ARE DEFENSE AND NON-DEFENSE MANUFACTURING PRACTICES ALL THAT DIFFERENT?*

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Abstract

We compare defense and non-defense manufacturing practices by examining the following questions: How separated are commercial manufacturing operations from military production? How do defense and strictly non-defense contractors compare in their use of advanced flexible manufacturing technologies and in their collaborative production networking practices?

We draw on our own 1991 national survey of a size-stratified, randomly selected sample of 973 establishments in the machining-intensive durable goods sector (MDG), supplemented by information from specialized government data sources and case studies describing the practices of selected defense contractors. Our study shows that defense manufacturing in this sector is generally not segregated from the commercial world. Rather, we find that: almost half the manufacturing plants in these industries do some defense work; integrated manufacturing is the norm, where defense and commercial products are made in the same facilities, on the same equipment, and by the same people; most defense contractors do only a small fraction of their work for defense; and defense contractors are more technically sophisticated at the manufacturing process level and more externally collaborative, on average, than strictly commercial plants in this sector.

To the extent that access to flexible manufacturing technologies and strong information sharing production networks are important elements of diversification into new markets and more generally for competitive success in increasingly dynamic markets, defense contractors may actually be well situated compared to their strictly commercial brethren.

I. Introduction

There are tens of thousands of firms in the defense manufacturing base. With defense procurement outlays in FY 1997-8 sixty percent lower in real terms than a decade before, much ongoing policy discussion centers on the conversion and diversification of defense contractors into commercial markets. Yet, beyond case study investigations of leading firms, there has been little attempt to systematically investigate how defense manufacturers' practices compare to commercial ones. Our ongoing research is the first systematic comparison in 35 years of defense contractors to establishments that do no defense contracting.

We evaluate the differences among the defense and strictly commercial industrial bases and the implications for the prospects for dual-use manufacturing and diversification by addressing the following questions: How separated are commercial and military production? How do defense and non-defense contractors compare in their use of advanced flexible manufacturing technologies? How do the collaborative practices of the broader production networks defense manufacturers operate in compare with those networks of strictly non-defense establishments? Wherever possible, we answer these questions through statistical comparisons of defense contractors to manufacturers with no contract ties to DOD but operating in the same industries and relying on the same underlying process technologies. In addition to our own 1991 survey of a representative sample of establishments in the machining-intensive durable goods sector (MDG), we use supplementary information from specialized government data sources and case studies describing the practices of selected defense contractors.

The defense industries in 1997-8 are rapidly moving targets in both structure and size. Caution is clearly in order concerning the applicability of conclusions from our 1991 data and case analyses done over the past few years. Nevertheless, we believe that our findings—which are contrary to long-held conventional wisdom—may refocus debate over the possibilities and challenges of defense diversification and dual-use manufacturing. To us the policy questions are not about the extent to which it is possible: even during the peak years of defense procurement budgets, we show that much defense manufacturing was already considerably integrated with commercial manufacturing. The questions should be, instead, more along the lines of how to maintain the strengths of the defense industrial network, since World War II the principle instrument of U.S. technology policy, in an era of dramatically lower defense spending.

II. Conventional Wisdom: Defense Industries as A Closed, Distorted System

High-tech products made for the military such as tanks, missiles, satellites, submarines, or fighter aircraft have some similar features. Each is a complex product customized to the requirements of a single customer. The manufacturing processes can involve exotic materials, sophisticated technology, and specialized engineering expertise. The customer also has the political power to restrict the sale or use of products to other potential customers. A company that makes a new high-tech weapon for the DOD cannot sell that weapon to another customer (i.e., another government) without the Defense Department's permission. The DOD still forbids commercial use or sale of some of the components of these systems. These and related peculiarities provide the basis for the assumption that there has been very little integration between a production system that satisfies defense procurement and one designed for commercial transactions (Gansler, 1995; Markusen and Yudken, 1992; Melman, 1974; Weidenbaum, 1992). More generally, the conventional wisdom holds that the defense industrial base is a closed, oligopolistic production system grossly distorted in its use of technology, batch sizes, and its dependency on a single customer. An analysis of the defense industry by Murray Weidenbaum (1992, p. 131), former Chairman of President Reagan's Council of Economic Advisors, is illustrative: "Truly, military and civilian decision making differ so substantially that they are almost worlds apart."

In the remainder of this paper, we examine two propositions about the character of defense-dependent companies and industries. Beliefs in these propositions discourage companies from embarking on their own diversification campaigns and underlie skepticism about dual-use manufacturing and the extension of industrial technology policies to the diversification of defense-related resources into civil and commercial applications.

1) The unique market structure and regulatory environment of the defense industry compel companies to isolate their defense production. The engineers, managers and workers employed in these operations have little experience with commercial customers. Conversion of this base would require re-organization, considerable re-training, and in many cases, entirely new management. Comments by Alic, et al. (1992, p. 142), among the leading proponents of dual-use manufacturing, are typical of this widely-held belief that firms "conduct military business in divisions that are managed separately from commercial operations,

often with separate work forces, production and research facilities, accounting practices, engineering design philosophies, and corporate culture.”

2) The absence of competitive pressures implies that government contractors will refrain from making investments in new productivity- and flexibility-enhancing technologies and organizational practices to the same extent as producers in commercial markets. As a result, compared to strictly commercial enterprises, defense contractors' manufacturing processes are technologically and organizationally behind and are limited in their flexibility to diversify into commercial markets. Retooling and reorganizing will be necessary to achieve the of military production capabilities into the commercial industrial base. Again, Weidenbaum (1992, p. 146): “Under the circumstances [Federal Procurement Regulations] it is not surprising that the major military contractors have been reluctant to make substantial new investments in their factories and production equipment.”

These propositions about the singularity of the defense industry are largely unexamined and hypothetical. Defense contractors' practices have been subject to considerable public scrutiny, and numerous studies have focused on the special problems of the military enterprise. Yet we cannot identify a single empirically rigorous study since Peck & Scherer (1962) 35 years ago in which the market structure and manufacturing and organizational practices of defense-dependent establishments are systematically compared to those of manufacturers of commercial goods. As Gansler (1995, p. 29) notes, “It is at the plant level itself, which is the most important area as far as individual employees are concerned, that surprisingly little information is available.”

Moreover, manufacturing of such complex products as aircraft and other weapons systems requires capabilities that no single company has by itself. Yet the larger set of facilities engaged in manufacturing some part of these products have hardly been studied at all. Our main criticisms of the literature are the absence of any systematic effort to compare practices of defense contractors to their commercial counterparts, and the failure to include in those comparisons the vast supplier network. Yet, that network's prospects for dual-use manufacturing and its flexibility in diversification are arguably as important a policy and economic issue as the top-tier prime contractors'. Only with such comparisons is it possible to sort out the real differences that divide the defense and commercial industrial spheres. In this paper, we undertake such an examination of defense and commercial production and the larger networks that support that production in the machining intensive durable goods sector (MDG).

III. The Extent of Defense Manufacturing

From 1980 to 1987, purchases by the U.S. Department of Defense were the single largest contributor to the growth in U.S. manufacturing. At the 1987 peak of the Reagan defense build-up, DOD accounted for almost 12 percent of the sales of durable goods manufactured in this country (Alic, et al., 1992). Yet, the concentration of Pentagon spending leads many analysts to conclude that only a small number of large companies benefited from this increase in defense spending. A frequently cited statistic in support of this conclusion is data compiled each year by the Pentagon, the largest 100 defense contractors receive about 60 percent (58.4 in FY 1996, 61.5 in FY 1993) of the value of the total defense prime contract awards in excess of $25,000.[1] Current concentration by this measure is down considerably since the early 1960s through late 1970s when it hovered around 70 percent.[2] Nonetheless, this domination by the major defense contractors has led to a long-standing and widely held belief in the difficulties the defense industry would have in competing in commercial markets.

Yet, when considering the implications for diversification and dual-use manufacturing, it is important to consider as well the vast supplier networks upon which these firms rely. Major weapons systems manufacturers stand at the top of a production chain similar in structure to manufacturing systems for complex commercial products. Within their own facilities, these prime contractors largely confine production activities to final assembly. In commercial manufacturing industries for such complex products as automobiles, trucks, and civilian aircraft, the final producers do not manufacture all of the components of these products. Subcontractors make the parts and components as well as the specialized equipment, e.g., robots or machine tools, which the final producers use in assembly operations. For defense products, the establishments that have either prime or subcontracts make up the defense industrial base. The size and proportion of all DOD purchases that go towards subcontracts provide convenient indicators of the importance of this broader industrial base, indicators missing from previous analyses, which focused on the largest prime contractors.

[1] U.S. Department of Defense, 100 Companies Receiving the Largest Dollar Volume of Prime Contract Awards—Fiscal Year 1996, DIOR/P01-96, Washington, D.C., US Government Printing Office, 1996. Also available at http://web1.whs.osd.mil/peidhome/procstat/top100/top100.htm.

[2] See Gansler (1980), p. 37 who charts this ratio from 1959-1978.

More importantly, the characteristics of this broad supplier network have important implications for the competitive abilities of the national defense industrial base to undertake dual-use manufacturing and diversification. For example, Gansler (1995) and Alic, et al. (1992) among others have speculated that the prospects for dual-use manufacturing may be higher at the component level than at final assembly.

Unfortunately, the only systematic information on subcontracts that DOD collects from prime contractors concerns subcontracts to small enterprises.[3] Various analyses that do exist of weapons systems' costs suggest that subcontractors are responsible for a substantial share of defense manufacturing.

In published sources and in our own interviews with manufacturing managers at major prime contractors, we find that the dependence on subcontractors ranges from 60 percent to more than 70 percent of prime contractors' costs. At Pratt & Whitney, a manufacturer of aircraft engines, "approximately 60 percent of the dollar value of its engines is materials and components purchased from suppliers."[4] Similarly, at AlliedSignal, which makes subsystems, purchases of materials and

[3] For certain contracts, an enterprise is considered to be "small" if it employs fewer than 500 employees. In other contracts, cutoffs are 750 employees or 1,000. For service and construction industries, a small enterprise is defined in terms of revenue, not employment. The DOD also tracks prime contracts to small firms. These two sources provide estimates of the share of all defense spending that "leaks out" from the large prime contractors. Using these data, the Congressional Office of Technology Assessment (1992) estimated that 35 to 37 percent of all defense purchases in the 1980s went to enterprises that met one or another criteria as "small." This estimate applies to all DOD purchases, including both services and manufactured goods. About one-third of all defense procurement in the mid-1980s went to the service sector (Blank and Rothschild, 1985).

[4] "IMIP: Pratt & Whitney Dependable Engines," informational brochure (Pratt & Whitney, E. Hartford, CT), p. 10.

components accounted for 60 percent of total costs.[5] For GE Aircraft Engines, subcontracts consume two-thirds of the overall cost of producing a military aircraft engine. At what is now Lockheed Martin’s Fort Worth F-16 manufacturing plant, managers involved in supplier development activities estimate that subcontracts consume more than 70 percent of the cost of the aircraft. These levels of pass-through (as reported by major prime contractors) are consistently higher than the 50-60 percent range reported in the Rand Corporation's 1965 study of the subcontracting cost of selected weapons systems (Hall and Johnson, 1965).

