT: Materials & Parts Planning		PA for Other Processes	
	Regr. Coeff.	Stnd. Error	Regr. Coeff.	Stnd. Error	Regr. Coeff.	Stnd. Error	Regr. Coeff.	Stnd. Error	Regr. Coeff.	Stnd. Error	Regr. Coeff.	Stnd. Error
Size of Plant	0.566***	0.062	0.723***	0.065	1.311***	0.093	1.024***	0.081	1.239***	0.089	0.619***	0.064
Defense Network	0.721***	0.141	0.434**	0.150	0.489**	0.164	0.994***	0.188	0.626***	0.165	0.422**	0.165
Cooperative Relationship with Largest Customer	-0.061	0.179	0.247	0.184	0.673***	0.203	0.519*	0.208	0.091	0.202	0.463*	0.193
Cooperative Relationship with Competitors	0.006	0.166	-0.042	0.177	0.182	0.187	0.228	0.210	0.166	0.187	-0.204	0.200
Technical Assistance from Industry Associations	-0.232	0.213	0.687**	0.217	-0.214	0.250	0.574*	0.236	-0.088	0.245	0.352	0.220
Intercept	-1.526***	0.194	-2.873***	0.227	-4.207***	0.293	-5.029***	0.331	-4.231***	0.291	-3.306***	0.247
-2 Log Likelihood	1178.42		1075.83		926.47		793.12		933.03		929.65	
χ^2	127.44***		206.03***		391.10***		303.60***		360.88***		145.87***	
Number of Observations			958		957		955		955		954	

*** Statistically significant at $p \le .001$
** Statistically significant at $p \le .01$
* Statistically significant at $p \le .05$

Table 3: Regression Results for Machining Production Hours Per Unit of Output, All Products#

	Cooperative Relations		Cooperative/Institutional Milieu		Full Model	
	Regr.Coeff.	Stnd. Error	Regr.Coeff.	Stnd. Error	Regr.Coeff.	Stnd. Error
Quality Attributes of the Product						
Geometric Complexity	0.922***	0.060	0.940***	0.060	0.894***	0.055
Precision Standards	0.096**	0.033	0.094**	0.033	0.177***	0.030
Specialty Materials Cost	0.379***	0.017	0.375***	0.018	0.342***	0.016
Cooperative Institutional Milieu						
Defense Network (1=yes, 0=no)	---	---	-0.213**	0.103	-0.081	0.091
Cooperative Relationship with Largest Customer	-0.207*	0.126	-0.192†	0.125	-0.153†	0.108
Cooperative Relationship with Competitors	0.408***	0.121	0.422***	0.121	0.323**	0.105
Technology and Operations						
Programmable Automation	---	---	---	---	-0.911***	0.129
Pct. New Machinery	---	---	---	---	0.0004	0.002
Size of Machining Operations	---	---	---	---	-0.191***	0.051
Batches of Product	---	---	---	---	-0.223***	0.033
Pct. Output in Large Batches	---	---	---	---	-0.009***	0.002
Pct. Output in Small Batches	---	---	---	---	0.015***	0.001
Labor						
Average Wage	---	---	---	---	0.386*	0.192
Min. Tech. Education: 2 yrs. post HS	---	---	---	---	-0.015†	0.107
Union	---	---	---	---	-0.227†	0.169
Labor-Mgmt. Problem-Solving Committees	---	---	---	---	0.015	0.092
Intercept	-5.339***	0.242	-5.230***	0.248	-5.739***	0.478
Adjusted R^2	.418		.419		.598	
Number of Parameters	5		6		16	
Number of Observations	1419		1419		1348	

\# Negative coefficient signifies reduction in production hours, i.e., greater efficiency. One tail test of significance applies to the following variables: defense network, cooperative relationship with largest customer, and unionization.