In 1991, we surveyed 1,124 manufacturing establishments, of which 973 were still in manufacturing and engaged in the precision machining process. The sample is the cohort of plants in the MDG sector, first surveyed by Kelley and Brooks (1991) in 1986-87. That sample was selected by stratifying all establishments identified in Dun and Bradstreet Company's plant universe (of 1984) belonging to the most machining-intensive industries into the following five employment size categories: fewer than 20, 20 to 49, 50 to 99, 100 to 249, and 250 or more workers. An equal number of plants was selected from each stratum, resulting in proportionally greater sampling from the larger plant sizes (and statistically weighted accordingly to give corrected overall population estimates). The overall effective response rate to the combined telephone and mail survey in 1987 was 89.3%. For the 1991 survey, the effective response rate is 91%.

The original survey was completed on a national sample of plants engaged in the machining production process.[6] Each of the 21 industries

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[5] Wall Street Journal, Aug. 17, 1993, p. A3

[6] Machining involves the use of precision tools to cut and shape metal

selected for inclusion in the sampling frame accounts for at least one percent of all employment in machining occupations in all of the manufacturing sector. Moreover, for each industry, machining employment constitutes at least ten percent of all production employment in the industry. We call this set of industries the machining-intensive durable goods (MDG) sector.[7] The manufacturing of high-tech military hardware, in the form of aircraft, satellites, and missiles, is concentrated in this sector. Collectively, the 21 industries selected by these criteria account for more than half (51.3%) of all durable goods purchased for defense[8] and more than one-fourth of all U.S. manufacturing employment.

Because the survey's technological focus (to enable comparing similar production processes across establishments) was on machining, the sampling frame does not include a number of important defense

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and includes grinding, drilling, milling, planing, boring, and turning operations. It is a process found in many manufacturing industries. Based on the industry-occupational matrix for 1984 constructed by the Bureau of Labor Statistics of the U.S. Department of Labor, we identified industries employing workers in occupations requiring specialized skills in these tools.

[7] 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, excluding metalworking (SIC 355), general industrial machinery and equipment (SIC 356), miscellaneous machinery, excluding electrical (SIC 359), electrical industrial apparatus (SIC 362), motor vehicles and equipment (SIC 371), aircraft and parts (SIC 372), guided missiles and space vehicles (SIC 376), engineering and scientific instruments (SIC 381), measuring and controlling instruments (SIC 382), jewelry, silverware, and plateware (SIC 391).

[8] This figure based on estimates of direct and indirect effects of defense spending in 1990 reported in: Industrial Output Effects of Planned Defense Spending 1990-1994, Office of Policy Analysis, Economics and Statistics Administration, US Department of Commerce, Washington, DC, February 1991.

industries, notably communications equipment, electronics, computers, tanks and shipbuilding. Conversion and dual-use issues may differ in these sectors, so our results for MDG manufacturers may not be generalizable to the entire defense base. Tanks and shipbuilding are among the most defense dependent of all industries, and technological change is notoriously rapid in communications, electronics and computers. Thus, we hesitate to speculate about that half of the defense base.

Nonetheless, our sample industries do represent a large and important fraction of defense manufacturing. Of the top 50 (4-digit) defense industries at the peak of the defense buildup in 1987, according to Alic et al. (1992), our sampling frame encompasses 26, including 16 of the top 20 as ranked by defense share of total industry sales. As a result, defense dependency in our sample industries may be overstated compared to the average defense industry. This makes the degree of dual-use manufacturing we find already occurring all the more remarkable.

The Department of Defense is the final customer (through prime contracts or subcontracts) for an enormous number of production facilities in the United States. From our 1991 survey of a sample of establishments, we estimate that 48.8 (± 3.1) percent of all plants in the MDG sector were defense contractors (Table 1). That amounts to nearly 40,000 facilities.[9] Our sample estimate is consistent with Census Bureau data on the extent of the defense industrial base in this sector. In 1988, the Census of Manufactures conducted a special survey on technology and defense manufacturing. With data from the Census survey,[10] we estimate

[9] In 1989, there were a total of 81,506 establishments in this sector (Source: County Business Patterns, 1989).

[10] These statistics were calculated by the authors based on unpublished data supplied by the Bureau of the Census from its 1988 special survey

that 49.7 (± 1.0) percent of establishments with 20 or more employees in the MDG sector in 1988 were either defense prime contractors (selling directly to one of the federal defense agencies) or were subcontractors to defense prime contractors. Despite declines in defense spending in real terms between 1988 and 1991, we find no statistical evidence of a decline in the share of the overall manufacturing base in the MDG sector that served the Department of Defense as of 1991.

The continued defense drawdown since 1991 may have reduced the breadth of the defense supplier base. However, a 1997 GAO study reported on a random sample of small California aerospace businesses that supplied goods or services to large military aircraft programs. That survey showed that between 1992 and 1995, 94 percent were still in business while 3 percent had either merged or been acquired (GAO, 1997).

[INSERT TABLE 1 HERE]

Even if the base consolidated since our survey year, in U.S. manufacturing, there remains a vast hidden defense industrial base consisting of a large number of subcontractors with no direct dealings with the Pentagon. AlliedSignal, for example, among the top 25 defense prime contractors, had about 3000 direct suppliers in early 1997.[11] As Table 1 shows for the MDG sector, 64.1 percent of plants with any defense-related sales did not sell directly to DOD in 1990, but rather served only as subcontractors or suppliers to defense prime contractors. Our survey data indicate considerable pass-through from prime

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of approximately 10,000 plants belonging to the set of industries we have designated as the MDG sector. For a description of the survey and the data, see: U.S. Department of Commerce, Bureau of the Census (1989).

[11] Minahan, Tim, "Purchasing rebuilds to battle poor quality," Purchasing, 122(1), January 16, 1997, p. 53.

contractors to this subcontracting base. Spending on subcontracts alone accounted for forty-one percent of all defense-related sales and shipments in the MDG sector during 1990. Moreover, more than half (54%) of the value of shipments to prime contractors from subcontracts in the sector came from lower tier suppliers, i.e., those that had no prime contracts with a federal defense agency.

Conclusions about the uniqueness of the defense industrial base that rely solely on information about prime contractors miss the influence of DOD on the tens of thousands of subcontractors that make equipment for the military. Related policy prescriptions overlook whether that broader industrial base is flexible enough to support diversification and undertake dual-use manufacturing.

IV. The Extent of Commercial and Military Integration in Production

Even the largest defense contractors belong to companies that depend on commercial sales for the greater part of their total revenues. At the corporate level, Alic, et al. (1992) found that, among the 100 largest defense prime contractors, even during the height of the 1980s defense buildup, the 67 publicly traded firms derived only 9 percent of their total sales from defense prime contracts over the five-year period ending in 1988. Moreover, only 9 of those 67 firms were highly defense-dependent, with 50 percent or more of their sales going to DOD during those peak years of the build-up.[12] Yet, because many of these companies have set up separate divisions for their defense business, little or no interchange is assumed to take place between the defense

[12] McDonnell Douglas, General Dynamics, Martin Marietta, Grumman, Loral, Oshkosh Truck, Avondale Industries, Dyncorp, and the United Industrial Group.

and commercial sides from the top to the bottom of the enterprise.

A separate division within a corporation indicates a separate chain of command for managers responsible for defense production. However, such an organizational structure may not imply a physical separation between the people and machines actually involved in defense and commercial manufacturing operations. For example, corporations commonly employ what is called a matrix reporting structure, in which groups with the same functional responsibilities have dual reporting responsibilities: to a product division, and to the director of a functional area, such as the chief of manufacturing operations. In such a matrix structure, the alleged segregation of defense work from commercial work may simply be an artifact of reporting lines of authority. This does not imply that the organization has literally constructed separate work groups or facilities for the two divisions.

Even so, the segregation from commercial operations of facilities and production equipment used exclusively for the manufacture of military products is frequently described in the academic and business press as if it were the established practice of most defense contractors.[13] This separation is also thought to extend from the headquarters to the shop floor. According to Markusen and Yudken (1992), special accounting rules, technical requirements, and the like are responsible for a "wall of separation" that divides production for the military from commercial manufacturing. Such high profile examples as Lockheed Martin's Skunk Works (the incubator for the U-2 and SR-71 "Blackbird" spy planes and later the F117A Stealth fighter), or General Dynamics' Fort Worth F-16

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[13] e.g., GAO, 1997; Gansler, 1995; The Economist, October 2, 1993; Business Week, Sept. 6, 1993; Lundquist, 1992; Markusen and Yudken, 1992; Weidenbaum, 1992; Center for Strategic and International Studies, 1991, OTA, 1989; Melman, 1974.

manufacturing facility (now also Lockheed Martin’s), have helped perpetuate the view that defense production largely takes place in facilities where no commercial products are made.

Drawing on our 1991 survey data of manufacturing establishments, we attempt to measure the extent of segregation between defense and non-defense production through an assessment of the following:

- What proportion of the defense industrial base in the MDG sector operates specialized facilities dedicated to the manufacture of military hardware?
- What proportion of total defense output in the sector is produced in segregated facilities?
- Do prime contractors [especially those that are part of large companies] have a greater propensity to operate defense-dedicated production facilities than subcontractors?

Our first indicator of segregation is the percent of total 1990 shipments from each plant sent directly to a federal defense agency (including any branch of the U.S. Armed Forces, the Defense Logistics Agency, depots of the services, and the Department of Energy) or to a prime contractor of one of these agencies.

As Table 1 shows, nearly two-thirds of all the output generated from defense contractors in the MDG sector in 1990 went to commercial customers. Overall, defense shipments contributed only 36.1 percent of the total value of 1990 shipments from plants that make military equipment in the U.S. MDG sector.

We find that, contrary to the conventional wisdom, the typical defense contractor in this sector is not very defense dependent, even at the establishment level at which we collected data. The median defense share was only 15 percent among plants with any 1990 defense sales in the MDG sector. The vast majority (80.4 percent) of establishments integrated commercial and military production in the same facility, selling more than half of their 1990 output to commercial customers. As Figure 1 shows, only 21.4 percent of plants with prime contracts had more than 50 percent of their sales going to DOD in 1990. For the lower tier contractors, only 18.5 percent shipped more than 50 percent of their 1990 output to defense prime contractors.

Because a large number of these establishments are small, we also investigated whether, despite the numbers of integrated establishments, most of the value of defense-related manufacturing was done in defense dependent facilities. In Figure 2 we cumulatively add 1990 shipments by establishments that reported any shipments to defense agencies or prime contractors to defense agencies at all, ordered by the degree of the plant's dependency on sales to defense customers. As Figure 2 shows, we estimate that more than half of the value of defense related work in this sector came from plants that did the majority of their work for non-defense customers. Moreover, less than one-third (32.7%) of the value of total shipments of military goods from the sector in 1990 came from highly segregated facilities (with 80% or more of their output going to defense).

[INSERT FIGURES 1 AND 2 HERE]

Another way we attempted to account for the variation in size and organizational strategies of companies in the defense industrial was to look at the differences between multi-plant firms and single plant firms. Multi-plant companies have the option to place all of their defense orders in one facility and commercial work in another. If multi-plant corporations adopt such a segregation strategy, we should find a higher incidence of dedicated facilities among branch plants doing defense work than among single-plant enterprises. In Figure 3, we see that there is no statistical difference between these two types of companies in the proportions of facilities which are highly specialized in making defense products.[14] For large, multi-plant firms, and small single-plant enterprises alike, fewer than one in five of the plants that do defense work sell more than 50 percent of their output to DOD or a prime contractor.

[INSERT FIGURE 3 HERE]

Although larger firms are not more defense dependent, on average, than smaller firms are, we do find that facilities dedicated to defense production are somewhat more common among those branch plants of large corporations that receive prime contracts. As we show in Figure 4, which looks only at branch plants of multi-plant firms, prime contracting defense plants belonging to multi-unit firms are significantly more dependent on sales to DOD, on average, than branch plants that only have subcontracting ties to DOD. For example, a larger fraction of prime contractors (22.3%) than subcontractors (12.1%) depend on DOD (or other prime contractors) for 50 percent or more of their sales. These differences are statistically significant ($p<.05$). If

[14] We performed several statistical tests (at p=.05) to examine the relationship between the size of plant or size of firm and defense dependence, measured by the percent of total shipments from the plant in 1990 that went directly to a defense agency or a prime contractor. We find no significant correlation between the degree of dependence on defense purchases and either size of the parent company or plant size (both as measured either by sales or employment). Moreover, Chi-square tests fail to show any significant differences in the distribution of plants among (plant or firm) employment size categories (1-49, 50-249, ∃250) and the extent of the establishment's dependence on defense sales, grouped by categories (0, 1-9%, 10-19%, 20-29%, etc.). We also performed ANOVA F-tests, categorizing plants as single-plant enterprises or branch plants of large multi-unit companies, to determine if there were any statistical differences between large and small firms in the sample plants' dependence on defense purchases. Again, we found no significant relationship.

branch plant prime contractors are more likely than subcontractors to do assembly work, then this finding is consistent with the view that prospects for dual-use may be higher on the component level than the system/assembly level. Regardless, facilities that serve both commercial and military customers are the overwhelming norm across both branch plant categories.

[INSERT FIGURE 4 HERE]

In short, at the level of the plant, we find considerable integration between the commercial and military industrial spheres in the MDG sector. Large multi-plant firms that do defense prime contracting tend to be slightly more dependent on average than subcontractors. But overall, we find that defense production in the MDG sector (whether directly for DOD or indirectly through subcontracts) more often than not takes place in facilities in which the majority of production is for commercial customers.

In order to satisfy ourselves that the integration of production for military and commercial customers suggested by our statistical data reflects practices on the shop floor, we undertook a number of more detailed case studies. We selected cases from respondents to our survey, from a review of previous research, and from interviews with managers of major defense contractors. Our case investigations were designed to identify if separate equipment, production workers, or engineers are assigned to military production in plants that are engaged in manufacturing for both DOD and commercial customers.

High Profile Cases of Commercial-Military Integration

General Electric has been among the top 10 DOD prime contractors for more than 40 years.[15] OTA (1992, p. 202) describes GE as the quintessential case of a company that fully integrates its commercial and military production: “GE Aircraft Engines is the leading example; ...[it] combines all aspects of its military and commercial business except for marketing, while still complying with DOD requirements.” The two sides of the business share management, R&D facilities, and manufacturing. Despite a huge dollar volume in defense sales, GE Aircraft Engines derives more than half of its revenues from commercial engines. Sometimes GE even sells the same engine to both defense and non-defense customers. In a joint venture with the French firm Snecma, they produce CFM56-2 jet engines, the technical core of which powers the B-1 bomber, for DC-8 commercial airplanes as well as the Air Force’s KC-135R tanker aircraft. Similarly, Pratt & Whitney sells the PW-2037 engine for both commercial and military use.

Hughes Aircraft, which in 1997 Raytheon is planning to acquire from General Motors, is a leading supplier of commercial satellites and also consistently among the top 10 defense prime contractors. Not only does Hughes produce commercial and military components in the same facilities, but it also integrates its design processes as well. According to Albert Wheelon, former CEO of Hughes, "The design and fabrication of spacecraft subsystems is centered in the engineering and manufacturing divisions. In order to capture the benefits of scale and retain the flexibility to interchange parts and manpower when needed, these two divisions serve all programs, regardless of the structure of the individual customer's contract. One implication of this organizational design is that technical manpower in the engineering and

[15] See OTA (1992) and the various years of: U.S. Department of Defense, 100 Companies Receiving the Largest Dollar Volume of Prime Contract Awards—Fiscal Year 19XX, Washington, D.C., US Government Printing Office.

manufacturing divisions is entirely interchangeable among projects" (quoted in Alic et al., p. 179).

Another example is Vought Aircraft. Vought produces major aircraft structural subsections for both commercial and defense-related customers. e.g. tail sections for Boeing's 747, 757 and 767; engine nacelles for Canadair's CL-601RJ regional jet; wings for the new Gulfstream V (G-5) corporate jet; tail sections, aerial refueling receptacles, and engine nacelles for McDonnell Douglas' C-17 Globemaster III military transport; and until recently, the complex B-2 Stealth intermediate wing section, about 1/3 of the total B-2 airframe structure by weight. In August, 1994, Vought Aircraft was acquired by the Northrop Grumman Corporation, itself created when Northrop acquired Grumman in March, 1994. Vought employs approximately 5000 people in its facilities near Dallas, Texas, and its annual revenues, according to Northrop Grumman, near $600 million.[16] Vought was made the home of Northrop Grumman's Commercial Aircraft Division. As discussed in detail in Watkins (1997), during our visits and dozens of interviews, managers and shop-floor personnel there clearly demonstrated how cross-functional teams are the organizational norm at Vought, making it a truly dual-use operation. Integrated, centralized functional groups such as engineering, machining and fabrication, quality assurance, supplier management and so on, serve all programs, both military and commercial, with the same people and procedures. Vought operates under an "integrated product/process development" (IPPD) philosophy with what their human resource managers call a "strong matrix" organizational structure. In addition to reporting to a functional group, one axis of the matrix, people also report to (and are co-located with) multi-

[16] Northrop Grumman press release, quoted in S&P Daily News, August 31, 1994.

functional product or process teams, the other axis, that have full responsibility for integrating and managing all aspects and the whole life-cycle of each commercial or military program, from development through delivery and post-production support.

Alic et al (1992) report similar integration at the Lord Corp., a leading supplier of rubber-to-metal adhesives and computerized vibration-control equipment. Lord uses a single division and the same engineering group to work on the Boeing 737, 757, and 767 aircraft as well as the Black Hawk helicopter and the Osprey tilt-wing transport. The Castings and Forging Division of Wyman Gordon Co. employs the same people, processes, and equipment in supplying special alloy castings to GE Aircraft Engines, Pratt & Whitney, Boeing, and McDonnell Douglas. Hewlett-Packard’s Microwave semiconductor division integrates military and civilian production as well.

Commercial-Military Integration in Subsystem & Component Manufacturers

We selected a number of smaller defense contractors that vary in their degree of dependence on sales to DOD or prime contractors. In every case, we find that these subsystem and component manufacturers operate completely integrated facilities, using the same people and equipment for both commercial and military products. We offer three examples to illustrate how these production sites handle differences in production requirements (if any) between their commercial and military customers.

Tecknit. In our first example, we might expect a high potential for segregating military work, because approximately 50 to 60 percent of the firm's business is defense related. Tecknit, founded in 1958 as Technical Wire Products, Inc., designs and produces materials and components for electromagnetic interference (EMI) shielding, grounding, and static discharge. The firm employs about 300 people in manufacturing and sales facilities in the U.S. and U.K., the majority of whom work in the main plant in Cranford, New Jersey. We visited the Cranford facility.

The company's original product line was seamless knitted-wiremesh rings and gaskets, manufactured for both military and commercial markets on equipment of their own proprietary design. Thus, the core capability of the firm was a process technology designed and built in-house. However, rather than remaining a wire knitting specialist, the company has re-focused on technologies that provide solutions to problems from electromagnetic interference.

Tecknit's product line now also includes a wide array of products with similar functions: patented conductive elastic polymers (similar to rubber), conductive adhesives, paints, and greases, as well as shielding screens, coated windows, and air vent panels. Their products are used in electrical equipment or components that either emit or suffer interference from electromagnetic radiation in the power, radio or microwave ranges of the spectrum (e.g., personal computers, power supplies, aircraft navigation equipment). Tecknit's largest customers include Westinghouse, Rockwell, Raytheon, Boeing, Hughes, Magnavox, and Texas Instruments. In addition, Tecknit sells to telecommunications equipment firms and computer companies, including Apple, DEC, Dell, Siemens and IBM.

Although the company offers a standard range of EMI products, Tecknit operates primarily as a job shop. Its production is low volume and labor intensive. Much of the assembly work (for example, the tasks of bonding elastomer gaskets to machined aluminum frames) is still done by hand.

We find no differences in the manufacturing process for defense and non-defense products. According to the manufacturing manager we interviewed, and our own observations, there is no special labeling on products made for defense contractors that would distinguish them from products made for commercial customers. The technology, manufacturing equipment, process flow, labor, and engineering are indistinguishable from one customer to another. The only differences in requirements occur in the documentation during final inspection. DOD has reporting requirements in tracking materials and in documenting inspecting and testing procedures that are not demanded by other customers.

Electroid. This case is more typical of defense contractors in terms of dependence on defense work. The share of sales going to defense prime contractors has never exceeded 20 percent. Again, we find complete integration between military and non-military manufacturing. The Electroid Company is a specialty manufacturer of high performance motion-control devices. Their core business is in electro-mechanical clutches, brakes, and solenoids. With current manufacturing facilities in Springfield, New Jersey, Electroid is a privately owned division of Valcor Engineering Corporation. Electroid employs about 100 people at this facility.

When most of us think about clutches and brakes, our automobiles come to mind. Yet Electroid has a clear corporate strategy that completely avoids the automobile industry, which management considers a low-performance, high-volume (and low-profit margin) market. Instead, Electroid supplies medium- to high-performance electro-mechanical stop/start motion-control equipment in low volumes. Their products are used in industrial machinery and a number of aerospace applications, largely in motors or actuators for the purpose of engaging or disengaging mechanical power, or stopping or locking moving parts. The company supplies such devices for packaging machinery, photocopiers, industrial robots, the Apache helicopter, and the turret on the M1 tank. NASA's Space Shuttles have Electroid's fail-safe brakes to lock the doors in position. Some of Electroid's major customers include AlliedSignal, Boeing, General Electric, Scientific Atlanta, and Westinghouse.