*** Statistically significant at $p \leq .001$

** Statistically significant at $p \leq .01$

* Statistically significant at $p \leq .05$

† Statistically significant at $p \leq .10$

Table 4: Regression Results for Machining Production Hours Per Unit of Output, Products for Commercial Customers

	Cooperative Relations		Cooperative Milieu		Full Model	
	Regr.Coeff.	Stnd. Error	Regr.Coeff.	Stnd. Error	Regr.Coeff.	Stnd. Error
Quality Attributes of the Product						
Geometric Complexity	0.935***	0.070	0.983***	0.070	0.961***	0.064
Precision Standards	0.141***	0.038	0.137***	0.038	0.172***	0.032
Specialty Materials Cost	0.366***	0.020	0.353***	0.020	0.300***	0.019
Cooperative/Institutional Milieu						
Defense Network (1=yes, 0=no)	---	---	-0.476***	0.116	-0.265**	0.103
Cooperative Relationship with Largest Customer	-0.099	0.147	-0.081	0.146	0.018	0.123
Cooperative Relationship with Competitors	0.584***	0.139	0.608***	0.138	0.417***	0.117
Technology and Operations						
Programmable Automation	---	---	---	---	-0.947***	0.143
Pct. New Machinery	---	---	---	---	0.003†	0.002
Size of Machining Operations	---	---	---	---	-0.111*	0.060
Batches of Product	---	---	---	---	-0.236***	0.039
Pct. Output in Large Batches	---	---	---	---	-0.011***	0.002
Pct. Output in Small Batches	---	---	---	---	0.013***	0.002
Labor						
Average Wage	---	---	---	---	0.634**	0.218
Min. Tech. Education: 2 yrs. post HS	---	---	---	---	0.018	0.122
Union	---	---	---	---	-0.228	0.183
Labor-Mgmt. Problem-Solving Committees	---	---	---	---	-0.051	0.103
Intercept	-5.739***	0.273	-5.479***	0.278	-6.221***	0.525
Adjusted R^2	.418		.426		.612	
Number of Parameters	5		6		16	
Number of Observations	1072		1072		1022	

\# Negative coefficient signifies reduction in production hours, i.e., greater efficiency. One tail test of significance applies to the following variables: defense network and size of machining operations.

*** Statistically significant at $p \leq .001$

** Statistically significant at $p \leq .01$

† Statistically significant at $p \leq .10$

* Statistically significant at $p \leq .05$

Appendix Table 1: Variable Definitions, Means and Standard Deviations for Logit Models for Production Applications of Information Technology

Variable Name	Definition	Mean	Std. Dev.
PA Use in Machining	=1, if plant manager reports use of CNC, NC or FMS in machining =0, if no programmable machine tools	0.576	0.494
Computer-aided Design	=1, if plant uses computers for part or product design = 0, if computers are not used for product design	0.391	0.488
IT: Process Monitoring	=1, if plant uses computers for process planning, scheduling or monitoring =0, if computers are not used for these functions	0.451	0.498
IT: Quality Control	=1, if plant uses computers for quality assurance =0, if computers are not used for quality assurance	0.261	0.439
IT: Materials & Parts Planning	=1, if plant uses computers for materials or parts planning =0, if computers are not used for these functions	0.408	0.491
PA for Other Processes	=1, if plant uses computers to automate other production processes =0, if plant does not use computers to automate any other production process	0.251	0.434
Plant Size	Log_e (number of employees at the plant in 1991)	2.765	1.363
Defense Network	=1, if plant manager answered "yes" to any of the following questions: Are any of the products manufactured at your plant shipped directly to a Federal Defense Agency, such as the Department of Defense, Army Navy, Air Force, Marine Corps or the Defense Logistic Agency? Are any of the products manufactured at your plant shipped to other companies or divisions of companies that are prime contractors to any of the federal defense agencies? With respect to the product selected by the manager as a typical job/ order: Is this job for any Federal Defense Agency, such as the Department of Defense, Army Navy, Air Force, Marine Corps or the Defense Logistic Agency? Is this job for a division or a company that is a prime contractor to any of these agencies? =0, otherwise.	0.522	0.500
Cooperative Relationship with Largest Customer	= 1, if yes to 2 or more of the following questions. During 1989 or 1990, did your largest customer ever: provide technical assistance to your plant? collaborate with your plant in developing new products? loan equipment or machinery to your plant? provide financing for materials, equipment, or supplies for your plant? = 0, otherwise.	0.215	0.411
Cooperative Relationship with Competitors	= 1, if yes to 2 or more of the following questions. During 1989 or 1990, have you done any of the following with any of your machining competitors: subcontract machining work to one another? share technical training? share information on methods of using machine tools? collaborate on standards? use each other's equipment or machinery? = 0, otherwise.	0.237	0.425
Technical Assistance from Industry Associations	= 1, if yes to the following question: In 1989 or 1990, did your plant receive any technical assistance or training from an industry or trade association? = 0, otherwise.	0.148	0.355