By defining their technological niche as motion control, Electroid naturally serves a broad cross section of industries. Most of their orders come from makers of industrial machinery, but the company has been a defense contractor since the beginning of the Reagan build-up in 1981. For its products, Electroid identifies military requirements to be as stringent as those in commercial applications in aircraft and nuclear power plants. That group of customers is collectively known at Electroid as "NAM" for "nuclear, aerospace, and military." NAM accounts for 15 to 20 percent of total sales. According to the vice president for manufacturing, the designs, materials, tolerances, inspection and reporting requirements for Electroid's NAM work are more exacting than the demands of their other customers.

Nonetheless, this manufacturing facility remains completely integrated between defense and non-defense work. The manufacturing process on the shop floor uses the same production workers, the same manufacturing equipment, and the same engineers for both commercial and defense jobs. A worker could spend one hour on a NAM job and then the next hour on an industrial machinery part. No equipment or any employee in the plant is dedicated to military (or NAM) production. The only feature of the production process that identifies military products is also used to distinguish all NAM work from products made for other customers. Work for NAM customers is placed in blue plastic tote bins and pieces for non-NAM customers in tan-colored bins. The main reason for this color-coding is to alert the employee at each work station to follow the written instructions that accompany the NAM item. For NAM products, whether for military or commercial customers, detailed specifications dictate the tasks to be performed (and checked) at each stage in the production process.

Delroyd Worm Gear. This case is another example showing that the process and standards for making some commercial and military products are indistinguishable. Delroyd Worm Gear manufactures large speed-reducing worm gears for use in high torque applications. The company is a division of IMO Industries and employs fewer than 100 people at the facility we visited. Their products are used, for example, in conveyors, printing presses, oil drilling pumps, and cranes. They make gears for canal locks, including some used on the Panama Canal, and for aircraft hanger doors. Customers can order products from the company's catalogue, but custom orders are also accepted. Delroyd has been a defense contractor since World War II. The DOD accounts for 5 to 10 percent of their business, largely buying replacement parts for Naval ships.

There is absolutely no separation of manufacturing work for the Navy from other work. No machines or workers are specially set aside. Nor are there any special testing or inspection requirements associated with defense contracts. The Navy simply places an order, identifying the replacement part it wants Delroyd to build.

Worm gears are a "mature" product. Technological changes occur very slowly. One production manager we interviewed said that new materials are the only major product improvement in the past 40 years. Today, worm gears are made with less expensive, more durable materials than two generations ago. The only defense-related peculiarity is that government purchase orders for replacement parts generally specify the same materials as the original order. For replacement parts on older ships, this can mean the Navy purchases products made with inferior (and more expensive) materials than used in new gears.

V. Comparing Networking and Technology Investment Practices

In addition to finding that most defense contractors are already considerably diversified into commercial markets, we also find evidence that they may be better suited than their strictly commercial brethren for dealing with changing markets and dynamic competition. Organizational and technological flexibility are important elements of any diversification strategy. By several key indicators, defense contractors have adopted more flexible manufacturing technologies and organizational practices.

Our findings lie in stark contrast to prevailing views on the defense industrial base. Appealing to economic theory, Markusen and Yudken (1992) argue that the normal conditions of exchange between buyers and sellers do not operate in the defense industry. As a consequence, defense contractors do not face the kinds of competitive pressures to innovate or to minimize costs that [at least in theory] affect companies operating in strictly commercial markets. In a similar vein, Demski and Magee (1992) identify a number of unusual features of military product markets that can be expected to further distort firms' behavior: administered prices, uncertainty, and a single buyer (DOD) with considerable regulatory power over its suppliers. Rogerson (1992) argues further that the cost-based pricing rules for defense contracts actually provide a perverse incentive for suppliers to under-invest in technology and to subcontract out less, employing more direct labor, than would be expected of enterprises operating in commercial product markets. This is because standard accounting procedures usually allocate overhead in proportion to direct labor.

Failure to invest to improve productivity has long been identified as a possible source of high costs among defense contractors. Indeed, as early as 1976, a major Pentagon review of procurement practices concluded that defense contractors used only 42 percent as much capital equipment and facilities per dollar of sales as durable goods manufacturers overall (U.S. Department of Defense, 1976). In 1980, the House Armed Services Committee drew similar conclusions about the lack of investment in new manufacturing technologies by defense contractors (U.S. Congress, 1980). The Pentagon undertook a variety of initiatives, such as the Industrial Modernization Incentives Program (begun in 1982) and reforms of contract pricing practices introduced through the Competitiveness in Contracting Act of 1984. These initiatives provided incentives to keep costs down (with the awarding of more fixed price contracts) and assisted those contractors wishing to undertake productivity-enhancing investments in new technology. If these reforms have had any effect on defense contractors, in our 1991 data we should expect to see the gap narrowing between their propensity to invest in new technology compared to their counterparts operating in strictly commercial markets.

More recent reforms have also been along the same vein. The Federal Acquisition Streamlining Act of 1994 provides clear statutory preferences for commercial products and “best value” contracting, and also raised the threshold for simplified acquisition processes to $ 100,000 from $25,000. Similarly, the Secretary of Defense in 1994 directed DOD programs where possible to use commercial specifications.

More broadly, firms face a general problem of imperfect information for learning about and effectively adopting new technologies. Accumulated knowledge and expertise is important for assessing potential benefits from adopting a new technology. Differences among firms in their access to such expertise explain, in part, why some firms are more likely than others to adopt a new technology or innovate themselves (Arrow, 1962; Cohen and Levinthal, 1990; Dosi, 1988; Kelley, 1993; Nelson and Winter 1977, 1982; Rosenberg 1972, 1982; Watkins, 1991). Thus, to the extent that these government policies provide a more supportive and information-rich environment for long-term investments in new technologies than companies ordinarily have in strictly commercial customer-buyer relations, we may even expect to find a higher level of investment among defense contractors.

The issue is not whether the product market and the competitive conditions in which defense contractors operate differ from some hypothetical ideal, but whether government policies through the defense procurement system have [positively or negatively] affected the propensity of private manufacturers to invest in flexible and productivity-enhancing technologies. Flexibility may be particularly important in the context of defense diversification. In this section, we draw on our 1991 survey data once again to address the differences in investment in new flexible and productivity-enhancing manufacturing technologies between defense contractors and their counterparts in the MDG sector.

Defense Contractors' Leadership in Flexible Manufacturing Technologies. Programmable automated machine tools (PA) are a particularly important and recent manufacturing innovation. PA, or computer-integrated manufacturing, refers to information technology applications in which computer software and microelectronic-control devices are used to direct and monitor such ordinary production operations as machining, welding, testing, and inspecting. What distinguishes PA from previous generations of productivity-enhancing technology is that the instructions controlling the operation of machines are incorporated into software rather than hardware. As a result, PA is a very flexible innovation that can be used to reduce the costs of product diversification and of both large-volume and small-batch production, even in the smallest companies and in a wide variety of industries.

A large literature addresses the cost, performance and flexibility advantages of PA (e.g. Ayres and Miller, 1983; Dosi, 1988; Freeman and Perez, 1986; Hirschhorn, 1984; Kaplinsky, 1984; Kelley and Brooks, 1991; Piore and Sabel, 1984). PA blurs the distinction between the economics of Fordist mass production and of small batch production (Cohen and Zysman, 1987). Batch production on conventional machine tools involves general-purpose machines hand operated by skilled workers. Unit production costs tend to be high because hand operations are time consuming and set up costs are spread over small numbers of units. Mass production, on the other hand, involves high fixed costs for dedicated machines. Unit costs are low because set up and equipment expenses can be amortized over large output volume. However, retooling for new products can be time consuming and costly.

In the diversification context, what is most relevant about PA is that it added “economies of scope” to the manufacturing lexicon. Cohen and Zysman (1987) believe PA’s potential for improving both static and dynamic flexibility is key to economic growth and competitiveness. Static flexibility allows for switching production among a number of different products. PA reduces the time it takes to switch from one product to another, and at the same time can increase utilization rates by limiting set up costs. Dynamic flexibility provides the ability not just to produce more than one product on a single line, but to enable production to evolve quickly with changes in either product or production technology. Dynamic flexibility, in this view, is critical for the timely realization of new ideas. Hence, both static and dynamic flexibility are relevant for diversification.

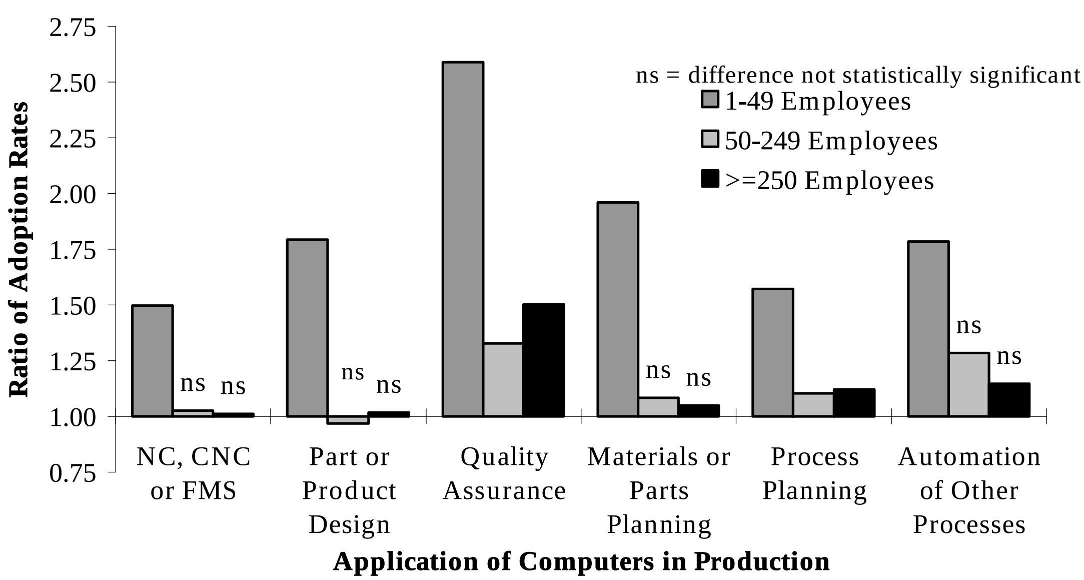
Going further, Piore and Sable (1984) and more recently Harrison (1994) see the introduction of flexible specialization as having fundamentally altered the nature of competition in manufacturing industries. If this is true, defense contractors may be comparatively well situated for competitive success in what Harrison (1994) calls “the age of flexibility.”.

Our survey results confirm a statistically significant difference ($p<.0001$) in PA adoption related to defense contracting: sixty-six percent of plants with any defense prime- or sub-contracts have PA machine tools, compared to 50 percent of plants serving exclusively non-defense markets (i.e. with no sales or shipments to defense agencies or defense prime contractors). Moreover, defense contractors that adopt this technology employ a much higher fraction of PA tools in their total machine tool stock than do establishments engaged in the same manufacturing processes but with no contractual ties to DOD.

Defense contractors have been more innovative in their application of information technology to other production processes as well. For six common uses of computers in manufacturing, we compared the adoption rates of defense and strictly non-defense plants. In addition to PA, the applications include computer aided design (CAD), computer-aided manufacturing process control systems (CAM—used to plan and monitor inventory, work-in-process and materials flow), computer-aided materials planning, and the use of programmable automation in other production processes. For every one of these technologies, we find higher adoption rates ($p<.0001$) among defense contractors than in plants serving exclusively commercial markets.

Figure 5 graphs the ratios of adoption rates of these technologies between defense contractors compared to strictly commercial establishments, for various size firms. In the figure a ratio of 1.0

Figure 5. Ratio of Technology Use in Defense and Non Defense Manufacturing Plants, by Firm Employment



would mean that the same proportion of defense and strictly non-defense establishments adopted the technology, while a 2.0 would mean defense establishments adopt at twice the rate of those operating strictly in non-defense markets. The adoption advantages are particularly important (ranging from about 1.5 to more than 2.5) for small firms, with fewer than 50 employees.

Although it is difficult to single out a particular cause for these differences, we believe that government policy initiatives and programs directed at the defense industrial base are at least partly responsible for the large technological gap we find between defense contractors and other U.S. manufacturing establishments in the MDG sector. From 1982 to 1992, the Industrial Modernization and Incentives Program of the DOD provided technical assistance to contractors in assessing the applicability of advanced manufacturing technologies to defense contractors' operations. Through its manufacturing technologies (ManTech) program, DOD has supported the development of advanced technologies and improvements in process technologies among defense suppliers. DOD spent between $150 to $200 million annually throughout the 1980s on ManTech alone, exceeding the level of spending by all state governments on technical assistance programs aimed at manufacturing firms during the same period (Shapira, 1990; U.S. Congress, Office of Technology Assessment, 1990). Although these programs directly assisted a relatively small number of defense contractors, DOD also sponsors annual conferences and workshops on new developments in manufacturing practices. These sessions highlight the lessons learned from the experiences of early adopters of advanced manufacturing technologies, providing the kind of learning opportunity for the larger defense industrial community that Von Hippel (1988) and Kelley and Arora (1996) identify as important institutional mechanisms for diffusing new technologies.

Defense Contractors’ Advantages in Collaborative Networking Practices

Indeed, as we discuss in the this section, we find considerably more collaborative networks of information sharing and supportive relationships surrounding defense contractors in the MDG sector than surrounding establishments with no defense related sales or shipments. Drawing on theories of the economic value of collaborative production networks, in our survey we gathered 43 measures about the history of external relationships each establishment had. These economic exchange relationships were with key external organizations, including: technology vendors, subcontractors, competitors, customers and other sources of technical information such as government agencies and colleges and universities. For each of the 43 measures we performed statistical tests to determine if the particular type of relationship, such as “collaborated in developing new products with subcontractor” was more likely among firms with or without defense ties. For continuous variables, such as “the number of years you have been doing business with this technology vendor,” we tested whether one group of plants had more durable (longer) and more intensive interchanges with their external partners. Again, we spilt the sample by whether or not the establishments hand any sales or shipments to the defense agencies or defense prime contractors.

Which group engaged in more collaborative networking relationships with their customers, suppliers, competitors and other external organizations? Whether the comparison is of defense prime contractors to plants with strictly non-defense work or between defense subcontractors and other plants, the overall pattern is striking. For defense prime contractors, on 19 of the 43 separate measures we find stronger or more prevalent collaborative external links than for plants with no defense sales. Similarly for defense subcontractors, 19 of the 43 measures are statistically greater than for other plants. Among both defense prime and subcontractors, a higher proportion of plants have close ties to their customers, competitors, sub-tier contractors, or technology vendors. Moreover, these relationships are more durable and intense, on average, for defense contractors than they are for other plants.

Figures 6 and 7 summarize these findings. These figures include only those external connections that were more prevalent or stronger in plants tied to defense compared to strictly non-defense plants. For each measure shown, the differences between plants inside and those outside defense production are statistically significant at $p<.05$. The arrows indicate the direction of the connection.

In Figure 6, we see that the differences between defense prime contractors and non-defense plants are particularly strong when comparing each group’s vertical relationships to their subcontractors and technology vendors. Out of ten different indicators of close ties to machining subcontractors, seven are significantly more collaborative for defense prime contractors than for plants in strictly non-defense markets. Defense prime contractors far more frequently say they provided technical assistance, loaned equipment or machinery, and provided financing, and technical training to their subcontractors in 1989 or 1990 than did non-defense plants. In addition, defense primes have a much more intensive relationship with subcontractors, meeting with the technical staff of their subs more than 2 1/2 times as frequently in 1990 as managers from non-defense plants report about contacts with their important subcontractors. With respect to links with technology vendors, we find that four of the seven measures are significantly greater for defense primes than for non-defense plants.

Note also the relative stability of the relationships that defense primes have to their key partners. Prime contractors have been doing business with their largest customer, most important subcontractor and technology vendor for a significantly longer period of time than non-defense plants. On average, defense prime contractors have been supplying their largest customer for more than 16 years, which is in the same range (15 to 20 years) recently reported to be typical of subcontractors belonging to keiretsu in Japan's metalworking sector (OTA 1990, p. 135).

While prime contractors have relatively stronger collaborative ties to subcontractors and technology vendors than do non-defense plants, defense subcontractors have comparatively closer relationships with competitors. Figure 7 shows that a higher proportion of defense subcontractors have lateral collaborative ties to competitors and are better connected to sources of information and technical assistance outside of their exchange relationships than plants that have no defense contract work. For four out of six indicators of links with competitors, we find a significantly higher proportion of defense subcontractors reported recent collaborative experiences than were identified by strictly non-defense plants. Defense subcontractors are more apt to share information on methods of using machining tools and to share equipment with their competitors. Defense subcontractors are also more likely to engage in joint training activities and to collaborate with one another on standards. Moreover, defense subs appear to be better connected to external sources of information. They report using five of eight outside sources of information about new developments in machining technology significantly more often than do strictly non-defense plants. And defense subs are also at least 60 percent more likely to have received technical assistance in 1989-90 from trade associations, government programs and institutions of higher education.

Defense subcontractors are not more likely than strictly non-defense plants to have long term contracts with their customers. Nor do defense subs have a longer history of a business relationship with their largest customer. However, compared to other plants, the largest customer of a defense subcontractor is more likely to provide technical assistance and to loan equipment. On average, defense subcontractors also have more intensive (frequent) interactions with the technical staff of their largest customer than typically occurs with the customers of strictly non-defense plants.

Finally, strictly non-defense plants have a higher incidence of collaborative ties to their customers, suppliers, competitors and other external organizations than do plants inside the defense network in only 4 of the 86 statistical comparisons we made. This includes only one of 43 comparisons to defense subcontractors, and three of that same set of 43 comparisons to prime contractors. Compared to prime contractors, non-defense plants are more apt to depend on colleges or universities for information on new developments in machining technology, and to collaborate with competitors and technology vendors in developing new products. However, on these same three indicators, a larger proportion of DOD subcontractors has these ties, but the differences are statistically insignificant.[17]

While stronger collaborative networking by defense contractors might be seen as inhibiting diversification—hindering breaking out of the defense industrial network—note again that most defense contractors already do more non-defense than defense work. To the contrary, as we show elsewhere (Kelley and Watkins, 1992, Kelley and Cook, 1997), this collaborative networking enables defense contractors to learn more quickly about flexible information technology applications than enterprises outside the network. Moreover, learning advantages are not confined to transactions specific to the Pentagon, but benefit the non-

[17] Note here that if we would assume no differences between the populations of defense contractors and non-defense plants, and that the measures tested are independent, then with a 95% confidence level we would expect about 1 in 20 tests on data from random samples to show a statistical difference, even when there is no difference. That is we would expect about 5% false positives -- type II errors. The 4 of 86 cases where other plants have statistically higher incidence rates could possibly, then, be explained by random chance. The 19 of 43 cases where primes have statistically stronger ties, and the 19 of 43 cases we find for subs, though, are not within any reasonable realm of chance.

military operations of the networked enterprises as well.

VI. Conclusions

Defense spending reaches a broad segment of manufacturing facilities in the MDG sector, affecting one-half of all establishments. Contrary to conventional wisdom, commercial-military integration is not only feasible, but is largely the normal practice in this sector. Our analyses indicate that the vast majority of defense contractors in the MDG sector manufacture military products in the same facilities in which they produce items for commercial customers. Most of the output from these facilities actually goes to commercial customers. For these already dual-use facilities, we see few technical or organizational barriers to converting these facilities to further serve non-defense markets. More targeted policies should be aimed at the small number of defense prime contractors and subcontractors, by our count fewer than one in ten in this sector, that are heavily dependent on DOD funds.

Moreover, the strictly commercial industrial base in the MDG sector lags behind the defense industrial base in using advanced flexible manufacturing technologies and in practicing collaborative production networking. Our research indicates that Defense Department policies and programs have supported the widespread adoption of these productivity-enhancing technologies. The DOD has supported a series of initiatives designed to provide technical assistance and incentives for defense contractors to improve their (and their suppliers') manufacturing processes. Our findings suggest that these initiatives have positively influenced the practices of a broad range of contractors.

In the MDG sector, DOD has provided a more supportive and information rich environment for long-term investments and the transfer of technology than we find among strictly commercial customer-supplier relations. The policy challenge is to preserve, within the constraints of much reduced defense procurement spending, the benefits of the relationships that have developed within this defense-contracting network.

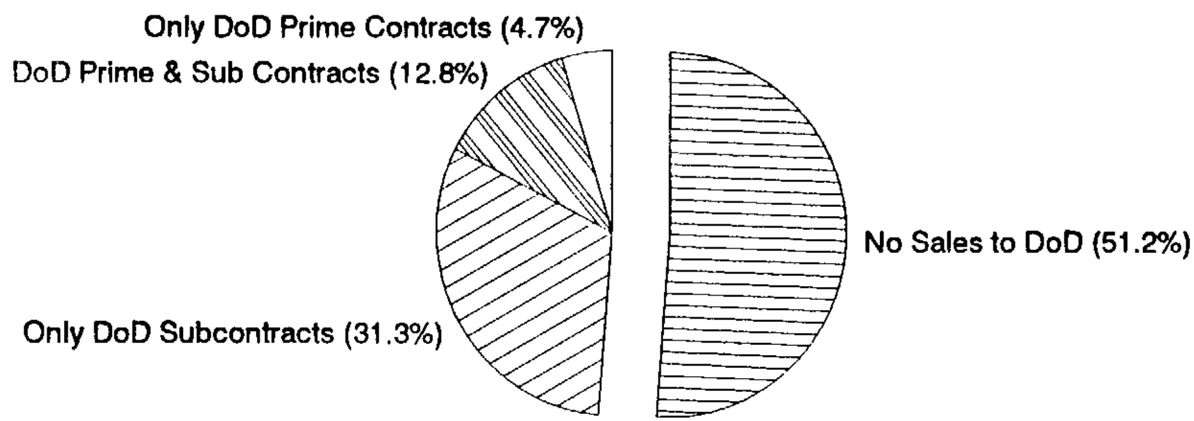
Table 1.