Appendix Table 2: Variable Definitions, Means and Standard Deviations of Regression Variables

Models including controls for product attributes, technology and operations, and labor characteristics		All Products		Products for Commercial Customers Only	
Variable Name	Definition	Mean	Std. Dev.	Mean	Std. Dev.
Production hours	For selected product, $\log_e$[(hours of setup per batch/ no. of units in a batch) + (machining hours per unit) + (hours to write and revise program/no. of units produced in the yr.)]	-0.557	2.521	-0.714	2.481
Geometric Complexity	For selected product, $\log_e$(number of tool changes per unit)	1.660	0.898	1.661	0.875
Precision Standards	For selected product, $\log_e(1 \div \mid \text{tolerance limit in fractions of inches} \mid)$	6.454	1.566	6.475	1.564
Specialty Materials Cost	For selected product, $\log_e$(specialty materials costs, in $U.S.*100)	6.651	2.972	6.542	2.926
Defense Network	=1, if plant manager answered "yes" to any of the following questions: Are any of the products manufactured at your plant shipped directly to a Federal Defense Agency, such as the Department of Defense, Army Navy, Air Force, Marine Corps or the Defense Logistic Agency? Are any of the products manufactured at your plant shipped to other companies or divisions of companies that are prime contractors to any of the federal defense agencies? With respect to the product selected by the manager as a typical job/ order: Is this job for any Federal Defense Agency, such as the Department of Defense, Army Navy, Air Force, Marine Corps or the Defense Logistic Agency? Is this job for a division or a company that is a prime contractor to any of these agencies? =0, otherwise.	0.541	0.498	0.525	0.500
Cooperative Relationship with Largest Customer	= 1, if yes to 2 or more of the following questions. During 1989 or 1990, did your largest customer ever: provide technical assistance to your plant? collaborate with your plant in developing new products? loan equipment or machinery to your plant? provide financing for materials, equipment, or supplies for your plant? = 0, otherwise.	0.234	0.434	0.213	0.410
Cooperative Relationship with Competitors	= 1, if yes to 2 or more of the following questions. During 1989 or 1990, have you done any of the following with any of your machining competitors: subcontract machining work to one another? share technical training? share information on methods of using machine tools? collaborate on standards? use each other's equipment or machinery? = 0, otherwise.	0.252	0.434	0.244	0.430

Appendix Table 2: Continuation

Models including controls for product attributes, technology and operations, and labor characteristics		All Products		Products for Commercial Customers Only	
Variable Name	Definition	Mean	Std. Dev.	Mean	Std. Dev.
Programmable Automation (PA)	For selected product, = 1, if made using computer controlled machines (NC, CNC, or FMS) = 0, if made using conventional machines	0.300	0.458	0.313	0.464
Pct. New Machinery	If PA =1, then percent of all computer-controlled machines < 5 yrs. old if PA =0, then percent of all conventional machines < 5 yrs. old	24.113	29.700	23.870	28.725
Size of Machining Operations	if PA =1, then $\log_e$(number of computer-controlled machines) if PA =0, then $\log_e$(number of conventional machines)	2.159	1.085	2.201	1.040
Batches of Product	For selected product, $\log_e$(number of batches made during the entire year)	2.067	1.391	2.201	1.040
Pct. Output in Large Batches	percent of total machining output (all products made in the year) produced in batch sizes > 500 units	17.254	29.053	18.096	29.068
Pct. Output in Small Batches	percent of total machining output (all products made in the year) produced in batch sizes < 10 units	46.113	38.154	45.123	37.236
Average Wage	$\log_e$ (estimated average hourly wage paid to machining workers, in $U.S.)	2.340	0.256	2.322	0.257
Min. Tech. Education: 2 yrs. post HS	= 1, if 2 or more yrs. of post-high school technical education required of all new hires in machining occupations = 0, if less (or no) post HS technical education required	0.241	0.428	0.211	0.408
Union	= 1, if production workforce is represented by a union = 0, if non-union	0.085	0.279	0.091	0.287
Labor-Mgmt. Problem-Solving Committees	= 1, if plant has established committees made up of both blue-collar workers and managers who meet regularly to deal with problems concerning: the implementation of new technology, quality control, or other production problems? =0, if no problem-solving committees.	0.505	0.500	0.479	0.500
Number of Observations		1348		1022	