Distribution of Defense Contractors' Sales in 1990 to Military and Commercial Customers by Type of Contractor

(Sales in $ millions)

Defense Contractor Type	All Sales	% of All Sales by Type of Contractor	Defense Sales	% of Defense Sales by Type of Contractor	Commercial Sales	% of Commercial Sales by Type of Contractor
Only Prime Contracts	$16,848.83	6.7%	$765.61	0.8%	$16,083.21	9.9%
Prime & Subcontracts	$153,254.91	60.6%	$70,336.89	77.0%	$82,918.02	51.3%
Only Subcontracts	$82,968.67	32.8%	$20,200.09	22.1%	$62,768.58	38.8%
All Defense Contractors	$253.072.41		$91,302.59		$161,769.82	
% of All Sales		100.0%		36.1%		63.9%

DISTRIBUTION OF MDG SECTOR PLANTS BY DEFENSE CONTRACTING STATUS



Note: Due to sampling procedure, population sales levels in the table are underestimated. But all percentages are unbiased estimates.

Figure 1.

Defense Contractors' Dependency on Sales to DoD in 1990 by Contracting Tier: All Prime Contractors vs. Subcontractors

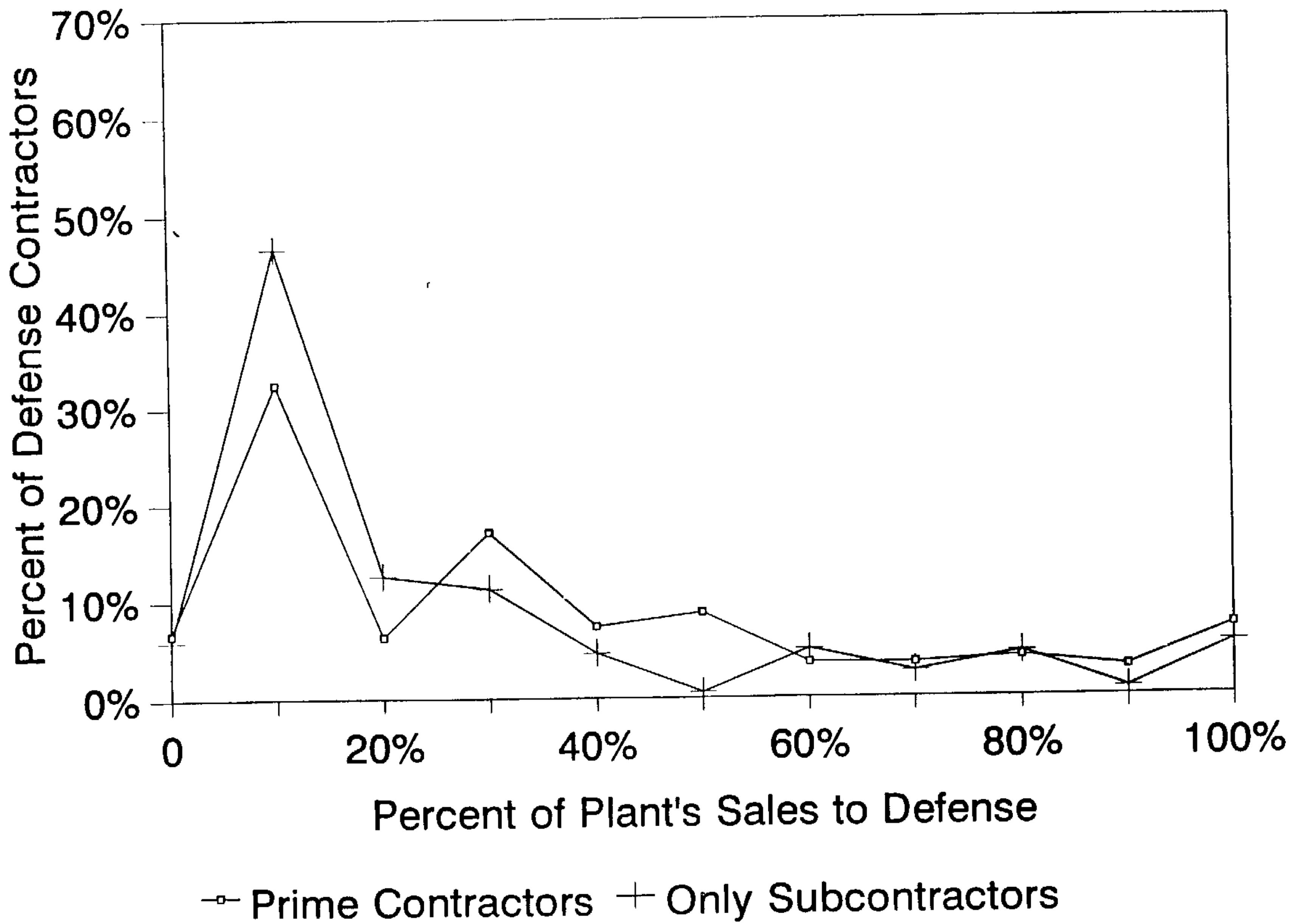


Figure 2.

Cumulative Distributions of 1990 Sales by Defense Contractors to Defense & Commercial Customers

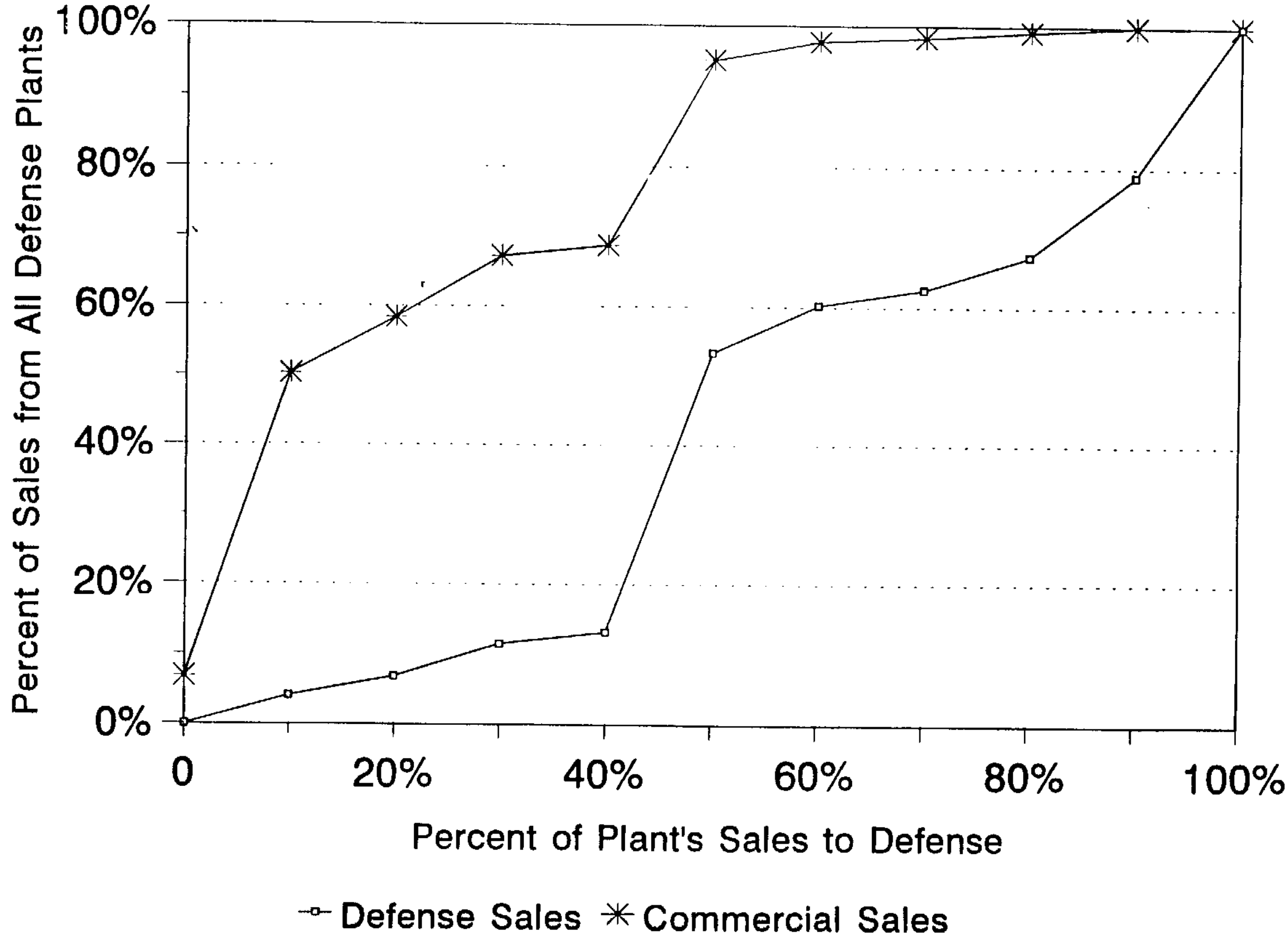


Figure 3.

Defense Contractors' Dependency on Sales to DoD in 1990: Single Plant Firms vs. Branch Plants

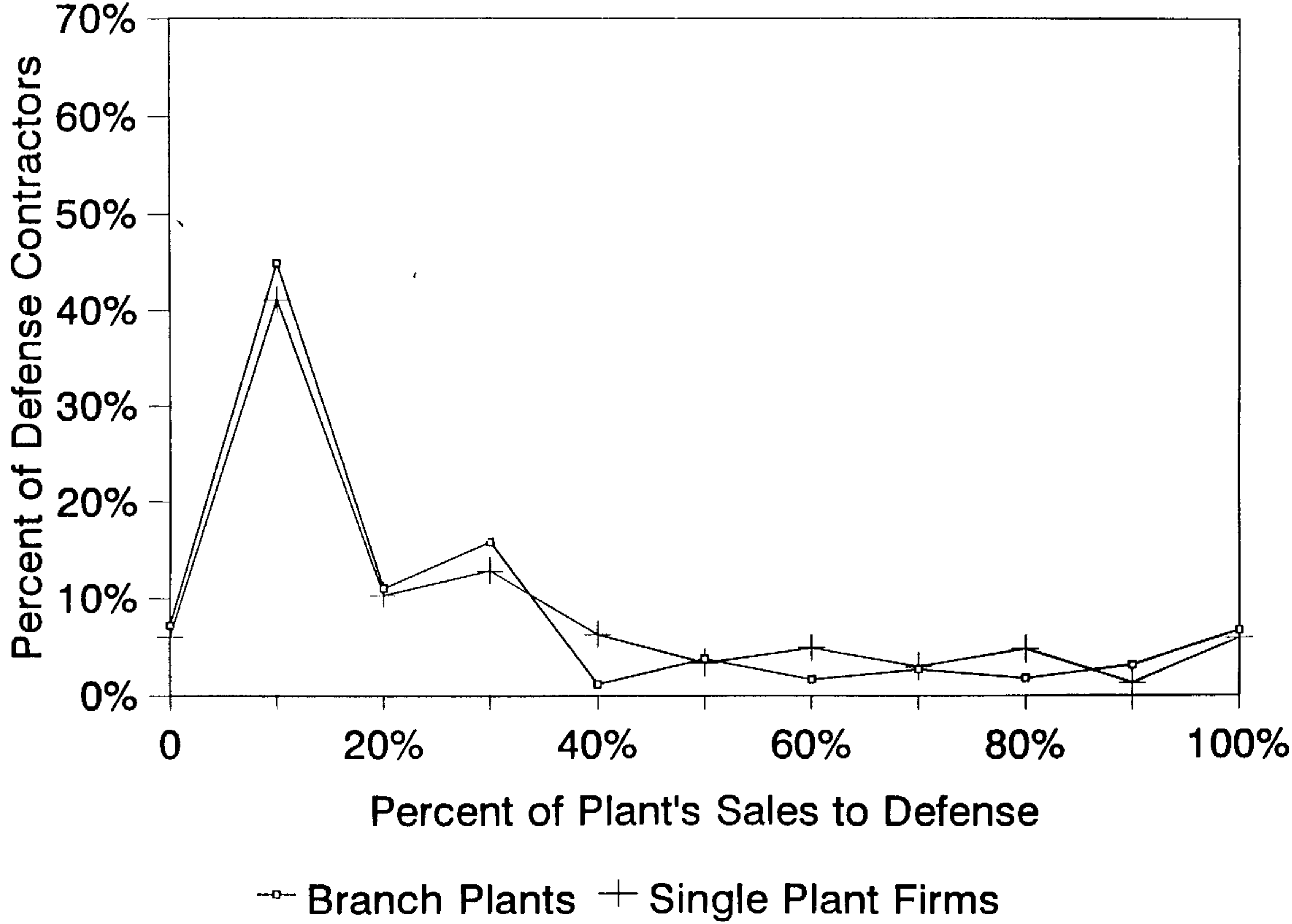


Figure 4.

Defense Contractors' Dependency on Sales to DoD in 1990
Branch Plants of Multi-plant Firms:
Prime Contractors vs. Second Tier Subcontractors

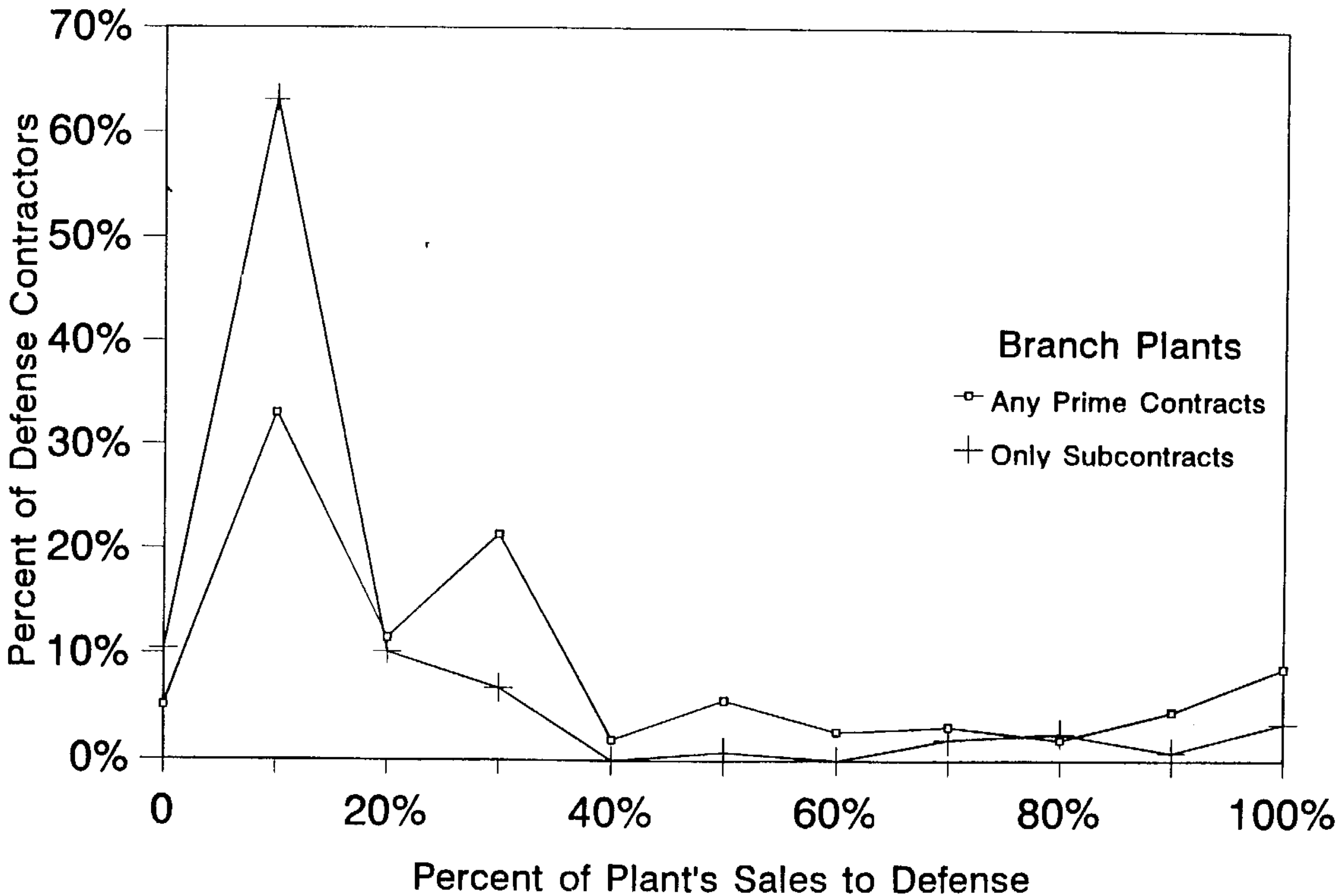
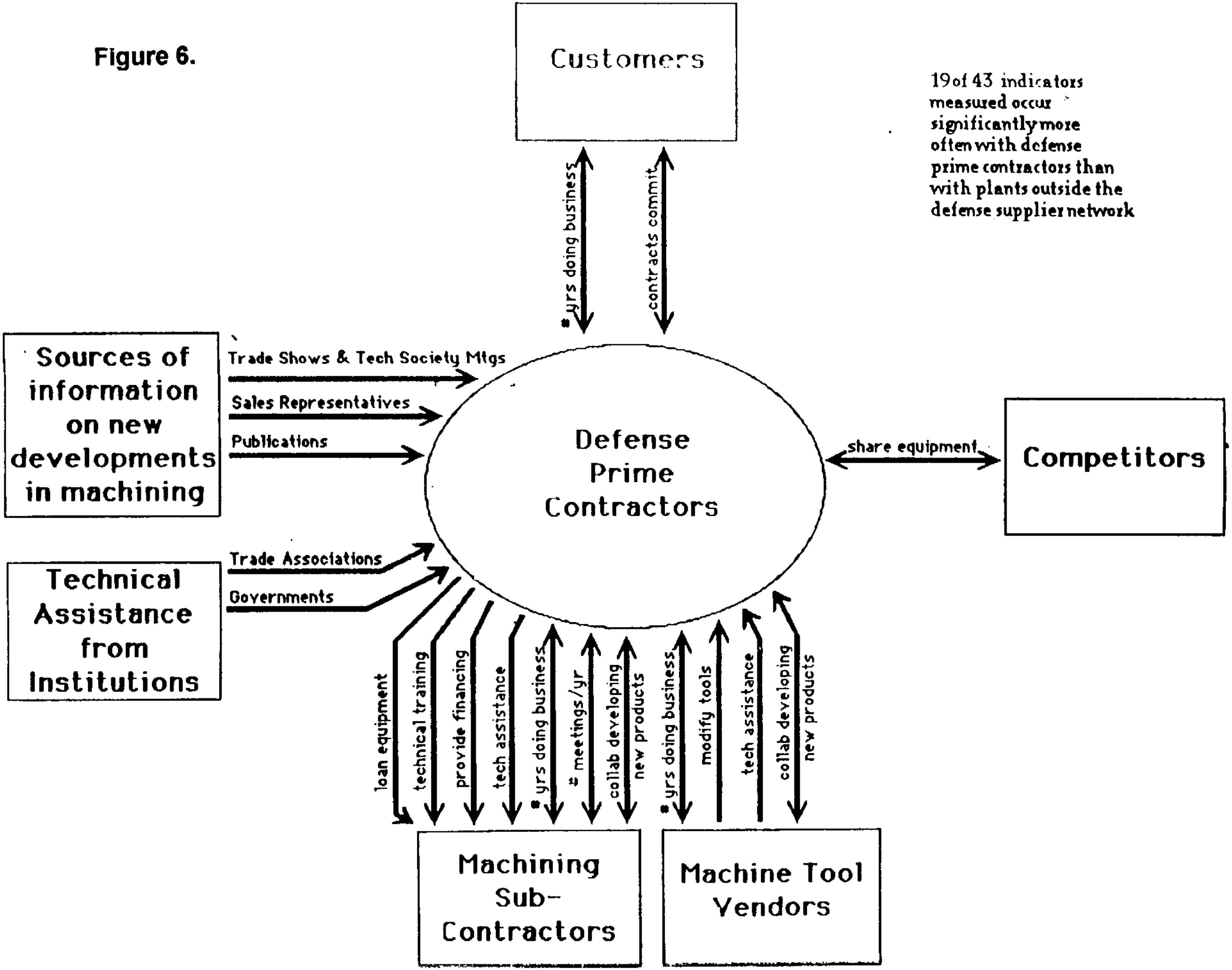
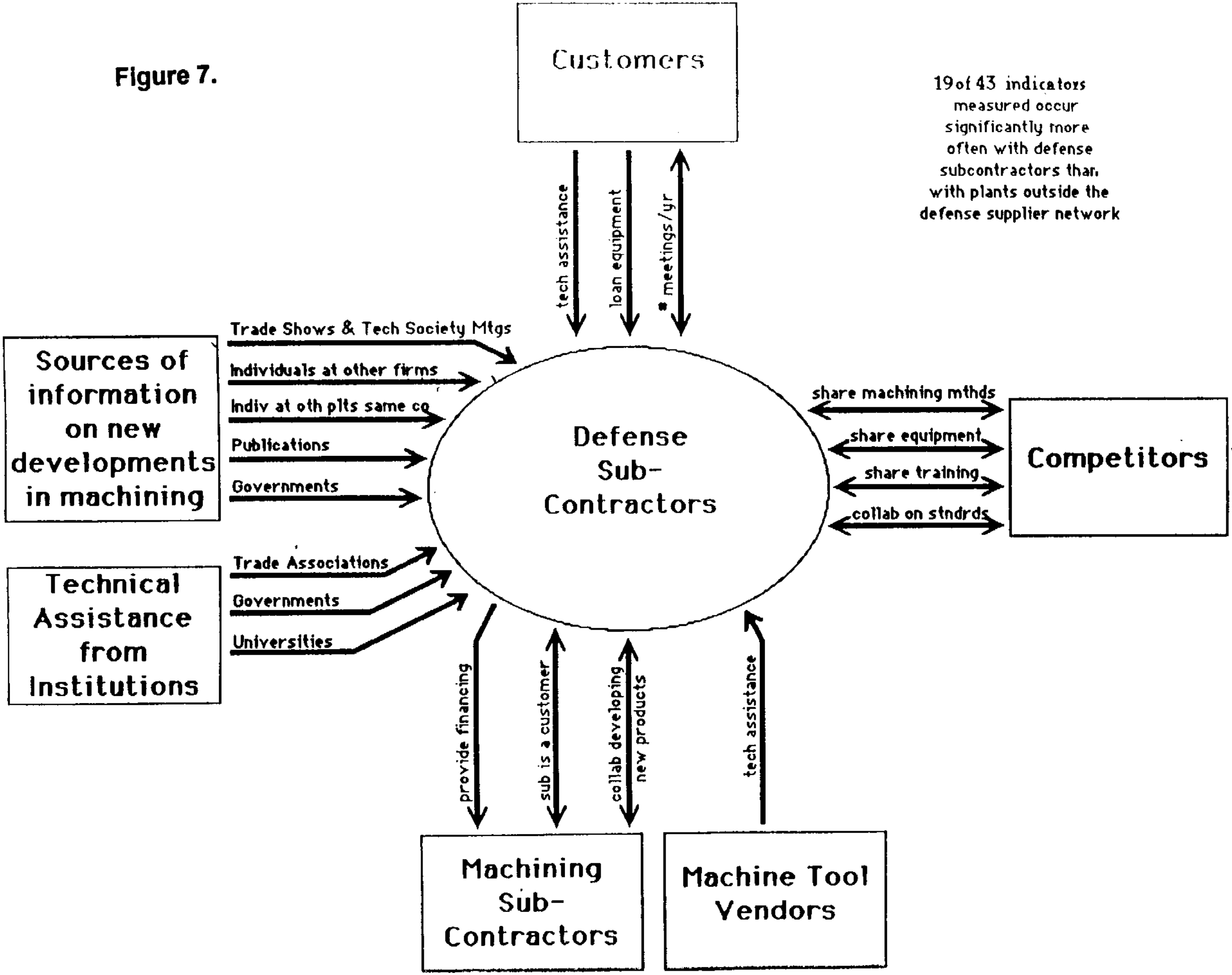


Figure 6.



19 of 43 indicators measured occur significantly more often with defense prime contractors than with plants outside the defense supplier network

Figure 7.



19 of 43 indicators measured occur significantly more often with defense subcontractors than with plants outside the defense supplier network

REFERENCES

Alic, John A., Lewis M. Branscomb, Harvey Brooks, Ashton B. Carter, and Gerald L. Epstein, *Beyond Spinoff: Military and Commercial Technologies in a Changing World* (Boston: Harvard Business School Press, 1992).

Arrow, Kenneth, "The Economic Implications of Learning by Doing," *Review of Economic Studies* (1962): 155-173.

Ayres, Robert U. and Steven M. Miller, *Robotics: Applications and Social Implications* (Cambridge, MA: Ballinger, 1983).

Blank, Rebecca and Emma Rothschild, "The Effect of United States Defence Spending on Employment and Output," *International Labour Review* 124 (Nov.-Dec., 1985) 6: 677-697.

Business Week, "The Godfather of Stealth Won't Let This One Slip By," (September 6, 1993) 60-62.

Center for Strategic and International Studies, Defense Industrial Base Project, "Deterrence in Decay: The Future of the U.S. Defense Industrial Base" (Washington, DC: CSIS Panel Reports, May 1989).

Cohen, Wesley M. and Daniel A. Levinthal, "Absorptive Capacity: A New Perspective on Learning and Innovation," *Administrative Science Quarterly* (1990) 35: 128-152.

Demski, Joel S. and Robert P. Magee, "A Perspective on Accounting for Defense Contracts", *The Accounting Review* (October, 1992) 67: 732-740.

Dosi, Giovanni, "Sources, Procedures, and Microeconomic Effects of Innovation," *Journal of Economic Literature* (1988) 26: 11201171.

The Economist, "From Guns to Gadgets" (October 2, 1993) 17.

Freeman, Christopher and Carlotta Perez, "The Diffusion of Technical Innovations and Changes in Techno-economic Paradigm," (Science Policy Research Unit, University of Sussex, 1986).

Gansler, Jacques S.*, Defense Conversion: Transforming the Arsenal of Democracy* (Cambridge, MIT Press, 1995).

Gansler, Jacques S., *The Defense Industry* (Cambridge: The MIT Press, 1980.

Hall, G.R. and R.E. Johnson, "A Review of Air Force Procurement, 1962-1964," Report No. RM-4500-PR (Santa Monica, CA: Rand Corporation, 1965).

Harrison, Bennett, *Lean and Mean: The Changing Landscape of Corporate Power in the Age of Flexibility* (New York: Basic Books, 1994).

Hirschhorn, Larry J., B*eyond Mechanization: Work and Technology in a Postindustrial Age* (Cambridge: MIT Press, 1984).

Kaplinsky, Raphael, *Automation: The Technology and Society* (Harlow, England: Longman, 1984).

Kelley, Maryellen R., "Organizational Resources and the Industrial Environment: The Importance of Firm Size and Interfirm Linkages to the

Adoption of Advanced Manufacturing Technology," *International Journal of Technology Management* (November, 1993) 8: 36-68.

Kelley, Maryellen R. and Ashish Arora, “The Role of Institution Building in U.S. Industrial Modernization Programs,” *Research Policy* (March, 1996) 25: 265-79.

Kelley, Maryellen R. and Harvey Brooks, "External Learning Opportunities and the Diffusion of Process Innovations to Small Firms: The Case of Programmable Automation," *Technological Forecasting and Social Change* (April, 1991) 39: 103-125.

__________, "Diffusion of NC and CNC Machine Tool Technologies in Large and Small Firms" in *Computer-Integrated-Manufacturing, Volume III: Models, Case Studies, and Forecasts of Diffusion*, R.U. Ayres, W. Haywood, and I. Tchijov, eds. (London and New York: Chapman & Hall, 1992).

Kelly, Maryellen R. and Cynthia R. Cook, “The Institutional Context and Manufacturing Performance: The Case of the U.S. Defense Industrial Network,” Ninth Annual Conference on Socio-Economics, Montreal, July 5-7, 1997.

Kelley, Maryellen R. and Todd A. Watkins, “In From the Cold: Prospects for Conversion of the Defense Industrial Base,” *Science* (28 April, 1995a) 268: 525-32.

_________, “The Myth of the Specialized Defense Contractor*,” Technology Review* (April 1995b) 98(3): 52-8.

_________, *The Defense Industrial Network: A Legacy of the Cold War*, Contractor Report, US Congressional Office of Technology Assessment, Washington, DC, 1992.

Lundquist, Jerrold T., "Shrinking Fast and Smart," *Harvard Business Review* (Nov.-Dec., 1992): 74-85.

Markusen, Ann and Joel Yudken, *Dismantling the Cold War Economy* (New York: Basic, 1992).

Melman, Seymour, *The Permanent War Economy* (New York: Simon and Schuster, 1974).

Nelson, Richard R. and Sidney G. Winter, *An Evolutionary Theory of Economic Change* (Cambridge: Harvard University Press, 1982).

__________, "In Search of a Useful Theory of Innovation," *Research Policy* (1977) 6: 36-76.

Peck, Merton J. and Scherer, Frederick M., *The Weapons Acquisition Process: An Economic Analysis* (Boston: Harvard University Graduate School of Business Administration, 1962).

Piore, Michael, and Charles Sabel, *The Second Industrial Divide* (New York: Basic Books, 1984).

Rogerson, W., "Overhead Allocation and Incentives for Cost Minimization in Defense Procurement," *The Accounting Review* (October, 1992) 67: 671-690.

Rosenberg, Nathan, *Inside the Black Box: Technology and Economics*

(Cambridge: Cambridge University Press, 1982).

__________, "Factors Affecting the Diffusion of Technology," *Explorations in Economic History* (Fall, 1972) 3: 3-33.

Shapira, Philip, "Modernizing Manufacturing: New Policies to Build Industrial Extension Services" (Washington, D.C.: Economic Policy Institute, 1990).

U.S. Congress, General Accounting Office [GAO], Defense Industry—Trends in DOD Spending, Industrial Productivity and Competition, GAO Reports PEMD-97-3 (Washington, DC: U.S. Government Printing Office, 1997).

U.S. Congress, House of Representatives, Armed Services Committee, *The Ailing Defense Industrial Base*, H.R. Doc. No. 29, (Washington, DC: U.S. Government Printing Office, 1980).

U.S. Congress, Office of Technology Assessment [OTA], *After the Cold War: Living with Lower Defense Spending*, OTA-ITE-524 (Washington, DC: U.S. Government Printing Office, 1992).

__________, *Holding the Edge: Maintaining the Defense Technology Base*, OTA-ISC-420 (Washington, D.C.: U.S. Government Printing Office, 1989).

__________, *Making Things Better: Competing in Manufacturing*, Report No. OTA-ITE-443 (Washington, D.C.: U.S. Government Printing Office, 1990).

U.S. Department of Commerce, Bureau of the Census, *Current Industrial Reports: Manufacturing Technology 1988*, SMT(88)-1 (Washington, D.C.: U.S. Government Printing Office, 1989).

U.S. Department of Defense, Office of the Assistant Secretary of Defense, Installations and Logistics, *Profit '76 Summary Report* (Washington, D.C.: U.S. Government Printing Office, 1976).

Von Hippel, Eric, *The Sources of Innovation* (New York: Oxford University Press, 1988).

Watkins, Todd A., "A Technological Communications Costs Model of R&D Consortia as Public Policy," *Research Policy* (1991) 20: 87-107.

Watkins, Todd A., “Dual-Use Supplier Management and Strategic International Sourcing in Aircraft Manufacturing,” Lean Aircraft Initiative Case Study, (Cambridge: Massachusetts Institute of Technology, October 1997).

Wall Street Journal, "AlliedSignal's Chairman Outlines Strategy for Growth" (August 17, 1993) A3.

Weidenbaum, Murray, Small Wars, Big Defense: Paying for the Military After the Cold War, (New York: Oxford University Press, 1992

I. self-defense is permissible against armed attacks by non-state actors. The vast majority of writers agree that an armed attack by a non-state actor on a state, its embassies, its military, or other na-tionals abroad can trigger the right of self-defense addressed in Article 51 of the United Nations Charter, even if selective respon-. Risen & Mark Mazzetti, C.I.A. Said to Use Outsiders to Put Bombs on Drones, N.Y. TIMES, Aug.